Adaptive Interface for Mobile Devices in User's Context

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By

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Dedication

This work is dedicated to my family and friends.

Acknowledgement

I acknowledge that this work was not possible without support of my family; especially my wife who looked-after my duties very well and urged me to complete my work with full devotion. I spent hours and hours in research and special credit goes to my kids who understood my situation. In my thesis completion, I miss my elder son (Aarij) as his happiness and laughter always provided me fresh breath, May his soul rest in peace. I am also thankful to my parents, who always prayed for me. It was not possible without their prayers and love.

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Publications

Journal Publications:

1. **M. W. Iqbal,** N. Ahmad, S. K. Shahzad, I. Feroz and N. A. Mian. "Towards Adaptive User Interfaces for Mobile-Phone in Smart World". *International Journal of Advanced Computer Science & Apps (IJACSA).* Volume 9, Number 11, Pp. 556-565, 2018.
2. **M. W. Iqbal,** N. Ahmad, S. K. Shahzad, M. R. Naqvi and I. Feroz. "Usability Aspects of Adaptive Mobile Interfaces for Colour-Blind and Vision Deficient Users". *International Journal of Computer Science and Network Security (IJCSNS).* http://paper.ijcsns.org/07_book/201810/20181026.pdf. Volume 18, Number 10, Pp. 179-189, 2018.

Conference Publications:

1- **M. W. Iqbal**, S. K. Shahzad, N. Ahmad, A. Amelio and D. Brodic. "Adaptive Interface for Color-Blind People in Mobile-Phones". *International Conference on Advancements in Computational Sciences (ICACS).* Lahore, Pakistan, IEEE Conference, Pp. 93-100, February 2018.

2- **M. W. Iqbal,** N. Ahmad and S. K. Shahzad. "Usability Evaluation of Adaptive Features in Smartphones". *21st International Conference on Knowledge Based and Intelligent Information and Engineering Systems (KES).* Marseille, France, Procedia Computer Science 112, Pp. 2185-2194, 2017.

Abstract

Adaptive User Interfaces (AUIs) are personalized for direct interaction of users with system. They observe the context for achieving user goals to adapt the interaction modes and visualization styles accordingly. Current adaptive user interface features, provided by the mobile phone vendors are static and rarely sense the context. This research work concentrates on User Centered Design (UCD) and development process of adaptive interfaces for mobile devices with the enrichment of detailed context understanding in the perspective of demographic properties and special needs. Currently, majority of mobile devices provide adaptivity features that are scaled according to user context. These adaptive features are analysed for variant context scenarios and interaction environments. The analysis shows promising improvements in usability of mobile devices in terms of effectiveness, efficiency and satisfaction. The analysis uncovered the dependency of usability on adaptivity pattern selection for a specific usage context. The adaptivity patterns currently provide manual selection without sensing the context of use. Thus, the machine understandable context models are required to develop AUIs. These context models are developed in this research using ontology and semantic frameworks according to defined classes for context elements to model the user context. These context elements (user, device, environment and task/activity) are comprised in the User Context Ontology (UCO) while Adaptive Interface Ontology (AIO) is introduced to model the mobile device interface. The UCD methodology is used to analyse the validity of user's requirements and optimization of interfaces according to their context. The UCD model is enhanced with the capacity to map the UCO to AIO. The context and interface model are logically verified through reasoning tools. Experimental AUI is drawn through enhanced UCD with instantiation of UCO, mapping function and AIO objects for android and iOS mobile devices. The research conclusion discusses the mobile device interface dynamic adaptation according to the changing context. The resultant UCD model enriches the connectivity, data sharing, decision making and ability to handle the contextual situation for adaptive mobile interfaces.

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Abbreviations

ADLs: Activities of Daily Livings

AIO: Adaptive Interface Ontology

Apps: Applications

ASQ: After Scenario Questionnaire

ATM: Automated Teller Machine

AT&T: American Telephone & Telegraph

AUI: Adaptive User Interface

CAP: Canonical Abstract Prototypes

CC/PP: Composite Capabilities/Preference Profile

CoBrA-ONT: Context Broker Architecture

CONON: Context Ontology

CQ: Competency Question

CVD: Colour Vision Deficient

DOLCE: Descriptive Ontology for Linguistic and Cognitive Engineering

GMM: Gaussian Mixture Model

GPS: Global Positioning System

GUI: Graphical User Interface

HCI: Human Computer Interaction

H/W: Hardware

ICT: Information and Communication Technology

IDE: Integrated Development Environment

ISO: International Standards Organization

IT: Information Technology

IxD: Interaction Design

LED: Light Emitting Diode

LIS: Italian Sign Language

LUI: Logical User Interface

MDE: Model Driven Engineering

ML: Machine Learning

OS: Operating System

OSGi: Open Service Gateway Initiative

OWL: Web Ontology Language

PCs: Personal Computers

PDA: Personal Digital Assistant

PUC: Personal Universal Controller

PUI: Physical User Interface

RDF: Resource Description Framework

RGB: Red Green Blue

SEQ: Self-Experience Questionnaire

SIM: Subscriber Identity Module

SMEQ: Subjective Mental Effort Question

SMS: Short Message Service

SOCAM: Service-Oriented Context-Aware Middleware

SOUPA: Standard Ontology for Ubiquitous and Pervasive Applications

S/W: Software

TV: Television

UAV: Unmanned Aerial Vehicle

UC: Use Case

UCD: User Centered Design

UCO: User Context Ontology

UI: User Interface

UIM: User Interface Model

UIML: User Interface Markup Language

UME: Usability Magnitude Estimation

UX: User Experience

WiFi: Wireless Fidelity

WIMP: Window Icon Menu Pointer

WWW: World Wide Web

Chapter 1. INTRODUCTION

This chapter provides the research domain, usability of mobile devices, smart adaptation, complex interaction styles and user context modelling. It states the significance and need of research. The chapter subsequently describes the problem statement along with research gap, objectives, scope and contribution. The research challenges to answer the given research questions, research impact and thesis organization is also discussed.

1.1 User Interfaces in New Technology

The usage of mobile devices is increasing tremendously throughout the world. Every user invests reasonable efforts, resources and time for buying, utilizing and customizing of these devices. Every device expresses the values, identities, affiliations and individuality according to user choice (Traxler, 2010). To maintain the continuous growth of mobile industry, new technologies are developing every day. These technologies are providing new features with easy to use interfaces to their customers but it’s an ongoing effort which requires iteration in designing where improvement, maturity and optimization comes with time (Jindal & Jain, 2012). Currently, mobile devices and their applications (Apps) are providing significant advantages to their users in terms of accessibility, portability and usability. So, this has engaged massive number of mobile Apps which are being developed over the past few years (Shneiderman & Plaisant, 2004) (Hakkila, J., & Mantyjarvi, 2006) (Glavinic et al., 2008) (Miller, 2010) (Nayebi et al., 2012) (Parant et al., 2017).

Due to the increasing effect in usability of mobile technology in our daily activities, the number of Apps is continuously increasing. Some of these mobile Apps assist the users in routine work for multi-purpose activities that make the usage more complex (Ali et al., 2014). A smart mobile phone interfaces are required for the enhancement of user experience to handle the complication and need. These interfaces are considered to achieve the goals of users with multiple networked devices in different situations (Marcal et al., 2016). The situation becomes more exciting when User Interface (UI) has diverse interaction capabilities with different interaction mechanisms with limitations. The diversity in UIs creates much complexity in the understanding of users that require high cognitive abilities (Kortum & Sorber, 2015). The modern mobile phones have several usability issues which may cause complexity and lack in flexibility i.e. the physical limitations in the modern era related to screen size and the methods to interact with the device. Such type of restrictions lead to issues in the usability of mobile Apps (Y. S. Lee et al., 2006) (Akiki et al. , 2014). The usability of UI elements varies among different users according to their situation and context. Currently, the heterogeneity can be identified for variety of computing platforms such as capabilities of input/output devices, modalities of interaction, usage of toolkits, user environments, variabilities in context and multiplicity of users (Shneiderman & Plaisant, 2004). Although mobile phone usability has been improved in modern world by developing features according to user desires (e.g. hierarchical menu systems) but the developers have still lot of challenges to handle the variety of user interests. User's concern to handle the complexity of contextual situations should be in consideration while dissolving or addressing the issues of heterogeneity (Meixner et al., 2011).

1.1.1 Personalized User Interfaces

AUIs can be beneficial in providing potential solution related to mobile devices to overcome the heterogeneous deficiency. Adaptation of the UIs that provides the behaviour according to context of user has been one of the key considerations in the designing of modern systems (Alvarez-Cortes et al., 2007). Adaptive techniques and methods illustrate that how to explain or engage with these methodologies (Wesson et al., 2014). AUI delivers the contents and functionalities that matched with user needs or interests (personalized) specifically without direct intervention of users. Adaptive interfaces are more likely to be implemented with simple and more frequent tasks (Hartmann, 2009) (Dostal & Eichler, 2011). The AUIs support automatic adaptivity that allow the users to customize interfaces (Akiki et al. , 2014). The personalization provides individual user identification, preference evolution, device sensing and location finding. It also considers the nature of mobile device's heterogeneity and computation with associated infrastructure along with their connectivity problems. On the other hand, adaptable UIs for specific context lack in intelligent decision making, manual switching to the respective mode and new context inability (Guerrero-García et al., 2009). To accommodate these type of diverse constraints, the context and sub-context with entities (place, person, physical and computational object) should be well defined in start of development of interfaces (Dey et al., 1999) (Ali et al., 2014).

1.1.2 Diversity in Interaction Styles

Diversity in the interfaces of mobile devices create complexity with the interaction of users (Poveda-Villalon et al., 2010) (Ahmed & Parsons, 2011). In the last few years the research on user profiling and context has been encouraged for the development of adaptive systems that are being used by heterogeneous users (Arechiga et al., 2009). In this regard, ontological modelling on user profiles is generally App specific that is created for specific domain or task (Jiang & Tan, 2009).

A user context ontological model can be developed on the basis of user's characteristics such as personal information, skills and preferences to provide personalized services (Bhogal et al., 2007). Ontology based context models are used to define and implant context information (Baldauf et al., 2007) (Holzinger et al., 2012). Generally, human perceptions and concepts are different and difficult to understand for various situations like at_hospital or in a_park. Technically it is required to build such methods by implication rules or semantic relations or through ontological classes (Skillen et al., 2012).

1.2 Motivation

Mobile phone usage is increasing throughout the world. This interest of users is motivating designers towards smart interfaces and dynamic features for better usability. Usage of smart phones create serious impacts on quality of life and behaviour. It can use to seek the health information for the older users as well as youngers (Ghahramani & Wang, 2019). Still the usage of smart phones is at peak level. We have seen the smart phone devices with enhanced interface usability which may have great user experience in 2020[1]. Figure 1.1 shows the projection of worldwide yearly growth rate in smart phone users from 2016 to 2021.

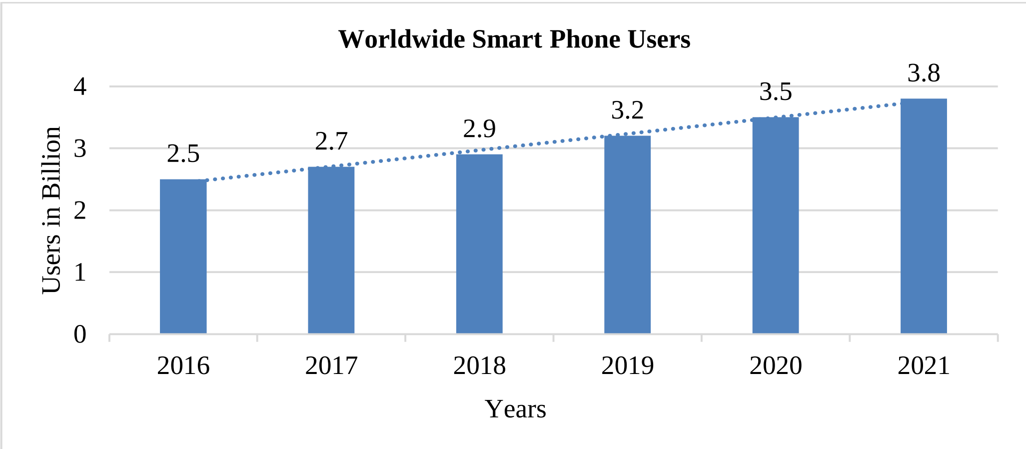

Figure 1.1: Worldwide smart phone users from 2016 to 2021[2]

[1]https://medium.com/swih/the-key-mobile-ux-trends-for-2020-c50665b68f24
[2]https://www. statista.com/statistics/330695/number-of-smartphone-users-worldwide

1.2.1 Usability Issues

There are lot of usability issues such as screen size, touch pad, display, deep navigation, information vs speed, resolution miscalculation, un-responsive gesture, confusing and vague contents that have been identified in different mobile devices (Holzinger et al., 2012) (Akiki et al., 2016) (Aliannejadi et al., 2019). Vendors are trying to accommodate these issues by developing high quality mobile devices.

1.2.2 Dynamic Customized Interface

The AUIs are projected to handle the adaptivity issues. These interfaces enable to provide dynamic customized environment for users containing similar properties and needs (Lavie & Meyer, 2010). The dynamic customized interfaces are still in progress to handle the adaptivity issues. AUIs help to users by providing supportive, constructive and communicative environment (Figueroa et al., 2014).

1.3 Problem Statement

In this section the analysis of research gap, research objectives, research scope and research contributions are addressed precisely. The mobile phone interfaces have much competition for providing more satisfaction and optimization of different types of users. The products that are designed considering the normal user's preferences may not be suitable for those users that have some special needs. Latest mobile operating systems like Android and iOS provide kids, guest, driving and night modes for the accessibility of Apps according to the user's task. Such type of modes are developed for specific environments with generic common features and provide predefined profiles with factory settings. User either suffers or is forced to learn these complex interaction styles and modes. The rapidly increasing heterogeneity in user physical demographic properties and limitations of smart device interaction styles bring us a challenge to develop a specialized interface for variety of users.

There is dire need to achieve the context specific interaction styles to assist the users in accordance to their requirements. There is still a requirement for dynamic and intelligent adaptation of UI according to the user context. The dissertation intents to discover the UI adaptation respective to the user preferences. The UCD approach can be used for interface development incorporating the user experience and adaptivity in mobile device interfaces. Further, ontological modelling can be a good option to make formal definition of usage context, interface styles and semantic relations among the users.

1.3.1 Research Gap

Currently mobile phone UIs provide different features and modes regardless of context of use. It is user's choice to select any adaptivity feature according to their choice. By definition, UI adaptivity is required to read the context and provide respective interaction style and mode. There has been many studies and researches, mentioned in literature review, that suggest context-based UI adaptivity (Jindal & Jain, 2012) (Wesson et al., 2014) (Figueroa et al., 2014) (Ahmad, Boota, & Masoom, 2014) (Moumane et al., 2016). Context has been modelled in various scenarios and application domain focused on different context elements like user demography, devices and software capabilities etc. Domain context modelling is also provided by some researcher using semantic and ontological frameworks (Mizouni et al., 2014) (Zheng et al., 2016) (Uddin et al., 2018). Context, in previous researches (Dey et al., 1999) (Bevan & Macleod, 1994), are modelled with the consideration of exact requirements and very specific to the App domain. There is still need to study the elements of context influencing the usability aspects of mobile device. There may be a merging of distinct context models stating variety of context elements like users, tasks, device and environment (Schmidt et al., 1999) (Poveda-Villalon et al., 2010) (Naseer Ahmad et al., 2014).

The previous solutions also provide programmable libraries, overlays and patches to add adaptivity in current UIs (Zheng et al., 2015) (Meditskos, Dasiopoulou, and Kompatsiaris 2016. These UI adaptivity solution are not aligned with any standard UI development process model (S. K. Shahzad, 2011) (Holzinger et al., 2012) (Aliannejadi et al., 2019). Thus, the AUI designing and development need to be enriched with ontological based context modelling. The AUI models are also needed to be formed in response to the context.

1.3.2 Research Objectives

The research, undergo, aims to explore the methods to solve the current and upcoming usability challenges for mobile phones. The idea is to achieve the data storage and processing capabilities of linked environment and provide an adaptive interface for mobile devices. The first step in such solution is to understand the mobile phone usage with detailed context of user, tasks, device and environment. Secondly, interface adaptation according to the context of user. Objectives of this study is to include the adaptivity in smart phones by providing user context-based design models and mechanism to reflect the context needs at UIs.

The research objectives are given below:

1. To discover adaptivity requirements of users in mobile phones (normal and special need users).
2. To formally discover semantic relations among user context through ontologies.
3. To map user context ontology to adaptive interface ontology.
4. To enhance UCD model with the capabilities of context reading and selection of respective interface model.

1.3.3 Research Scope and Limitations

The research focuses on the AUI design process model that enables AUI to read the context and provide respective interaction model. The research work concentrates on the adaptive interfaces for mobile devices in user context by considering the demographic properties and special needs. The demographic properties include location, age, gender, profession, level of education and disabilities. The adaptive features of mobile phones are scaled according to the user preferences. These are purely UI features including information representation mode (visual or speech), user interaction mode and response mode (look and feel). The usability of adaptive features is tested by using two different smart phone devices having android and iOS operating systems.

The research is focusing on interface usability of different Apps according to user's requirements. The research aims to propose independent model-based interface development to reduce the device and OS dependencies. The research also focuses on standardized, shared and scalable context model development. The current research provides the process model by consistency and context knowledge validation. The process distribution over device and cloud architecture is not discussed in this research and may be explored in future.

1.3.4 Research Contributions

Following are the contributions of said research:

1. The adaptive capabilities of smart phones are studied with their impact in usability enhancements. Further, a user context model is developed which uses normal user's classification and special needs.

2. The user context and UI features are discovered with the semantic relations among the studied classes of user context and mobile interface.
3. UCO and AIO are developed over discovered classes and relationships.
4. Enhanced UCD is developed with enrichment of ontological modelling of context and interface. It provides the adaptation strategy by reading user context model and selection of adaptive UI style respective to the semantic relations.

Furthermore, contribution to research on adaptive interfaces in mobile devices provides adaptivity in different aspects of user background knowledge. A prototype is developed that facilitates the adaptive behaviour according to user requirements. Smart phones are used as targeted device in the study and results may be applied to other devices accordingly.

1.4 Research Questions

In this research, questions are defined to deal with usability and satisfaction of user with customized interfaces according to user context. The research questions are given below:

RQ1: How AUIs can map the context knowledge to UIs?

RQ2: How adaptive interfaces improve user efficiency and satisfaction as compared to non-adaptive interfaces?

RQ3: How context aware AUIs can be designed by UCD paradigm?

1.4.1 Research Challenges

Following are the research challenges:

1. Context elements identification.
2. Ontology modelling to understand the context formally.
3. Discovering semantic relations among different context elements.
4. Context and interface mapping.
5. Incorporating ontological models of context and UCD.

1.4.2 Research Impact

The impact of research provides that the interface adaptation has reduced the gap between mobile devices and users. Likewise, the usability of mobile devices has improved by optimizing their adaptivity using context knowledge. Further, the designed adaptive interfaces provide scalability and interdisciplinary environment for mobile device users. The AUIs also contribute to provide reusability according to the context of user. Lastly, the significant impact of adaptive interface for mobile devices is to enhance the satisfaction level of end users.

1.5 Thesis Organization

The thesis is organized into further chapters. The summary of each chapter organization is given below:

Chapter 2 discusses the interaction design in mobile phone interfaces, their classifications and usability enhancement. It also provides the overview of contextual usage of mobile devices, context environment, learning, human perspective and knowledge representation of context. Further it introduces the UCD process model for ontology engineering in the usage of context.

Chapter 3 illustrates the background and literature review briefly. It elaborates the usability of mobile phone interface, context, usability engineering, dynamic & static interfaces, adaptive behaviour and its development criteria.

Chapter 4 defines the research methodology and its phases such as analysis of adaptive features, UCO & AIO, their mapping and experimentation through UCD process model.

Chapter 5 explains the usability of adaptive features in mobile phones, their classification, and sample to conduct experimentation, results of user effectiveness, efficiency and satisfaction.

Chapter 6 simplifies about the usability of special needs mobile users (colour-blind & colour vision deficient). It shows the outcomes after conducting experimentation in adaptive and non-adaptive environment.

Chapter 7 clarifies the context ontology engineering for mobile phone users according to specified context, its entities and environment. It produces the taxonomy, semantic relations and their constraints. Moreover, the sample use cases are verified through Reasoner and SPARQL query for mobile usage context modelling.

Chapter 8 produces the UCD mapping with UCO and AIO. For this purpose, different semantic policies and rules from knowledgebase is defined to create mapping.

Chapter 9 concludes the study with the answers of research questions. It provides the enhanced UCD framework as research outcome to design and develop adaptive interface.

Chapter 2. INTERACTION DESIGN IN MOBILE PHONE INTERFACES

This chapter shows the outline of interaction design, UI, contextual adaptive interface and user context environment. It also describes the ontological context knowledge representation and UCD process model. Information Technology (IT) is helping us to improve the daily life of human beings and make this world a better place. Generally, software engineers design Apps carelessly resulting in underutilization of features of the App due to poor UI design and having complicated functionality. Hence, the overall objective of developing software is lost and the burden on the user is increased.

2.1 Interaction Design

Interaction Design (IxD) tries to solve problem by building digital products that give a better user experience and increase overall productivity of App (Rogers et al., 2002). IxD is considered as a human based design with an interface, App and Web UI, where all these components help the developer to enhance user experience. Each one of these disciplines has added benefit and their main concern is establishing hands on work in Apps for building UI interaction. The building of every interaction design is to encourage usage of diverse approaches and skills for assisting UI experts for developing appropriate structure. The desired behaviour should be synchronized with user's cognitive model for efficient mobile UI. User friendliness and usability has now gained strong appreciation on different interfaces under the term "personalization". The beneficial products always reduce training cost, support expenses and provide ease of use for mobile users. But still there are number of products available without UI quality consideration which may cause poor interaction of mobile users. While designing an adaptive App, designers need to determine contextual features and respective interaction patterns of the system. So, that there may be more than one solution for adaptivity due to the variety of usage context of any general-purpose App or mobile device utility.

The designer can be incapacitated for every possible situation, in different environments for human's complex perceptions. The ontologies and semantic framework have proven their strengths for formal expression of these complex concepts to define a computational model. Although, many ontologies have been developed to represent the specific contexts of users, but they lack specifically in user's context for mobile adaptive UIs.

The goal of HCI is to make computers more usable and environment friendly for humans. HCI specially concerns with techniques and methodologies for interface design, interface methods, processes for criticizing and contrasting interfaces, new interface development and techniques for interaction design and developing descriptive and prescriptive models and approaches of interaction. The basic purpose of HCI is to build such Apps which could reduce hurdles among the humans using an interactive approach (Dix et al., 2004). Human Computer Interaction faces the main challenge of the process of translation between human users and software Apps. The accomplishment of such process lies in the fact that how the good UI design bridges the gap between users' need to convert their goals into tasks that can be performed with the help of suitable App (Coutaz, 2010).

As a fact, users involvement is also required to finalize whether the action performed moved the interaction process towards the desired goal (Ruiz et al., 2017). Such processes can be contracted by applying design principles of the UI to the process of development (Tenner, 2015). This also includes knowledge regarding human interaction abilities; for example, recognition of UI elements and famous metaphors of visual search. Such information helps designers to choose amongst various versions of UI clones. Additionally, an important task of good UI design is to test Apps for usability within their interest, area of use and favourite designs. However, tests with users can be complex, which requires a lot of efforts in terms of time, expense and expertise, but this generally pays off well by saving expenses at the end of the day (Wesson et al. , 2014). At this time, the benefits of developing AUI of the interfaces in user's context are being recognized (Miller, 2010). To enhance the usability and height of satisfaction of user, all AUIs can be directly utilized (Akiki et al. , 2014). AUI is an attainable version approach, provides best fitted method for adaption, which can deal with each problem of user's interactivity in better way.

2.2 User Interface

New advancements particularly in the area of mobile devices, led by fragmentation, are one of the essential points of increasing interest in the adaptation of UI. Device fragmentation here refers to the main features regarding hardware, formats, browsers, audio/video playback/steaming, etc. For instance, it is obvious fact that the screen resolutions for Personal Computers (PCs) are different from mobile devices resolution. Mobile devices screen resolutions vary around 320x240 and 1136x640 (iPhone 5) and1920×1080 (Galaxy S

4) pixels whereas PC resolutions range around 800x600 and 1920x1200 pixels (Arthur & Olsen, 2011). With the introduction of new mobile technologies, certain inconveniences occur due to variety in platforms. This is due to the fact that there are some UIs specially designed for a particular task and some tasks are more suitable for certain platforms and interfaces (Gajos et al., 2010). For example, certain activities like watching a cricket match is more appropriate to watch over a distance with larger resolution rather than on a smart phone screen. It simply deprives someone from details and comfort.

One of the key elements of software Apps is the UI which acts as a layer that connects end-users to functionality. A vigorous and well-designed App becomes useless due to a weak UI layer. Certain engineering techniques for UI including universal design (Mace et al., 1991), inclusive design (Keates et al., 2000) and design for all encourage the idea of building all-in-one context based UI (Calvary et al., 2003). The "one for all" approach is difficult to achieve because it is not possible to cater all the varied possibilities at the time of designing, mainly due to the fact that manual designing is costly and it is the only way to develop a UI having multi-dimensional functionality in all contexts (Fonseca et al. , 2010). To tackle this issue, adaptive UIs are introduced as they can adapt according to changing user contexts and functionality. UIs having such adaptive capabilities are also termed as multi-targeted and multi-contextual.

2.2.1 Classification of User Interface

The features of UI are divided in terms of functionality such as (i) input like soft keys, alphanumeric buttons and navigation options (ii) display like indicators & icons (iii) audio like ringing tones & microphones (iv) ergonomics like slide, touch & feeling (v) detachable parts like battery and SIM card (vi) methods of communication like bluetooth (vii) Apps like making a call and games (Ketola & Roykkee, 2001). Similarly (Kiljander, 2004) presents three types of mobile friendly UIs namely, Logical User Interface (LUI), Graphical User Interface (GUI), and Physical User Interface (PUI). Current study states that LUI (e.g. menu and navigation structure) is interface which connect with information contents and task execution structure. GUI (e.g. icon and font) is termed as an interface associated with visual or graphic items accompanying task-related information. PUI (e.g. keypad and microphone) consists of interconnected, physical interface properties, manual operation used to carry out tasks.

UI acts as a bridge between user and system. The purpose is to design an interface that is as much user friendly as possible. A user-friendly interface allows the user to complete task without thinking a lot. Designing a good UI is a difficult skill to developers. In this regard Jakob Nielsen presented 10 heuristics for interactive interface design (Nielsen, 2005). The contemporary pervasive trend of computing has now shifted from being a working tool to something that is a constant support in many areas of life. Current demands in this aspect are to design such an interface that adapts according to the user needs rather prompting user to follow it (Miller, 2010). This mechanism points towards a shift in UI crafting inclinations. Incorporating new sensing possibilities from environment and gathering information about users' interests is a good way to design an adaptive UI (Zheng et al., 2015). This also includes information about users to display content alterations, user interests and history of interactions. Examples of such adaptations range from lots of different location-based services to product sanctions while browsing web stores (Dostal & Eichler, 2011).

Plasticity is the key elements at work here, that denotes an ability of the UIs to retain their usability across different contexts-of-use (Coutaz, 2010). Idea for an AUI is very simple since it states that: "The interface should be adaptive to the user needs; rather than the user learning & following the system", even then there are certain complexities attached to designing such AUIs (Norcio & Stanley, 1989) (Shneiderman & Plaisant, 2004).

2.2.2 Usability of Mobile Applications

In modern world, mobile phone Apps have also operational problems along with communication and computational issues. Looije et al points to the fact that the mobile equipment is currently suffering from multiple operational problems. These operational problems can be divided in three main parts (Looije et al., 2007):

1. Technical: This refers to the mobile phone's battery life, network speed and screen size issues.
2. Environmental: That points to luminosity value, sound sheer level and diversions, temperature, ease of usage, mental and behavioural barriers, race of gaining focus of user from other functionality and their need to use objects despite the mobile equipment itself.
3. Social: This points to operational problems in relations to solitude, receiving, adoption, ease and personal contexts.

The operational issues marked in this study included (Wesson et al. , 2014):

1. Speed: Most important point engaging user poor performance.
2. Screen: If screens sizes are not sufficient, it will be limited to certain level of information that best fits on mobile screen dimension.
3. Typing: Typing on mobile phone devices is not an easy task. An example is inserting passwords and usernames that contain a combination of digits, letters and special characters.

When designing for the mobile platform, there is a variety of different smart phones to consider and support. In 2009, Jakob Nielsen discussed that there are three different types of smart phones. The types identified in the article are (Nielson, 2009):

1. Regular mobile phones with a small screen. Generally referred to as feature phones, which cover majority of market (at least 85% according to some statistics). They offer awful usability, allowing only certain interactions with websites.
2. Smart phones, typically with a mid-sized screen and a full A-Z keypad, sometimes contain features of 3G internet and wireless fidelity (Wifi) connectivity. Smart phones offer poor usability, forcing users to struggle to do complete website tasks.
3. Full-screen phones (mainly the iPhone) with a device-sized touch screen and a true GUI driven by direct operation and touch gestures. These phones offer 3G Internet connectivity and even faster speeds when connected to a Wifi. They also offer enhanced usability, simple tasks & easiness and suitable if users are on optimized for mobile well-designed sites.

Nielsen further explains that essential to have two different mobile websites, one for covering the former category of regular phones and a second one for catering the smart phones and large-screen phones. The focus is now on developing a prototype that covers the later; smart phone and third; full-screen phone type.

2.2.2.1 Smart Phone Devices

Smart phones have become one of most needed devices of current times. Advancements in technology have made smart phones cheaper and easier to obtain. In 2015, there were available 3.2 billion smart phone subscriptions, with 6.3 billion predicted to be available in 2021. People have their smart phones every time and everywhere not just for entertainment purposes but also for important tasks. Since smart phones have an array of sensors and good recording abilities, they can easily be used for observing user behaviour (Andone et al. , 2016).

The smart phone allows the user all the basic opportunities needed at work or at home. However, incompetently designed devices and poor interfaces of the Apps can lead to frustration (Wesson et al. , 2014). Many users expect the device to not only help with certain task but to synchronize with their daily situations. The users now, in fact, expect the Apps to guide them in achieving new and present goals. In order to cater this need (Marcal et al. , 2016), all UIs must display the needed information properly and the information should be customized to the current user's needs, abilities and in competencies.

2.2.2.2 Smart Phone Operating Systems

The two main categories in mobile devices world are iOS & Android. At present, the most explicit Operating Systems (OS) are Android (Google) and iPhone (Apple) providing many Apps with multiple features. More than 98% of worldwide market share is shared by these two mobile operating systems (Iqbal et al., 2017). The latest survey is done by statista.com and it predicts the prominence of smart phone in market for the years of 2019 (3.2 billion), 2020 (3.5 billion) and 2021 (3.8 billion)[1].

The UIs of many Apps still have operational issues of complexity and flexibility. The physical hurdles of devices have not only affected on the size of the screen and mechanism of interaction but it also add to operational issues for mobile Apps (Petrovcic et al., 2018). There happens to be a wide range of Apps other than device operating systems e.g. documentation, web-browsing, photos, communication, time management, and entertainment tools which are used by a person belonging to any profession, region, age group or gender (Dix et al. , 2004). They do however contain special features to enhance modes of interaction depending on the environment of work and physical properties (Jovanovic et al., 2014).

2.2.2.3 Usability Enhancement of Interfaces

The mobile interface is a key to build relationship which is reliable among the devices and the customers. In recent time mobile equipment are designed containing options of UI with multiple types of interactivity. Such varieties of UI have multiple usage needs and techniques which sets the interaction design working complicated (Iqbal et al. , 2017). The dominant part of interactive systems is the UI. It is closely connected with mobile user for utilizing the features of an App. In many well designed Apps, users works on the functionality of available usability and major part remains underutilized due to poor designing of UI (Ali et al., 2014).

UI element usage is different among various users which depend upon the usability needs. UI developers gets a lot of issues during building design for interactive Apps for multiple reasons. If we like to define heterogeneity it would be wide array of number of users, computational devices, inputs and outputs, abilities to interact modalities, mark-up tagged toolkits, end user Integrated Development Environment (IDE) and a lot of various options. Special Apps containing different modes have been designed for a number of years and these Apps depend on user's situation. Users having different demographics or special needs had specialized versions of software until advent of adaptive UIs. Still, there is a need to manipulate the advantages gained through adaptive UIs for smart phones (J. Hussain et al., 2018).

The user-friendliness of smart phones requires usability which brings forth many advantages: enabling users to use different features of smart phone. Usability eliminates the need for customer support to a large extent and adds to satisfaction level of users (Y. S. Lee et al., 2006). Increasing numbers of functions while reducing the size of mobile phone and making designing is more of a challenging task. Another design challenge to face is the short life span of smart phone model which results in lesser time for development (Jokela et al., 2006).

A product with high operational capability guarantees about the feasibility to get knowledge in a fast and effective way to give user an amazing time while using it (Rogers et al., 2002). While it's imperative to pin point attention on the product throughout designing time and continuously run validation to make sure outcome of the product is a higher user experience. In contrast to the common misunderstanding which gives advantage to user in terms of usage, all stakeholders get benefit from the interactivity (Bak et al., 2008). There are many researches stating the merits and instances of announced features that raise the return on the investment and decrease the production charges (Teka et al., 2017).

2.2.3 Adaptive and Adaptable Interfaces

Adaptive and adaptable UI are different in such way that both allow personal contexts to user, the only difference is the management of process. The interfaces related adaptivity automatically fixes to provide support user in operating it. The AUIs have ability to auto adjust their displays and provide functionality to user in performing goals (Glavinic et al., 2008). The AUI is defined as "a software artefact that improves its ability to interact with a user by constructing a user model based on partial experience with that user". The main idea that works for AUIs is about multiple kind of user behaviour in terms of using interactivity in an App. Each such App should have the functionality to adapt according to user choices rather bounding user to use to specific working pattern. Every user has its own way of working or interacting with system and requires system to adapt to his or her needs (Shankar et al., 2007). The AUIs are varied in terms of their number of inputs which effects adaptivity and the kinds of adaptive behaviour. Below are the four possibilities which effect adaptivity (Looije et al., 2007):

1. User: This technique is commonly used in AUIs. In which each AUI can provide functionality to user according to needs, information and ability to use system.
2. Task: The adaptivity according to user choices in his current task can guarantee the AUI functionality is adaptive and successfully helps user to perform their work.
3. System: Adaptivity works on handling functionalities related to network connection and usage in mobile devices.
4. Context: The Adaptive behaviour context according to user choices plays a vital role specifically in mobile devices or systems.

The AUI have the ability to work in different ways related to above features. There are many AUIs that are used to add adaptivity in the UI that works for each kind of user, which helps in performing day to day task, information set related to user choices and the mode of displaying information set (Lavie & Meyer, 2010).

There are three main categories of adaptive functionality which has been found associated with mobile navigation systems (Wesson et al., 2014):

1. Information: The usage of knowledge and classification of information can be adaptive easily.
2. Visualization: Adaptivity in displaying knowledgeable data.
3. User Interface: An interface that has the functionality to auto adjusts itself providing all the user controls and interactivity methods.

There are number of hooks that have high end benefits related to AUI that helps in creating accurate and efficient help in user training. These AUIs are tested solutions for issues like information overload and searching. There are complicated set of Apps which automate user tasks. Each AUI gives serious power in context high end customization in software with comparatively low price per user (Hook, 1999). The AUI gives multiple supports and are not without issues. Few main usability methods are pointed out by Nielsen (Nielsen, 2014) is about giving user access and choice. These AUIs can be taken as giving control away leaving at systems judgement. There are other issues related to privacy, doubts, learning, and presumptuous (Paymans et al., 2004).

There are some Apps which are adaptive and tries to provide a transparent support to user after learning their choices and provide assistance in building them more precise model of the system (Kuhme, 1993) (Iqbal et al., 2017). The variety exists in choices of each user-based nature. Also, each user works on different kinds of working machine (mobile, tablets, desktop PC etc) with diverse kinds on input and output functionality and communication method (Hammer et al., 2015). If we look into the pros of AUI we will realize that they build UI for user's point of view. These are used to enhance the functionality and capability of user satisfaction. The adaptivity in AUI makes it approachable for user to adapt. This happens because each user idea of interactivity is handled in each AUI (Gulla, et al., 2015).

In a comparison point of view, the AUI provides high end functionality and custom features by getting dependent on the user input in the adaption mechanism. While if we look on the adaptability itself has the features of user's choices which are set before hand and are not considered as constant throughout the interaction (Alotaibi, 2013). The line among the adaptive and adaptivity is based on very small difference as both have their own pros and cons. One of the most significant benefit is user friendly App in which user are in total control and user can easily manage their UI (Gulla, et al., 2015). Other than this, using adaptive UI looks like to assist user engagement with features which results in decreasing any further assistance to use the App (Kobsa & Schreck, 2003). This method helps greatly in complicated App to reduce mental overload challenges (Lavie & Meyer, 2010).

2.3 Contextual Adaptive Interface

Context is something that specific to App and requires the pattern of the properties (context factors) and function(s) that are specific to each domain. Contexts are varied and this variability degree reflects in the context to which classification is applied (Dey, 2001). These are divided into two types (i) static context which is termed as ‘customization’. This describes a state in which the ‘look-and-feel’ and provision of content is essentially user-driven, the user having an element of control. Whereas (ii) a dynamic context termed as ‘personalization’ describes a state in which user is static, or at least less in control, system functions to monitor, evaluate and react to the users situated actions and roles (Galleguillos & Belongie, 2010).

The ways the context is used to describe, the different types are: (i) as a retrieval clue (a static context) and (ii) to tailor system behaviour to match user’s system usage patterns (a dynamic context). A context consists of properties (context factors) that demonstrate and define an entity in computer-readable form, the properties describing any information that can be used to characterize a body (Viktoratos et al., 2017). A context definition must define and describe a number of elements that combine to create an overall definition of context. These factors include (Moore et al., 2010) (i) spatiotemporal, (ii) personal, (iii) device(s), (iv) infrastructure & connectivity constraints and (v) resource(s). A context is made by putting together property values that describe a diverse range of elements which includes: (i) variable functionality requested by user, (ii) all kinds of computing equipment, (iii) system or network architecture, (iv) physical requirement including place and (v) locality.

2.3.1 Contextual Usage of Mobile Devices

The concept of context is related to user emotional and behavioural attention, time, place and situation, also the surrounding entities and users in the user’s space (Dey et al., 1999). Additionally, user's environment that the user's computer knows about is another way of describing synonyms for the term context. The state of the user, environment of the App surroundings, context of application and existing situational features are also considered. To define information that could be considered as context, should be more precise during the development of adaptive-Apps (Uddin et al., 2018).

2.3.2 Contextual Usability

The learning concept focuses to get user choices that include the basic mechanism for adaptivity for the domain of mobile systems. This model can be utilized in different methods, for example predicting user needs in relation to his or her behaviour in the past or filtering out information based on user past searches or interest (Park & Han, 2012). All such set of knowledge related to App UI provides greater effect on the content given inside the system. Because of the variation in the mobile equipment, modelling a user's choice in desktop UI is less of an issue than modelling of the mobile environment (Mizouni et al., 2014). Usability as a quality of use in a context is a feature of the overall system. The existing products are limited in their prediction of usability more accurately in terms of tasks, users and environment.

The quality of use of overall system is measured directly by their effectiveness and other resources like time, expenses or mental effort extended towards achieving the intended goals i.e. efficiency; and the satisfaction of the user in overall system (Iqbal et al., 2017). For instance, the overall system comprises of number of users, their working, devices related to machine and software and actual company environment which effects on the interactivity. Promotional programs, such as "Usability Now!" in the UK, have made buyers more conscious of the profits of usability, and more inclined towards greater weight to ease the usability when making the purchases. As apparent from the advertisement campaigns of Amstrad and Microsoft, Usability is essentially providing product suppliers a market edge promoting comfort of use as the basic feature. International standards of usability and UI are reaching a level of fineness that can be counted as according to the European Display Screen Equipment Directive (Bevan & Macleod, 1994).

2.3.3 Contextual Properties

Most of the research has done in this area is to synthesizing context-aware computation that uses sensors and situation information to automates services, such as time, location, action and identity. Adaption in detail is conveniently ignored, for e.g. the input data based on context. In this research, it is attempted to build the user's properties from both domain experience and mobile technology experience, and to collect all the context values relating to the user's task and then to automatically adapt the mobile UIs to this context information (Zheng et al., 2015). Every working user as an aggregation becomes the integral piece of the concept of context. All the systems which are contextually-ready have their own distinct functionality that changes according to context. Due to this reason every program developer wants to know about to build and create in the application according to context.

2.3.3.1 User Properties

The context is based on user place, climate, time, person's sentiments and person operational mode like walking, sitting, resting or driving. All these activities are actually seen with built-in sensors like GPS, accelerometer, camera, mic, etc. User's sentiments are being monitored by using past contextual data (Schmidt et al., 1999). The arrangement of properties will be different from a personal data archive in the social network. Individual information (like name, date of birth, address, etc) represents the same domain doctrine. Properties of identification i.e. Name, Family etc, and address properties i.e. Zip Code, Country Code, Date of Birth, Email address etc (S. K. Shahzad, 2011). As humans are different in terms of lifestyles, these differences and their aspects need to be designed. In result, user profile designing for personalized services is needed to achieve good interaction to a specific user. A user profile may be defined as an ordinal depiction of a user and are stored within the layer of modelling and management of any context-conscious system. User account information can be categorized with the types of user- based items. The five profile items comprising of Capability Profile, Pinterest profile, Preference Profile, Education Profile and Health Profile are used to state the moving profile aspects. As it can be said that derangements in mobile contexts is handled through the user profile based theory to support the people (Skillen et al., 2012).

2.3.3.2 Device Properties

The variety in mobile equipment, a mobile system should be ready to present many versions of it. Today the mobile devices functions vary according to user's requirements. Each device has its own special features and designing mobile Apps is not simple. As features, OS based on that system will enhance all physical or hardware functionality ranges that can be listed for instance, screen, memory, GPS, network engagement). All these characteristics can play a significant part when devising Apps. Devices' context usually concerns the development of mobile App interfaces across domains. Noting that constructing frameworks like Android or iOS put forward functionalities in getting technical information of the device for instance, get screen size, get sensors list, get memory usage (J. Hussain et al., 2018). Font size either small, medium, large, Font colour either RGB colour, black and white, Font format either Times New Roman, Tahoma etc. Background colour either Auto adjust or changing manually, Data Entry either Typing or tapping, voice, Display information (Text, sound) Message delivery (Text, voice, alert, silent, pre-answer) Brightness level

(Increase/decrease) Ring volume (Low, medium, high, alert, vibration) Sound level (Mute, regular, loud) etc.

2.3.3.3 Environmental Properties

Environmental context-driven mode or night mode model information includes environmental conditions such as humidity, noise, luminosity etc. During the development of the environment outlook, an ontology module6 from *CoDAMoS* can be reused in order to get only the relevant information for the model. In this way, to obtain a core model about situations and their relationship with the mentioned above environmental conditions (Poveda-Villalon et al., 2010). Various platforms related to mobile systems are based on mobile architecture which has equipment connectivity, service development, UI design (J. Hussain et al., 2018).

2.3.3.4 Task Properties

Adaption of mobile systems related to usage shows its contextual data type which requires being mobile system based. Other than the former the AUI, aims at to create methods like sound, device vibration, speech recognition as methods of interaction among the App with person (Iqbal et al., 2017). Further, the system becomes capable to understand the user current activity. For this each developer would require sensor like Global Positioning System (GPS), accelerometer to capture the user movement of the screen. Another option for user profile that can be used for its operations which are left for user to decide, like normal driving, sport, night, guest and kid mode (Meditskos et al., 2016).

2.3.4 Adaptive Assistive Technology

Assistive technology is an umbrella term that includes assistive, adaptive, and rehabilitative devices for people with disabilities or old people that requires special functionality like choosing place for them and performing Activities of Daily Livings (ADLs) independently, or even with assistance. ADL’s based on the user operation including getting to washroom, moving around, taking food, washing up, getting dressed etc. Assistance-based functionality can ameliorate the non-functioning which keeps performing the day to day activities. Such technologies using ADLs to perform greatly by activating special features for the disable people (Barrue et al., 2007). Assistive technology works on using methods and techniques that enhances interaction with user, using the technology like wheel chairs or independent mobile units unable to walk would need assistive eating devices or do their necessary movement without any hassle. With such functionality in operation disable person get new opportunity for adding more to their lives. That helps greatly lowering extra cost in special institutes that are built to help such people (Parant et al., 2017).

If a general technology-based role of assistive technology, there can be multiple scenarios in which this functionality can help in housed, education and in society. Its impact is greater for mass application, for example according to a research many babies, and young teenagers possess some kind of disability that makes things difficult for them. With assistive technology their well-being can be assured and they can be as active as any other person in the society. In addition to this a big care giving load will be lift off from family and social departments as person would be able to self help him or herself. In this way more people can be taken care in lesser time which will result in more efficient society (LoPresti et al., 2004).

The term adaptive technology is often used as synonym in explaining such functionality. There are multiple ways that this technology can be elaborated, like a part of device or an App system. Even, from commercial thinking, it can either be building or changed from existing model as an enhancement in design and features to fit needs of disable persons. Assistive technology brings great deal of change while looking at its App in the information technology and digital sector.

2.4 User Context Environment

Contextual environment is classified as the state of an object, user, or thing. Such a state can be an entity that is considered relevant to the user and App to provide the interaction between them (Dey, 2001). The given definition by Dey provides the flexibility to developers to compute the context for defined or specific scenario of Apps. Further, the information is considered as context if it can be used to characterize the situation of a participant in an interaction (Rodden et al., 1998) (Aliannejadi et al., 2019). Likewise, context’s variables are present in which, the classification applied to context which defines the degree of variability (e. g. user context, device context, environment context, task context etc). There are two broad classes (i) static context is user-driven (customization) in which contents are provided and controlled by user principally (ii) dynamic context (personalization) is not user driven in which user is essentially inactive or has less control (Mehrban & Asif, 2010) (Iqbal et al., 2017). To understand the context, an example of canonical context-aware application is discussed (an indoor mobile tour guide). This example has noticeable entities such as user, application and tour sites. The weather and presence of other people are considered as piece of information to determine whether either one is context (Dey & Abowd, 1999). The weather is not context because it is being used indoor so that it does not affect the App. On the other hand, the presence of other people is context because sites may be visited of particular interest and it can be used to characterize the user's situation (Dey et al., 1999).

Moreover, the context is comparatively stable for desktop computers in contrast of mobile devices while designing web services. Mobile users can move everywhere, they can use mobile throughout the day where ever they go; e.g. in park, in store, in kitchen, on bus etc. The environmental context is always changing due to the mobility of mobile users which can create complexity for developers. This variability can result in failure of certain interaction methods and create design challenges for mobile devices such as noise, screen size, weather, brightness, camera etc (Nokia Forum, 2011).

The usage of mobile devices creates the difference of user from real world; they use their devices differently within different social contexts. It is very hard to get ahead that how a certain user may use mobile phones in a given situation. Therefore, it is impossible to know all the contexts of user and environment while designing the mobile. Full attention from users all the time for web services of mobile devices is not required. The context-aware information provided through websites may increase difficulties of user, but dynamic behaviour offers broad opportunity for designers to design a variety of contexts. Latest technologies of mobile device such as sensors, location awareness, network connectivity and accelerometer provide the platform for innovative interaction design (Hakkila, J., & Mantyjarvi, 2006).

2.4.1 Context Modelling and Elements

In the smart world, the increase in user interaction with interfaces has influenced on context directly to perform user's task in any situation. The context and defined task can effect on the change that is being required for specific action (Riahi & Moussa, 2015). The wide range of variables that is cognitive skills, background, demography, personality and preferences are available regarding user's environment and have lot of meanings in interface usability. The foremost challenge in HCI is different interpretation and mismatched abilities for command names, icons and displays (Lavie & Meyer, 2010). For computational understanding in mobile devices or real time location based scenarios of a person or equipment like place and moment (Holzinger et al., 2012). Due to which the user modelling works in the mobile based systems can give functionality by analysing user's previous behaviour and profile status. This kind of information has great impact on system's UI. The smaller amount of domain knowledge is required for supervised learning approaches while there is no need of domain knowledge for unsupervised learning approaches (Klaassen et al., 2013) (J. Hussain et al., 2018). The relevant information of users is very difficult to find because many of them are not aware about its importance. This problem creates much difficulties for App developers to develop adaptive features as per user's context (Dey et al., 1999).

Moreover, a context modelling is defined that how data can be structured and maintained to support the efficient context management. Actually, the context is surrounding element for system and a model provides behavioural description of the surrounding environment through interfaces. The aim of such modelling is to produce a formal or semi-formal description of context information that is provided through context-aware system. Key role of context modelling is to present simplified structure into development and represent reusable context information of the components (Helal et al., 2008) (Trullemans et al., 2017). Due to the variety in contextual information, the defined elements are required to represent through semantic relations and constraints (Arechiga, et al., 2009).

The dynamic context model is required to fulfil user's requirements that are mined from environment which help to identify the situation of user at certain time and location. In fact, a "situation" is a multifaceted conception that may be seen in different conditions. In ontological context modelling, the static context information is represented while dynamic characteristics are not added. Though an ontology permits the existence of multiple instances of classes that may change with passage of time (e.g. living conditions of user) (Golemati et al., 2007).

2.4.2 Human's Perspective of Context

The human precepts are taken through senses and experiences for performing activities because the reality cannot be found in original form. So that the human's perspective should present in the concept of user context. On the basis of these perceptions, the human creates mental model about desired system and expect its behaviour accordingly (B. Smith, 2004). To fulfil the real-world concepts of computational model, all automated systems are comprised of software and hardware. The interaction and usage of these systems is affected by human's perspective and App design.

A conceptualisation of a domain into a human-understandable but machine-readable format consisting of entities, attributes, relationships and axioms is defined as ontology. To recognize the benefits such as the capacity of information communication and the ability to name concepts in machine readable form are the abilities of ontology. It can define these concepts in different classes and specific instances (Viktoratos et al., 2017). Hence, ontology is a formal specification of human perspectives. There is no issue when ontology organizes the semantics through reasoning with the body of knowledge (K. M. De Oliveira et al., 2013). The existing work in ontology practices predominantly in the field of knowledge representation which is not assumed with reality but the concepts conceived as human creations (Poveda-Villalon et al., 2010). The assumption is that knowledge exists in the minds of human subjects. Hence humans can have knowledge of their own concepts according to required conditions instead of real entities. Another argument provides that what human know about errors belonging to knowledge in past.

2.5 Context Knowledge Representation

The assumptions, that human contains in their minds are required to shape formally through ontological representation. This formal representation of knowledge is based on two components such as conceptualization and generalization. An abstraction of world that desire to be representing for specific purpose is called conceptualization. The knowledge-based systems and knowledge level agents are devoted to some conceptualization explicitly or implicitly. Therefore, ontology is an explicit specification of conceptualization and organized interpretation of existence (Guarino et al., 2009). To signify the knowledge-based system what "exists" exactly that can be presented. Relations with objects that can be described in knowledge-based program are reflected in vocabulary that represents knowledge. Such kind of ontology illustrates the association amongst entities, classes, functions, relations, objects or constraints with the readable text of human (Gruber, 1993) (Uschold & Gruninger, 1996).

The attitude of knowledge-based systems has special requirements for interoperability which provide communication in formal knowledge representation. These systems take background knowledge as an input for negotiation and exchange of knowledge. The example for such system can be relationships between all employees of a company. The ontology engineer analyses relevant entities and organizes them into concepts and relations, being represented, respectively, by using predicates. Furthermore, the generalization hierarchy of concepts (i.e. taxonomy) is considered as backbone of ontology. For example, person, manager and researcher might be relevant concepts in human resource aspects, where first is a super-concept. Additionally, relevant relations can be considered between persons. A concrete person working in a company would then be an instance of its corresponding concept (Guarino et al., 2009). Currently, ontologies are used for specifying content specific agreements for a variety of knowledge sharing activities (Gruber, 1995).

The system needs to plan by adapting an existing knowledge base to a new App domain or from scratch (B. Smith, 2004). It is assumed that knowledge exists in the minds of human subjects. Hence humans can have knowledge of their own concepts according to required conditions instead of real entities. Further, the humans can do mistakes while taking decisions on the basis of previous knowledge and observation. It provides the evidence that human have about mistakes/errors belonging to knowledge in past (Uddin et al., 2018).

2.5.1 Ontology for the Context of Use

User context ontology is used to define formally the concepts of usage context of user in detail. The context elements can be read and understood by any machine or computational system with formal definitions stated in OWL/RDFs (Strimpakou et al., 2006). While defining context, it is referred as knowledge which is utilized to explain a particular functionality of an entity while that entity or object can be a user or a location (Meditskos et al., 2016). Furthermore, the context can be look-attentively as a specific type of knowledge that can be modelled as ontology. Context based ontology models permit to represent complex and formal semantics to context knowledge, which provisions the sharing and/or integration of context information (Gulla et al. , 2015). Even though, distinct ontologies have been developed with different perspectives and approaches, however, there is no mutual model available that can be used/reused for modelling context in Apps (Poveda-Villalon et al., 2010).

The ontologies have capacity to communicate information and ability to represent entities to name the concepts in machine readable form. It can define these concepts in different classes and specific instances. Humans have concepts, based on knowledge cognition including system devices, senses, experiences and context. These concepts are abstract, vague, composite or real. Humans create mental model and expect to behave the system accordingly (B. Smith, 2004). All automated system comprised of software and hardware provide a computational model of real-world concepts. Ontologies are used to express these concepts formally to define a computational model. Ontology driven information systems approach is being used to design App in human's perspective (Gruber, 1993) (K. M. De Oliveira et al., 2013).

Thus, exploiting the benefits of ontologies to formally state the usage context of adaptive UIs is established in literature previously. The ontology may be comprised of representational terms for the elements of the mobile usage context. This type of ontology represents association amongst objects with natural classification (e.g. relations, objects constraints etc).

2.6 User Centered Design (UCD)

The term UCD was invented in research laboratory of Donald A. Norman in University of California, San Diego. In 1986, UCD concept became popular after the publication of book "User Centered System Design: New Perspectives of Human Computer Interaction" (Anderson et al., 1988). Further, concept of UCD raised when another book "The Design of Everyday Things" came into market. In these books, Norman describes psychology of good and bad design through examples relevant to daily life. Some principles are also included for well-designed products and consequences of errors in bad design. The major consents based on the needs of user are given below (Norman, 2003):

1. Simplify the tasks structure for possible actions at any moment that can be accepted.
2. Build entities such as concepts of application, functionality and outcome of such functionality with response for better understanding.
3. Accomplishment of mappings between intended results and required actions.
4. Take care of implementation and manipulating the constraints of systems.

UCD can be defined as a set of processes that are not limited to UI and specific functionality. It provides the extensive attention at each stage of design process for usability goals, characteristics of user, environment, tasks, product workflow and services (Henry, 2007). It can be characterized as a multistage problem-solving process, providing facility for designers to predict and validate their assumptions with regard to user behaviour in real world tests. This test/user study can be conducted with/without actual users during each stage of process, pre-production and post-production models to ensure the feedback of product (Rubin & Chisnell, 2008). Such type of testing/user study is necessary for designers to understand the user experience and learning regarding the product. In design industry, UCD is commonly used to increase the usefulness and usability of product (Vredenburg et al., 2002).

2.6.1 Difference Between UCD and Other Design Models

The key difference between other product design philosophies is that UCD tries to optimize the product according to user's requirement rather than accommodate the product forcefully to change the behaviour of user. The user has two phases when to use a product (i) the product context, development objectives and environmental capabilities (ii) details, organization and flow of the task. Design is based upon an explicit understanding of users, tasks and environments which are refined by user centered evaluation and addresses whole user experience. The process is iterative which involves the users throughout designing and development process.

2.6.2 UCD Process Model

A typical UCD methodology has an analysis phase, design phase, implementation phase and deployment phase. There are six basic steps in implementing UCD methodology (Anderson et al., 1988) (Shaw, 1996): (i) get to know the users (ii) analyse the user tasks and goals (iii) establish usability requirements (iv) prototype some design ideas (v) usability test and (vi) repeat as necessary. The Figure 2.1 shows the general phases of the UCD process[3]:

[3] https://www.usability.gov/what-and-why/user-centered-design.html

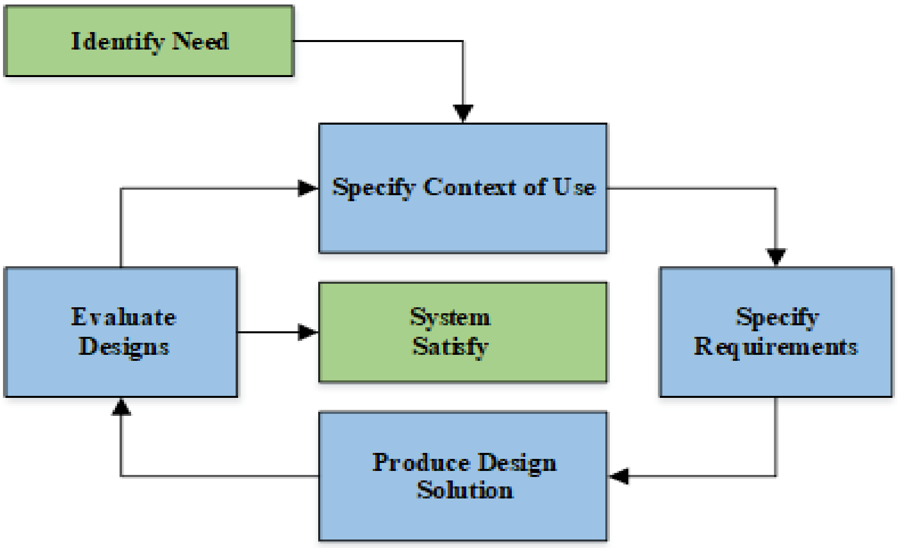

Figure 2.1: User centred design process model[3]

The biggest cost benefit that UCD can provide is by more accurately defining user's requirements. The UCD methodology is adopted in this research, in which all development proceeds with the user as the centre of focus and it covers all aspects of end user experience including user needs, goals, motivation, triggers, obstacles, limitations, tasks, activities, behaviours, geography, environment, work and language.

2.7 Summary

This chapter describes the detailed definition of interaction design of UIs, contextual adaptive interfaces, context learning, context properties and adaptive assistive technology. Further, the information has been presented about user context environment, context modelling, human perspective of context, context knowledge representation, ontological context and UCD process model. In the perspective of these learnings, there is a need of strong background and literature review, which is going to be discussed in next chapter.

Chapter 3. BACKGROUND AND LITERATURE REVIEW

This chapter describes the background and literature review of adaptive interface for mobile devices in user's context. Further, the usability of mobile phone devices and operating systems are discussed. User context along with its elements and context of special needs have also been described. Usability engineering of dynamic and static interfaces and comparison between them is shown. Likewise, Intelligence for dynamic mobile UI and development criteria for smart AUI is elaborated. In the end, the interface evaluation has been discussed in the perspective of usability, task, environment and device. The intelligent interfaces are the requirement of mobile users for better usability and accessibility.

3.1 State of the Art

The mobile phones were invented in early 1940s when engineers were working at AT&T to develop the smart base station. In early 1980s and 1990s, at the time of early mobile invention, these were not regarded as computers. However, an advanced system was introduced in 1991, which was known as Digital Global System (DGS). It incorporated with varieties of communication components such as Short Message Service (SMS) and with this ramification and performance, mobile gadgets began to progress swiftly (Jindal & Jain, 2012).

In addition, the uptake of mobile technology was acknowledged worldwide. Mobile developers were faced with immense challenges in producing interaction design, not only for making phone calls, but also in handling contacts, memos, text messages and internet browsing. In the late 1990s, interaction design for mobile phones was undeniably influenced by the work at Nokia, which led to a series of innovative and revolutionary handsets (Lacohee et al., 2003). The 2000s saw the declaration of comprehensive range of different smart phones that were assigned to complete unambiguous, especially portable music players, video players and regenerations. Obviously practically devoted smart phones were not another wonder as, early smart phones; for example, stash number crunchers, mobile phones, GPS beneficiaries, computerized cameras, and PDAs could verifiably be delegated data machines as well. In any case, what was fascinating about the pattern of dissimilarity in the mid-2000s that it was a purposed connection structure decision and not an innovative essential. Likely the most respected case of a data machine was the Apple iPod from 2001 (Kortum & Sorber, 2015).

In spite of the fact, not being the main portable advanced music player, its communication configuration, incorporating the unification with iTunes and later the iTunes Music Store, fundamentally changed overall music usage and obtaining reaction. While, most smart phones available in the mid-2000s had the ability to play MP3 files, individuals still wanted to convey an auxiliary device, the iPod, for playing their music as it gave a worthy client experience to the explicit undertaking, and the gadget itself had turned into a sought after and saleable design item.

In 2010, the aggregate number of iPods deal outperformed i.e. 290 million units. The communication configuration test of a deviated smart phone is considerably disparate from that of a joined one since its useful skill is limited. The history of mobile phone vendors showed that Motorola (1983-1998) and Nokia (1998-2012) were market leaders respectively (Roger Cheng, 2014). As time changed in 2012, that Nokia's sale reduced (82.7 million units) rather than Samsung (93.5 million units) and retained its top position till 2017. Worldwide top five manufacturers in 2017 were Vivi (6.5%), Oppo (5.7%), Huawei (9.8%), Apple (14.0%) and Samsung (20.9%) [4]. At this time in 2018, Huawei overtook Apple as the world's second-largest phone manufacturer (The Guardian, 2018).

The interfaces of smart phone, in past, have different methods of connection which contains different possibilities and procedures to make the way of communication progressive from many-sided (Benyon & Murray, 1993). The aggressive condition has utilized the specialized alternatives in communication plan where designers and end users confront more difficulties in grasping the interface and programming specialized representations (Petrovcic et al., 2018). Personal Computer (PC) interfaces have progressively prevailing in usefulness and programming frameworks. These are getting increasingly mind overwhelming due to increasing in size online data. With enormous improvement in specialized help, the variation utilization designs are likewise rising (Hervas & Bravo, 2011).

Currently tremendously new users are available who are not good mobile users with less practice to processing gadgets, for example, non-specialized experts, elderly individuals and kids. These users have various aptitude, as well as they differ in numerous different

[4]https://www.gartner.com/en/newsroom/press-releases/2018-02-22-gartner-says-worldwide-sales-of-smartphones-recorded-first-ever-decline-during-the-fourth-quarter-of-2017

attributes for instance, information, abilities, scholarly and physical capacities, mind-set, inspiration and objective to use innovation rightly (Iqbal et al., 2017). Many extraordinary Apps cannot penetrate in the market because of their unusual, unappealing, awkward and confused UIs. The effect of non-adaptive UI for mobile phones creates displeasure and clearly complications for execution, feasibility and social affair among the customers (Akiki et al. , 2014). In the focus of an organizing of user mobile interfaces, customer demands should be analysed in the extent of credibility, learn ability, understandability and objectivity (Petrie & Bevan, 2009). Most recent versatile working frameworks like Android or iOS are providing such type of modes (e.g. kid mode, guest mode, driving mode and night mode) for utilizations of user task. These modes are given for particular context in variety of basic substitutions like light, age groups and structure of access. These features offer pre-characterized and static profiles with factory contexts. The client preferences and requirements are absent inside the interface contexts for pre-characterized collaboration modes (FernaNdez-LoPez et al., 2013). AUIs can give a great deal of advantages to address the ease of use for completion of tasks. User modification has been recognized, a long time back, as a basic state of mind subject to address in current information frameworks advancement (Paymans et al., 2004).

The variety in mobile phones physical contextual properties and confinements of bad connection style presents a test to build up specific UI for variety of users (Kane, 2009) (Ali et al., 2014). Numerous users face issues in customization panels, it is extremely hard to comprehend in development. The requirement for customization is important prerequisite requested by kids or elderly people (Peissner et al., 2012). For substantial interfaces of mobile devices, the expected tasks necessarily be mapped with user's psychological model (Paymans et al., 2004). At present, advantages of adaptive UI have been acknowledged to build up the interface in user's specific situation. It is plausible variant methodology than adaptable, in light of the fact that it gives reasonable technique of context adjustment and it can deal with the ease of use for user's interaction (Bhaskar et al., 2013) (Francesca Gulla & Ceccacci, 2015).

The AUIs for mobile devices are proposed as answer for the issue that empower any mobile App to give dynamically customized mobile interface to various categories of users having comparable properties and necessities. The user's context-based interface helps to make the shared, steady, productive and open exercises simple.

3.2 Usability of Mobile Phone Interface

Usability largely started as profession in 1980s, it has been used for ergonomics and human factors in the beginning of 20th century (Nielsen, 1994). The said author tried to unbiased assess the customer involvement on cutting edge stages. It dates back to the 1990s when he portrayed ten imperative usability investigative benchmarks which are till now significant and used in ordinary day to day presence (Nielsen, 2005) (Molich & Dumas, 2008). In case, it is very difficult to use any device interface or PDA, even it has extraordinary functionalities, it doesn't have any kind of effect, the customer will move towards basic choice (Shehzad & Ahmad, 2017). For example, better usability of product is very important; if product is not useful then UX is bad and may cause to reject the product. In Huff industrial marketing, in 2015, 46% of user leaves a website due to less effectiveness and 37% users leave due to poor design. In the centre of examination time of UI design development, the convenience is seen as basic for user comfortability to work together with system.

By seeing the multifaceted idea of mobile phone interface usability, there are diverse game plans that have been anticipated through UCD. Among the distinctive present user models, there is not a basic model which thinks about the different complex features, for instance, scholarly, motor and mental (Figueroa et al., 2014). Nielsen evaluated a comparative thing that contained unmistakable stepped issues. The convenience examinations of programming App for new users took autonomously and were furthermore driven in meeting. Only a solitary issue was perceived as customary in four gatherings while others were exceptionally unprecedented (Nielsen, 1992).

Molich et al. evaluated a comparative site of nine relationships to check the reliability in comfort testing. In this manner, 310 total issues were represented and 232 of them were unique (Molich et al., 1999). Effectiveness, efficiency and satisfaction are the parameters of convenience in ISO 9241-11 standard (ISO, 1998). Another usability study of mobile Apps conducted in 2009 by prominent Nielson Norman research group. As a result, there were 59% tasks completed successfully during the usability testing. Henceforth, throughout the conduction of usability test, there were three issues found like efficiency, screen size and text addition (Wesson et al., 2014). Still there is certifiably not an exact apparatus to measure usability of any item while it can be used to upgrade communications between users and products to finish the activity as indicated by the context (Fischer, 2001) (Lewis, 2006).

3.2.1 Usability of Mobile Phone Operating System

Google brought the Android in 2005, but its first commercial device was launched in 2008. It has been best-selling OS throughout the world since 2011 and tablets since 2013. Furthermore, it has more than 2 billion active users in 2017, while the range of Google Play store features were installed over 3.3 billion as of 2018 June (Android, 2018). On the other side, Steve Jobs invented the iPhone in 2005 but originally unveiled in 2007, the iOS has been extended to support other Apple devices. The App Store contains more than 2.1 million iOS Apps in 2018 (Costello, 2018). Utilization of smart phone gadgets is expanding significantly and as mentioned in previous section, there are two noteworthy sellers (iOS and Android) in the worldwide market. iOS is anticipating selection of clients by giving well-disposed Graphical User Interface (GUI). It (Apple) additionally furnishes a recreation time to clients with most believed equipment bolster.

Then again, Android is likewise a noticeable brand yet battling for better equipment bolster. Alongside equipment, the convenience of smart phone Apps is turning into an undeniably noteworthy part among clients (Andone et al., 2016). Additionally, the working frameworks (OS) alongside specialized conceivable outcomes and App compatibilities to empower the functionalities of end gadget can assume crucial job as far as undertaking performing (Jindal & Jain, 2012). The highlights of interface (Ahmad, Boota, & Masoom, 2014) are created contrastingly in isolated gadgets as indicated by user requirements for better ease of use. These interfaces may give huge screens, little screens, improved information/yield gadgets (e.g. trackball, console or touch pen) to enhance the productivity, viability and fulfilment (Eisenstein et al., 2000) (Heijst 2016).

In this section, considerable limitations are presented as an argument in support of the significance of research along with most relevant studies. In HCI, usability is considered as one of the real ideas which has just delivered rising sight with respect to item usage and consumer satisfaction (Hewes, 1992) (Mian & Ahmad, 2017). Previously, a study was conducted for empirical evaluation of Google Maps and Google Apps by using ISO 9126, 9241. There were 32 users involved to perform tasks on their devices based on expert data and descriptions. The relationship illustrated that Google Maps was faster on iPhone 4/5, S3, S4 rather than Nokia E72, S young S2 and Nokia Music. The median was 100 for both Google Maps and Google Apps which means that majority of participants were able to complete their tasks. In reality, screen size, display, resolution and storage capacity of mobile devices have important role in usability of Apps (Moumane et al., 2016). Alike, one more study was conducted for the usability evaluation of smart phones i.e. Android and iOS Apps. Contributors were asked to perform defined tasks for Google Maps and Google Apps to investigate usability issues. There were 6 males and 4 females, age range from 22 to 37 years old. 6 of them were mobile Apps familiar users while others were novice users. Overall the users were more satisfied with iPhone. But in contrast, the users were not gratified with Google Apps running on Orbit and they think that App was not stimulating and rigid (Hussain & Utara, 2012).

In the discussed researches, usability of adaptive features and evaluation of interfaces are performed in specific environments. Further, a little work is performed on usability engineering of adaptive features. A defined usability engineering model is required for AUIs in mobile phones like UCD. Furthermore, the research studies highlighted the dependency of mobile phone usability over OS. These OS providers facilitate the user by adaptivity features but lack the context sensing and context base interface adaptation strategy. There is a need to provide context sensing and understanding for interface adaptivity.

3.3 Usage Context of Mobile Phone

An interesting perspective about context states that it integrates user’s condition of feelings, consideration, socioeconomics and every one of the components present in the user’s environment (Dey et al., 1999). Indeed, even the term context refers to nature of use giving perceptions regarding user's innovative information, present situation, application's experience, App contexts and present utilization circumstance (Zheng et al., 2016) (Uddin et al., 2018).

In context of adaptive Apps, user model can be helpful in few directions: the user recorded utilization example can recognize and even foresee the client needs and select data of utilization's advantage (Park & Han, 2012). The task to show the user with a mobile phone and changing condition has all earmarks of being much troublesome than playing out the equivalent for a user in work area situations (Mizouni et al., 2014). Usability is generally combined with interface, while it is the property of by and large framework/system. It includes to the nature of utilization in an explicit context. As referenced, current strategies and methods for usability expectation are deficient with respect to their precision due to thought of partial context of users, tasks and environment (Hoseini-Tabatabaei et al., 2013) (Aliannejadi et al., 2019).

There exist multiple techniques to decide the nature of utilization of any framework particularly for ICT area. The limited time campaigns have launched in UK for purchasers of any system about the significance of usability. The impact of these awareness programs, purchasers currently give more thought to convenience of any (S/W or H/W) framework in their choice. Correspondingly, the makers and providers of the products with high ease of use, get client consideration and a market edge. Microsoft and Amstrad have featured the convenience as a significant moving component in their ongoing promotional efforts and gain advancements. Global ease of use and the UI standards are by and large progressively referred openly acquirement. They likewise mean to satisfy European display screen equipment directive (Bevan & Macleod, 1994).

Two different research communities consider the context in dissimilar viewpoint. One is user centered view which succeeds in the HCI and second is device centered view which dominates in mobile and ubiquitous computing. Despite of advancements, context modelling and UI design methods are still poorly integrated. Contextual factors can reduce or enhance the usability effects from user, device and environment perspectives. A framework named Unmanned Aerial Vehicle (UAV) was used to bridge the user context and design models to develop an AUI. Relations between contextual factors were defined with association of rating scale for different types of evaluation. Some relations expressed by using qualitative scale from 0.0 to 1.0 or from 0 to 100% with resolution for instance 1% (Jovanovic et al., 2014). Another adaptive multi criteria decision making mechanism was presented for relevant services to the context of mobile user. The “relevance” was defined as user centric approach for user’s context. In experimentation, the distributed ratio and hit ratio was obtained from 100 simulations. The distraction ration touched the value (0.2) while hit ratio approached to the value (0.8). In other examination with changed contexts that assumed that high performance services had probability of (0.7) and low performance services had probability of (0.3) (Yazidi et al., 2011).

3.3.1 User Context Elements

Context-aware strategies and methods have been utilized in the majority of the examination for adaptive interface improvement. The user's properties and behaviour using domain involvement and portable technology for the experimentations expects to assemble all the context components with scale and esteem. Thus, it gives plan rules to the interfaces that can automatically adapt as indicated by the gave context (Zheng et al., 2015).

The user itself, as a compound entity, is a fundamental piece of the specific context. There has been extremely particular arrangement of practices given by any context-aware application to respond against clear context varieties. Hence, the product designer should obviously comprehend the advancement objectives and arrange different context cases in the focus on App.

3.3.1.1 User Context

User's properties are most worried in a significant number of the context-aware Apps where context in spoken to by the user's status like age, sex, socioeconomics, thinking and feelings (Schmidt et al., 1999) (Aliannejadi et al., 2019). The arrangement and classification of user's properties is not at all like to information of an individual utilized in interpersonal organization. User properties can be classified over the semantics and utilization of qualities known to mankind behaviour. A portion of the user properties are raised for distinguishing proof name any IDs (username, government managed savings number), address, city, nation etc. The address properties (e.g. postal district, nation code, phone number, telephone number, place of residence, email and different business properties may incorporate date of birth) (S. K. Shahzad, 2011). The user profile is a computerized depiction and context-aware framework places it in displaying and executive’s layer. A user profile can be depicted as various related classes. Different powerful profile perspectives have been talked about in five classes comprising of capability, interest, preference, education and health profile. Necessities of user with specific prerequisites have additionally been inclined to philosophy built for user profile to help individuals with versatile conditions of use (Skillen et al., 2012).

A multimodal UI was designed for context identification with content adaptation. The results were obtained for 32 participants from user-based evaluation where 3 contestants were not able to use App for 5 days. Overall the average usage of App for all participants was 27 days. Further, the values attained after UX were as like that attractiveness (0.771), perspicuity (0.855), efficiency (0.836), dependability (0.556), simulation (0.453) and novelty (0.753). After experimentation of AUI that A-UI/UX-A tool was good for users accessibility and functionality (J. Hussain et al., 2018).

3.3.1.2 Device Context

The context of device cannot be ignored due to its direct influence at the usability of any App. Mobile interfaces have become more complex due to complexity and diversity. The developers are required to deploy and run Apps to handle the device context with network connectivity, display, GPS sensors etc. Android and iOS are provided different OS platforms with technical functionalities e.g. memory, display, size, resolution etc (J. Hussain et al., 2018). The device properties such as font size, colour, format, background, data entry mode, display information, message delivery, brightness level, ring volume and sound level.

A usability testing was conducted to evaluate the key features of Android and Apple. The sample size of 64 participants were selected where 32 were android users and remaining 32 were apple users. The key features were divided into 5 categories such as OS, Apps execution, multitasking, integrated technology and framework compatibility. The values represented for Usefulness (android=58, apple=60) efficiency (android=59, apple=61) and satisfaction (android=60, apple=62). The effect exhibited for usefulness, efficiency and satisfaction for smart phones was almost more than 50% for each (Naseer Ahmad et al., 2014).

3.3.1.3 Environmental Context

Natural properties present the data about the surrounding condition like geographical data. In reality, learning can be assembled through a few sensors with aggregate information of the cloud. In writing, Module6 of CoDAMoS is a context ontology which has been demonstrated and reused for environmental context. In this manner, core show for situations and their semantic relations with the above expressed ecological conditions (Poveda-Villalon et al., 2010) (Wiens & Lohmann, 2018). The versatility of the mobile devices exchange, starting with one then onto the next condition makes it fundamental to consider the use condition in portable App interface advancement (J. Hussain et al., 2018).

Environment is an essential part for users in their work place, which is mostly considered as complex. To evaluate the environment context, an E-business mathematical App was developed for android operating system. The experiment was conducted for adaptive and non-adaptive environment. There were 408 calculations performed, 198 were found for AUI in portrait mode (8=landscape mode) while 133 were found for non-AUI (portrait mode only). Overall, the result showed for perfect calculations for AUI was 83.3% while 79.9% for non-AUI (Holzinger et al., 2012) (Aliannejadi et al., 2019).

3.3.1.4 Task Context

Along with any adaptive App improvement, designers need to distinguish the plan and exercises. It is additionally identified with the functionalities that gave in explicit context by the adaptive App. Along these lines, the App is required to peruse the earth to decide the present movement to be performed by the user. Here, the fashioner requires some state distinguishing proof to break down the errand and choose the correspondence choices (e.g. sensors, touch screen, network). The choice of profile determination (e.g. driving, sport, night) can be given for an specific activity (e.g. messaging, calling or tuning in to news and so on) (Baldauf et al., 2007) (Meditskos et al., 2016). A study was conducted in 2010 for AUI in the context of “In-Vehicle Telematic System” by taking 24 participants in particular driving task. The users drove the cars at fixed speed (Approx. 30 km/h) and the lane position was fixed. In familiar situation the adaptive system was beneficial rather than in-familiar situation (Lavie & Meyer, 2010).

In the above sections (3.4 and 3.4.1), different studies about the usage of context and user elements are discussed. The substantial limitations are presented in terms of the usage context of mobile phones and context elements. Partial solutions of context elements are available about user, device, environment and activity (Lavie & Meyer, 2010) (Holzinger et al., 2012) (Jovanovic et al., 2014) (Naseer Ahmad et al., 2014) (J. Hussain et al., 2018). Actually, the collective and integrated picture of context is missing. We need to have same device interface adaptation rather than specialized devices for special need users. Thus, there is a need of usability engineering process model for AUIs that can generate adaptivity design with adaptation rule strategies based on user context (Zheng et al., 2016) (Uddin et al., 2018). It also requires a machine understandable context model for the selection of respective UI style.

3.3.2 Special Needs, ICT & Accessibility

The world is compressing into global village that built on the growth and development in ICT which has become vital tool of special needs people. From last decades, the scientific and technological progress has brought economy expansion globally but variations in culture, social relations, education etc. To improve the quality of life, the development of telecommunications, media and information technology have great potential. In wider perspective, this quality cannot obtain an appropriate level without assistance of specialists of technology and people with special needs (Andronie & Andronie, 2014).

People with disabilities are expecting the same standard level of technology as other members of society. However, blind people required suitable hardware and software (i.e. alternative text as image and text translated into an audible format). People with low vision can use technology with large text format and colour contrast while have cognitive impairments use simple language or easy reading. The Apps produced for mobiles may keep away from that clear match of shading in different items recognizable proof in one canvas particularly in frontal area and foundation mixes. It is likewise proposed to give a shading change by the OS to maintain a strategic distance from such mix in App running at that stage (Iqbal & Ahmad, 2018). Hard of hearing' clients to take in the sign language that depends on the mix of developments of hands, arms, body and outward appearances. An examination expresses that there have been about 60,000 individuals living in Italy who utilize hard of hearing Italian Sign Language (LIS) as their mean of correspondence (Nadeem Ahmad, 2014).

The eAccessibility, plan of 2020 for special education affect the quality in assistive technologies. First of all, at access level, assistive technologies (such as speech recognition and tactile screens) are still considered very important, they should be available, compatible with new and emerging devices (tables and smart phones) and technologies (virtual reality, augmented reality). Moreover, collaboration, especially through social media, is considered to be the key for the improvement of teaching and learning for special needs. As for the main technologies which are considered as most important for special education, they include affective computing, gaming, learning analytics, robotics and smart home environments (Karagiannidis et al., 2012). One of the existing works developed for AUIs for CVD subjects with web systems. The results showed from developed prototype scenarios that most suitable re-colouring approaches could be determined and automatically employed in order to adapt the interfaces (De Araujo et al., 2016). Another study was conducted for adaptive interface for colour-blind people in mobile phones. The results showed that the effectiveness for adaptive and non-adaptive environment is 20% for all types of colour-blindness while major difference for CVD is 40% in Tritanomaly. A great difference in the efficiency of colour-blind people in Protanopia is 9.9% while the difference in Tritanomaly is 21.7% for both adaptive and non-adaptive modes. The highest satisfaction for adaptive environment in Tritanopia is 5.6 but 4.9 in Tritanomaly (Iqbal & Ahmad, 2018).

The above studies show that every person has different profiles, therefore any single, one-size-fits-all solution can not address their different needs, abilities and preferences. There is a need to develop systems which can adapt to each individual earner and the learning context in general. The rapid evolution and adoption of mobile and ubiquitous technologies can offer an additional motivation for research in this direction, since in such environments all learners can be "disabled" for specific time periods due to their context of use.

3.4 Usability Engineering

The exchange offs in UIs done by the producers and App engineers have brought about disappointment among the users. One of the significant reasons is their non-AUIs. AUIs help us in addressing these issues and increment the ease of use of utilizations by giving the usability that centres around the user necessities (Mizouni et al., 2014). Variability with respect to user's condition are accessible in wide range, for example, demography, intellectual aptitudes, foundation, training, identity and inclinations (Hoseini-Tabatabaei et al., 2013).

HCI Provides fast increment in user collaboration with interfaces and direct impact of context on user's assignment in a situation. The unique circumstances and assignment characterize the change that should be performed at an unambiguous development on UI's. In portable processing, context mindfulness or physical condition incorporates surroundings of a client and gadget (e.g. area and time) (Lavie & Meyer, 2010) (Holzinger et al., 2012) (Riahi & Moussa, 2015). User demonstration in portable Apps can be performed by observing client's past practices or profiles. This sort of perceptive learning has an effect on App interfaces and its substance. Learning approaches require little measure of space information while unsupervised learning don't require the area learning (Klaassen et al., 2013) (J. Hussain et al., 2018). It is exceptionally hard to gather pertinent data from clients that greater part of the users does not know which data is imperative. This issue may make challenges for App designers to create versatile Apps as per client's logical data (Dey et al., 1999).

3.4.1 Dynamic & Static Mobile Phone User Interfaces

The two methodologies, for example, adaptivity and adaptability are utilized to personalization for UIs of mobile phones. The point of the two interfaces is to give personalization to the users while these two methodologies are diverse in the adjustment (Greenberg & Witten, 1985). Recently, the adaptivity and versatility have accomplished high ubiquity on the internet (WWW) under the idea of personalization due to low tendency of homogeneity of site users than the users of business programming's (Findlater & McGrenere, 2004). In adaptive methodology, the interface naturally changes and helps the user. The AUIs can adjust their exercises by observing client status, condition of framework and the present circumstance as per adjustment methodology. Typically the power of adjustment is estimated on account of adequacy, proficiency and fulfilment for UI (Tenner, 2015) (Iqbal et al., 2017).

The components, for example, spatial soundness which builds the user fulfilment and high territory, enhances discoverability of adjustment in speaking to interface in its unique position. Spatial dependability is required to keep up the psychological model of use. Besides, precision gives the user discernment to calculation consistency, while UIs with higher exactness give greater consistency. Further, the connection recurrence and assignment unpredictability assume an imperative job in the view of adjustment (Petrie & Bevan, 2009). Just in case that there is a need of expansive mechanical associations with basic undertakings, the adjustment territory assumes vital job for complex errands (Cadenas et al., 2009). Table 3.1 elaborates the difference in adaptive and adaptable interfaces.

Table 3.1: Comparison between adaptive and adaptable systems

Parameters	**Dynamic (Adaptive)**	**Static (Adaptable)**
Definition	It has dynamic adaptation by the framework itself to play out the present task	In adaptable framework, the user can change usefulness of the framework
Knowledge	It is contained inside a framework	It is broadened
Strengths	There is no need of uncommon exertion and information by the user	The framework has control of user. Likewise, user knows the task which is expected to effectively finish
Weaknesses	There are very few remarkable models that exist. User experiences issues to build up a comprehensible framework	Framework multifaceted nature and incongruence expanded. User needs to learn adjustment part

Mechanism Required	Model users, assignments, and exchanges; learning base of objectives and plans; ground-breaking coordinating abilities; steady refresh of models	Layered engineering; space models and area introduction; "back-talk"' from the framework; plan method of reasoning
Application Domain	Customization, differential portrayals and data recovery framework is required	Data recovery, end-user modifiability, tailor ability, modifying, and configuration is utilized

Adaptations dependably support to accomplish objectives of users for performing genuine undertakings as opposed to wrong expectations (Findlater & McGrenere, 2004). On the other hand, the adaptable interfaces give components of customization depend on the adjustment of user instruments. In versatility, the user's inclinations and qualities are known before making connection (Glavinic et al., 2008). The data framework can be embraced physically by the user or head or naturally by the framework to satisfy the prerequisites of users. AVANTI framework gave adaptivity and versatility which is included inside the UI. This framework gives extraordinary information and yield gadgets, visual/non-visual interface protests and coordinated connection strategies. The substance, methodology & unmistakable quality of data, route helps, look office and connections to other hypermedia pages are adjusted (Oppermann, 1994) (Fink et al., 1997). Users are completely controlled in adaptable interfaces while adaptive frameworks are totally coordinated with user's psychological model. It gives collaboration frameworks by thinking about the client execution, simplicity of framework, limiting solicitation encourage, evacuating unpredictability and staying away from the issues of psychological over-burden (Francesca Gulla & Ceccacci, 2015).

The graphical UI instrument to control the customization is typically given by non-automatic adaptable frameworks. For the most part, these sorts of interfaces are extremely useful for giving direct control of interfaces. The client fulfilment level over the interface communication can be expanded by utilizing this sort of customization (Manca & Paternò, 2016). It additionally gives the feeling of accomplishment about culmination of undertakings particularly in circumstances where obligation should be transferred to the user of a basic framework (Shneiderman, 1997).

3.4.2 Dynamic and Intelligent Mobile Phone User Interfaces

The rules that establish the framework of adaptive interfaces, consider the circumstances that make the need of adaptation essential. Essential decisions that establish the adjustment procedure of AUI configuration are (Gulla et al. , 2015):

1. Context up the job of the adaptation and by whom the adaptation will be performed.
2. Meaning of general objectives of the client and the adaptation procedure.
3. Meaning of adjustment rules which will deal with the adaptation.
4. Meaning of factors and dimension of association that is required for adaptation.
5. Meaning of an entire inferring system and techniques that will play out the adaptation procedure. Every one of these strategies ought to be in accordance with the user feelings.

The mobile phone industry is entering in the market and users require particular interfaces to satisfy their requirements. In spite of the fact that adaptivity is the need of hour and it has a few issues and huge advantages to make user fulfilment. On one side it is obligatory for the framework to monitor each undertaking of user for building a profile, be that as it may, on the opposite side, it makes a security threat for the user (Hartmann, 2009). AUI gives user adaptivity of formation of interface at configuration level, this enables the user to roll out the required improvements amid execution too. This makes the user free and does not confine the engineers of the framework to choose ideal arrangement that are clear to a user. By utilizing AUIs the framework has ability to adjust to user requirement and helps in future adjustments by keeping a past filled with adjustments performed. Adjustment has just been actualized in a wide range of frameworks extending from work area Apps to Web Apps, advanced smart Apps, wearable gadget programming and a lot more stages (Oppermann, 1994).

The essential start that an adaptive interface takes the user show, this model is based on user’s information, conduct (which is recorded by monitoring activities by the user) and natural conditions. The framework predicts user’s movement and gives significant data, usefulness and recommendations to the user. By utilizing this component, the substance is customized for every user and depends on the client demonstration created by interface at runtime (Hartmann, 2009). Henceforth, the App performs distinctively for every user for examination in telematics gadgets accessible in vehicles. Sixty-four understudies, including

35 male and 29 female understudies, from Ben-Gurion University having normal time of 25.7 taken an interest in the examination. It was seen that the general execution time reduced with expansion in adaptivity, henceforth the study reasoned that adaptivity level specifically impacts the general execution time of the user (Lavie & Meyer, 2010).

3.4.3 Smart AUI Development Criterion

The need of UIs is rising bit by bit throughout the world. These interfaces are running on numerous devices alongside different highlights. Any kind of incapacity in interfaces makes inspiration to build up the rules of interface age and depiction of UI. There are conspicuous methodologies including MARIA, TERESA with concur task trees, Personal Universal Controller (PUC) as utilized in huddle and uniform, User Interface Markup Language (UIML), Canonical Abstract Prototypes (CAP) with late adjustments in CAP3. The accompanying parameters may create criteria for mobile phone AUIs.

3.4.3.1 Run-Time Adaptations in Mobile User Interface

Run time adjustment of UI is utilized in couple of frameworks to give programmed age and ease of use. In any case, various writing has been explained on potential issues of self-adaptive (Mian & Ahmad, 2017) UIs. Exceptionally, it needs in straightforwardness which is depicted to enhance the run time adjustments by enlivened changes. In any case, the point of AUIs to openness enhancements may have a need of various methodologies where the interface plays an increasingly proactive job (Peissner et al., 2012). In more extensive point of view, the objective of insightful UIs can be accomplished by calming of multifaceted nature.

3.4.3.2 Direct and Indirect Adaptation

The immediate and unusual adaptation can support to make a methodology for a more extensive variety of contexts. Yet the examination among adaptive and non-adaptive interfaces is not develop enough, just in a few interfaces (e.g. universal), it is important to adjust UI with direct adjustment. The examination is directed by creating model as a frontend to business word processor. For instance, members utilized MS-Word individual interface for assessment in a month, where 14 out of 19 users spent less or over half time in their own interface utilization (Mcgrenere et al., 2002). In day to day life, the brilliant situations which are being utilized in using the PCs as tools. It supports the users for moving communication (immediate and circuitous) with PCs from a solitary framework to an unpredictable and appropriated condition. The required synchronization of the parts is an issue with circulated UIs (e.g. MASP) which adjusts the smart home UIs based on variability in condition (Blumendorf & Feuerstack, 2006).

3.4.3.3 Adaptive Behaviour Extensibility

Extensibility is an essential element for the advancement of new UI. It helps for different adjustment (e.g. availability, perception and so on) of UI on the grounds that it is not limited to single sort of adjustment, for example, format streamlining. The extensibility of adaptive conduct makes accessible to include new versatile conduct at run time when wanted to arrange an assorted variety of angles. For instance, COMET is proved for supporting polymorphism that has a place with various innovative spaces (e.g. HTML, OpenGL, vocal). The dynamic capacity to tailor the UIs with planner and end user to find structure options by substituting COMET at configuration and also runtime (Demeure et al., 2008).

3.4.3.4 Non-Developer Design Participants

The new plan participants can be non-designers (end users, IT personals) on account of AUIs. For instance, utilizing networks through publicly supporting could demonstrate helpful for Apps that require a ton of exertion for characterizing the adaptive conduct.

3.4.3.5 Integrated Development Environment

The Integrated Development Environment (IDE) is a style of UI which appears to be like Visual Studio or Eclipse. It can give effortlessness to association UI and adaptive conduct articles of largescale programming frameworks (Olsen Jr., 2007).

3.4.3.6 Multi-Level Abstraction

The CAMELEON recommends the freedom of task displaying, deliberation and innovation of cement UI. In addition, the distinctive dimensions may be proper for particular kind of adaptation. By adjusting most abnormal amount, the UI highlights can be reduced and furthermore through various dimensions, the format could be improved (Demeure et al., 2008).

3.4.3.7 Modelling Approach Selection

In this method, selected translated runtime displaying grants, pushed adjustments to be directed (Soley & OMG Staff Strategy Gropu, 2000). The obsolete methodology Model Driven Engineering (MDE), utilized in HCI has restored ordinary (WIMP) UIs. This methodology brings some expectation by giving hypothetical and undertaking level demonstrating into a binding together and orderly way to deal with the issue of UI adaptivity (Coutaz, 2010).

3.4.3.8 Modelling, Instantiation and Coordination

It gives deliberation at all dimensions where instruments of model driven UI advancement, make effectiveness to engineers. Consistency for software engineers, is essential and ought not to be disregarded amid the improvement of tools. However, synchronization is one of the fundamental components that makes user fulfilment (Myers et al., 2000).

3.4.3.9 Multiple Data Source Handling

The designs and systems of adjustment empower the users interface age and dynamic adaptivity amongst run time (Peissner et al., 2012). The numerous information sources grant adjustments to be completed in different circumstances. The models having adaptive conduct can epitomize information based on various examinations, which is the situation of adjusting UIs to social inclinations by MOCCA (Akiki, 2013).

3.4.3.10 Designer Input on UI to Enhance the Outcome

UI of mobile devices is used to enhance the interaction between user and system. No doubt, the developers and designers are facing lot of problems due to complex contextual information. So that, sometimes, the designers may wish to save a few qualities to improve the consistency of result (Myers et al., 2000).

3.4.3.11 Iterations to Produce Possible Solutions

It is accomplished that if a tool diminishes the exertion required to emphasize on the conceivable arrangements dependent on the adaptivity, adaptability, usage expression, low limit, high roof and exchange off examination (Olsen Jr., 2007).

3.4.3.12 User Feedback on AUI

The user input on AUI gives attention to computerized adjustment choices and the capacity to take need over them at whatever point required (Peissner et al., 2012).

The above AUI development criteria provides the theoretical guidelines for designers and developers to make their Apps adaptive as well as responsive for user’s context. The contextual factors of different users may be considered as gender, skill, preferences or special needs etc.

3.5 Evaluation of Interfaces

Convenience properties are grouped in two kinds such as objective and subjective measures. There are five convenience attributes that assist us to assess an interface in HCI. Targeted measures are extremely helpful in assessment of an interface, be that as it may, the accumulation of information equitably is a costly, tedious and testing undertaking. Then again, subjective information can be gathered effectively, quickly and with relatively less exertion. Traits like user supposition and inclinations can likewise be estimated to utilize emotional methodology of assessment (Hussain & Utara, 2012). For example, a significant number of current advanced mobile phone Apps have various ease of use issues which incorporate the route, poor help for performing undertakings, complex interfaces, complex cooperation styles, restricted collaboration methods and confusion because of a ton of choices given to user. The size of issue is expanded for mobile phones on account of their restricted preparing power, screen size, portability and numerous system availability issues.

There exist a lot of calculations that can be utilized to play out different sorts of adjustment and every calculation has its quality in the assessment procedure (Wesson et al., 2014). According to an investigation by Lewis in 2006, hidden menus of pre-2007 forms of Microsoft Office brought about various convenience issues that may be modified version of MS-Office released after 2007 contained predefined adaptive parts which used to demonstrate user fulfilment and enhanced general usability (Hartmann, 2009), in this way turned out to be increasingly valuable for user. Menthol venture, another study, inspected the parameters like age and sex on mobile phone usage which provide as outcome demonstrated that these parameters have an immediate connection to ease of use of an advanced mobile phone. The task breaks down previously mentioned components where dataset is a yield of a longitudinal report. The sample of 30,677 members were chosen, out of which around 16,147 were male and 14,523 were female. The middle age of members was 21 years and they were followed for 28 days. It was seen that the females utilize their devices for a more extended period than boys, with daily mean of 166.78 minutes versus 154.26 minutes. Another finding of the venture was that the more youthful members were increasingly disposed towards excitement and interpersonal interaction Apps through specific UI design of Apps. Youthful users additionally invested more energy than the clients who are more established in age. After examination it was discovered that the more seasoned users utilized the advanced smarts for inspiring general data and liked to utilize the PDA as a traditional telephone (Andone et al., 2016).

A user driven plan was pursued to assess the usability of adaptivity of UI. It was seen that the users favoured the picture mode while composing. Since it gives the user, simplicity of composing by utilizing single hand, it is to be noted that the general adequacy of the element of screen revolution was 25% less powerful. A fascinating finding was that the voice order adaptive component, in spite of the way that the element was 6% increasingly proficient, yet shockingly it was 19% less successful within the user cooperation. One reason that were seen in less adequacy of the voice order included the issue in perceiving the complement of the user. The viability of LED notices adaptive element was recorded as 88%, this as well as the general productivity was additionally 89%, thus, the LED warning component was exceptionally successful and proficient. For children, the adaptive condition include was observed to be 28% more proficient and powerful than utilizing the mobile phone in ordinary mode. It was seen that in view of the indistinguishable adaptive highlights given by numerous sellers, there were a great deal of flexibility issues. Another point that makes the issues is that the sellers do not think about the user's capacity to play out task and the situation of the assignment. From the trial discoveries, it is gathered that the adaptivity positively affects the usability of an advanced smart, when it is connected in a proper context (Iqbal et al., 2017).

Another model that strengthens the discoveries was an adaptive bar which was displayed by Debevc et al. In this toolbar, the product interface was proposed which increases removals of errands to the user; proposals are given based on history, recurrence and context of the user. The consequences of another investigation demonstrate that the adaptive instrument bar was progressively viable and helped users to fabricate their own device bar all the more proficiently, hence, upgrading the user encounter (Debevc et al., 1996).

3.6 Summary

This chapter contains the contents of detailed background and literature review in the perspective of usability and usage context of mobile phone interfaces. The interaction with interface plays a vital role in usability of mobile devices. Therefore, interface should be developed according to the usage context of users. Moreover, context has been defined in different scenarios according to specific domain and environment. The usability of dynamic and intelligent mobile interfaces is influenced by many usage context elements. The studies mentioned above also emphasize to introduce adaptive behaviours in mobile device interface to enhance the usability through synchronization with the usage context. It is defined that the transparent interface is the best interface that provides rich interaction between user and system. It is the need of hour to design and develop models for adaptive interfaces. The literature review, here, provides us the ground for planning further research to explore AUI designing methodologies.

Chapter 4. RESEARCH METHODOLOGY

In this chapter the usability preferences are studied in terms of user demography, user special needs, usage environment, task, and device features. Though, it is difficult to measure these preferences with unified scaling but can be determined by extracting such information through studying various context and suitable methods. The user studies are performed in analysing user context and respective interaction styles. Further, user context modelling and knowledge engineering is performed to design adaptive interface by using UCD process model. The research methodology, in this chapter, layout the plan of such adaptive feature's analysis, user context, ontological interface modelling and enhancement of UCD process model.

4.1 Adaptive Features Analysis (Phase1)

The Phase1 in methodology is to conduct the study of currently available adaptive features of mobile devices. These features (e.g. smart stay, voice recognition, screen rotation and driving mode etc) are provided through by major vendors such as android and iOS who capture the maximum market share worldwide. Currently, the display, sonic and mode based adaptivity options are presented by smart devices. Some modes are providing assistance to users with special needs. Due to rapid changes in information and user context, the HCI is also concerned with universal design. It is suggested that the combination of universal design and adaptive interfaces can be effective for special need users and normal users (Steinfeld et al., 2019). Further, the analysis is the part of UCD approach to design and implement the contextual UIs. The analysis is conducted to evaluate the user's effectiveness, efficiency and satisfaction.

4.1.1 Adaptive Features in Mobile Phones

It is to discover the functionality of adaptive features and its usage impact of mobile phones. The aim is to analyse the usability evaluation of existing adaptive features. Various users performed multiple tasks by differentiating the adaptive and non-adaptive modes. To measure the usability of features, ISO 9241-11 is used for effectiveness and efficiency while After Scenario Questionnaire (ASQ) is applied to measure the user's satisfaction. The study suggests that adaptive features must be applied after careful analysis of user tasks and context.

4.1.2 Adaptive Features for User with Special Needs

It is to explore the functionality and usability impact of special needs adaptive features in mobile phone. The purpose of evaluation for special need modes is to measure the significance of usability in user's context. The special interfaces are required to fulfil the tasks of disable, blind, colour-blind users because they have different situations and needs. ISO 9241-11 and ASQ is used to measure the effectiveness, efficiency and satisfaction of colour-blind users. It is used to emphasize that ICT present an accessibility barrier for those who have special needs. It is concluded in the study that the carefully designed interfaces, considering user's context and limitations provide more satisfaction level.

4.2 User Context Modelling & Knowledge Engineering (Phase2)

In modern world, dynamic, distributed and highly customizable devices (e.g. PDAs, smart phones etc) are inspiring new kind of Apps. These Apps create a challenge to the developers due to the context's features such as environment, time, user preferences or current usage of devices. Therefore, it is very difficult to understand the context because of its complexity, rather it is difficult to define it formally. Context is more conceptual and qualitative entity including individuals, environment, devices and intended actions. In the context aware system development for mobile AUIs, more detailed investigations are required including scales and value ranges etc. Elicitation of user context is a precondition for analysis and modelling of the context. Modelling of user context provides the classification of user-based groups, combinations and semantic relations.

Different situations produce several context elements which are directly influencing on the usability of task to be performed by user. User demography, ergonomics, device, task, location, time and environment represent different type of context for each element. Unfortunately, whole context has long list of combinations that generates many issues which can be addressed as temperature, humidity, user current mental state etc. So that, to reduce the complexity, it is required to define a scope and boundaries for mobile user context modelling. The user preferences can be segregated into two approaches such as qualitative and quantitative (Dostal & Eichler, 2011). Qualitative data is descriptive and useful for studies at individual level to find in-depth responses and context of users. The qualitative approach is used to extract the demographic information of users such that location, gender and profession etc. The quantitative approach is based on the collecting data which can be measured directly such that age, literacy rate and special needs (Dix et al., 2004).

In this research, a scope has been defined in which prominent mobile features and context elements are taken as sample. Ontologies are used to define context formally for adaptive interfaces of mobile devices. The exact determination is to provide help for solving context information problems when changing from one resource to another. Basically, ontologies make available the basis for semantic modelling of subject domain, information integration, and communication in the domain.

4.2.1 User Context Ontology (UCO) Engineering

Overall UCO enables to capture all information according to the context of user. It provides dynamic UI features according to the situation. UCO is responsible to discover the dependencies and semantic relations amongst the classes and attributes. The target here is defined by the competency question that we can define, store and retrieve user context with its semantic relations and constraints. Currently, to address the heterogeneity issues in mobile devices are handled through adaptive interfaces. This adaptivity has capability to learn, sense and modify context even it is known or unknown. Ontological formal knowledgebase has ability to keep consistent, standardized, shared and scalable. By keeping in view, some test scenarios have been built to describe user context on the basis of carefully defined competency questions. The contextual ontology model using OWL while taxonomy is developed using protégé for different values of context for adaptive mobile interfaces.

4.2.2 Adaptive Interface Ontology (AIO) Engineering

The adaptation is based on user context which is influenced by goals and associated tasks. Interaction mode represents information of parallel assistance for visualization. It also deals with user response modes such as look and feel. AIO enables all interfaces to change its behaviour of user accordingly. It deals with the interface features that has to be presented such as adjustable display voice, interaction styles, sound levels, brightness and colour levels etc.

4.3 Design of Adaptive Interface Using UCD (Phase3)

UCD is used for interface design and development that provide suitability according to user’s context. The major aim of this model is to capture and address the whole User

Experience (UX). Vendors and organizations are regularly used to analyse and monitor the behaviour of users to understand their experiences. It is a complete process model that demands involvement of users. It provides enhancement to read the context from UCO and design AUI through AIO.

4.3.1 User Centered Design Process Model

UCD process model is used to analyse and validate the mobile device interface according to user context. This framework is not restricted to interfaces or technologies while it is widely used to solve multi-stage problems of software designing in user's point of view. It involves the users throughout the design process to provide highly usable and accessible product. In this process model, extensive attention is given to user's context for the understanding of their preferences and limitations. UCD is used to develop simple graphical or architectural models, mock-ups or prototypes for interaction design or visualization etc).

4.3.2 UCO to AIO Mapping

The mapping of UCO and AIO is required to analyse, read, adapt and validate the context of user. For this purpose, different semantic policies and rules from knowledgebase is defined to create mapping merger. Further, respective UI adaptation is going to happen on the basis of defined case studies according to user context. Finally, Semantic query (SPARQL) is used for knowledge attainment and Pellet and HermiT (Reasoners) are utilized to identify the inconsistency among different classes.

4.3.3 Enhanced UCD Process Model with UCO and AIO

All features of UCD process model are used to provide benefits throughout in the UX. The development of prototypes in UCD are reflected as valuable to translate user preferences into contextual experience. The enhanced UCD process model with UCO and AIO is responsible to provide usability, satisfaction and optimization of adaptive mobile UIs. Specially UCO and AIO is being used to develop optimized adaptive mobile interfaces according to defined scenarios and organize the user's concepts and perceptions.

Table 4.1: UCD standard phases and reformed phases with ontological definition

UCD	Standard	Ontology and Adaptivity Features
Requirement	Clear understanding of requirements in the context of user	Ontology engineering for UCO and AIO

Analysis	Analyze the user and organizational requirement	Adaptivity matrix for AUI Mapping functions UCO to AIO
Design	Produce designs and prototypes	Design AUI prototypes
Evaluation	Testing of working designs and prototypes against requirements	Evaluation of designed prototypes, adjust AUI features according to user needs

There are four important phases of UCD approach (requirement, analysis, design and evaluation). These phases provide the guidelines throughout the development process. The UCD standard phases and respective reformed phases with ontological definitions and adaptivity features are shown in Table 4.1.

4.4 Design and Experimentation of Enhanced UCD (Phase4)

Further the functions of UCD process model are clearly mapped with the functions of proposed ontology-based process.

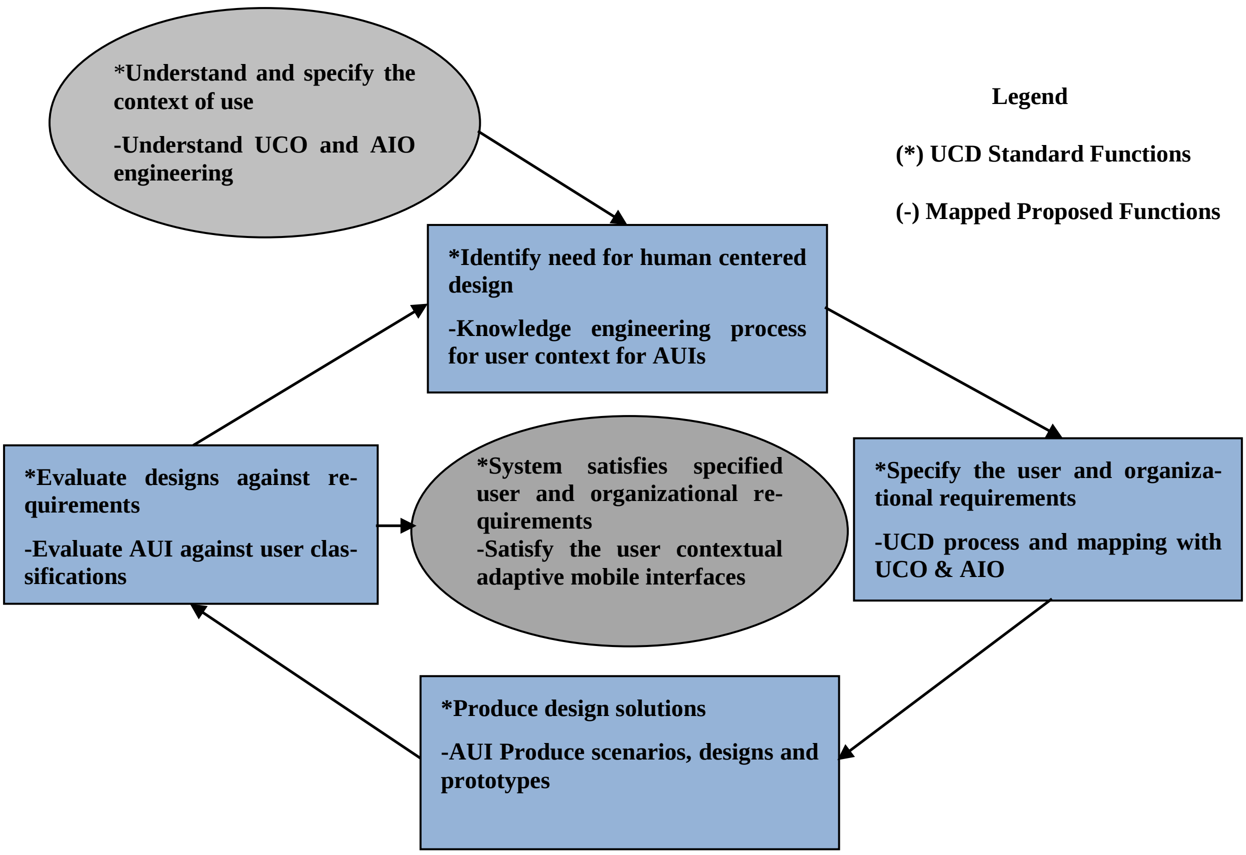

Figure 4.1: Adaptive user centered design (UCD) process model

For clear understanding of the philosophy and the depth of research problem Figure 4.1 shows the mapping of UCD functions with UCO to AIO according to the user's preferences for mobile adaptive interfaces. It also represents the proposed research roadmap where the two ontologies (UCO and AIO) are engineered for interfaces of mobile devices in the perspective of user context. Further, it shows the mapping function contents for UCD with UCO to AIO. This mapping opens the door for experimentation and afterward evaluation of results.

4.5 Adaptation Strategy

The following steps such as adaptation aspects (related to user, device, environment, task), elements, rules and model are given below:

4.5.1 Adaptation Aspects

The increasing of adaptation in mobile technologies has become important due to interaction in context of use and variations. There can be various aspects of the contexts of use and can be grouped accordingly. In our research, four adaptation aspects such as user, device, environment and task are taken.

4.5.1.1 User Related Aspects

User related aspects are name, date of birth, address, family, zip code, country code, email address etc (S. K. Shahzad, 2011).

4.5.1.2 Device Related Aspects

Device related aspects are font size, font colour, font format, typing, voice, display information, brightness level, volume, vibration etc (J. Hussain et al., 2018).

4.5.1.3 Environment Related Aspects

Environment related aspects are location, humidity, noise etc (Poveda-Villalon et al., 2010) (Alirezaie et al., 2017) (Aliannejadi et al., 2019).

4.5.1.4 Task Related Aspects

Task related aspects shows the system capability to understand the user's current activity (Meditskos et al., 2016)**.**

To characterizing a UI, any aspect can be modified according to changes of the context of use. Therefore, UI can be adapted in perceivable aspects, dynamic behavior and contents.

4.5.2 Adaptation Elements

These are purely UI features including information representation mode (visual or speech), user interaction mode and response mode (look and feel)**.** According to the impact on UI there is a possibility to adopt many adaptation strategies. There is a need to consider the general objectives of user and adaptation mechanisms. Further, rules, dimensions and associations are required to play out the adaptation procedure (Gulla et al. , 2015). Elements of proposed adaptation strategy include context change detection, triggering progressive adaptation (contextual adaptivity), scaling of UI (brightness, vibration, volume, flashlight, background image, font size etc), rearrangement (changing the layout). All these strategies are used according to the user contextual model.

4.5.3 Adaptation Rules

The rules that establish the framework of adaptive interfaces, consider the circumstances (e.g. change of context) that make the need of adaptation essential. Adaptation rules aim to change UI properties according to user's context. The adaptation rules are expressed as context model (task, event, action and environment etc) and the possible impact at UI properties. The event occurrence triggers the evaluation of the rule for current context of use. The semantic relations are used to execute the associated actions; it can be related with previously happened actions or some state conditions. The adaptation rules can change UI for mobile devices in user's context. Some adaptation rules are given below:

1. Event (user accesses application); condition (is user elderly); action (increase font sizes 10%).
2. Event (user is outdoors and it is lunch time); condition (are there restaurants near-by); action (show list of nearby restaurants).
3. Event (application is accessed); condition (is the device a mobile phone); action (show master and detail in different presentations).
4. Event (the UI is activated); condition (is the user colour-blind); action (change the foreground colour to black and the background colour to white in order to provide a high-contrast UI).
5. Event (the UI contains an element with a timeout); condition (has the user a cognitive disability); action (remove the timeout or increase the time limit considerably if necessary).

6. Event (the UI is activated); condition (has the user poor vision); action (activate a screen magnifier) (Paterno 2013).

4.5.4 Model Based AUI Design

Models are abstraction of real entities and often used generally in real life. These models provide benefits to developers to concentrate on semantic aspects by using languages. In this way, it provides link to semantic information and implementation elements.

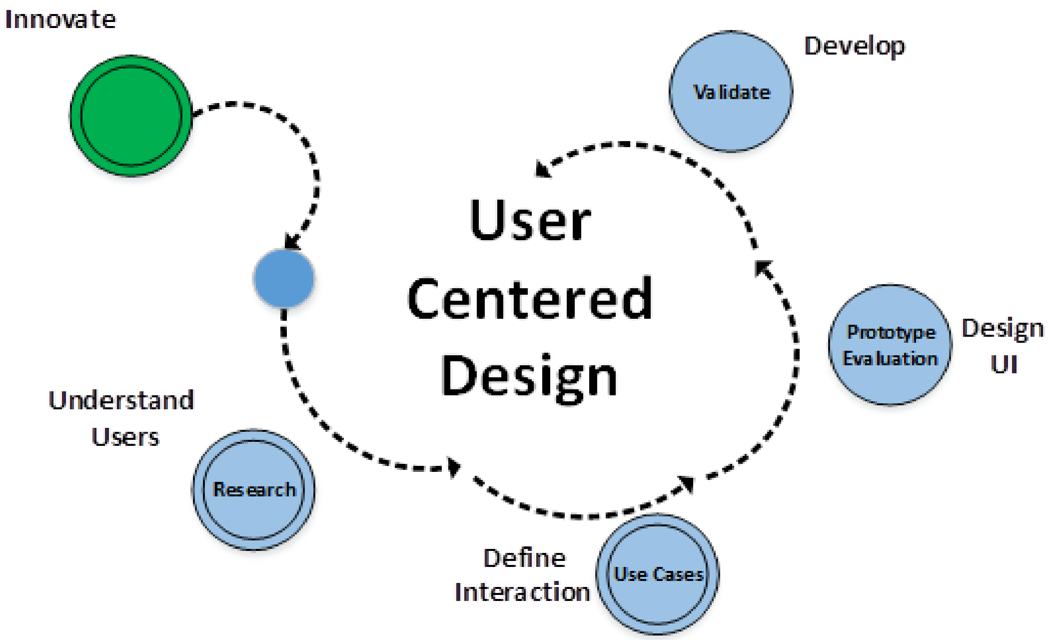

Figure 4.2: User centered design (UCD) model with adaptation strategy[5]

The Figure 4.2 shows the procedure of UCD model stating its adaptation strategy. Innovation is an external phase of UCD process that starts the implementation of adaptivity strategy. The first App phase is user understanding and context modelling and recognition. Next step is to identify the respective interaction model followed by interface development and validation.

4.6 Summary

The research plan has four phases including study of user context, mapping methods, experimentation and conclusion. Figure 4.3 shows the phase wise research plan[5]:

[5]https://www.google.com/search?q=UCD+model+as+adaptation+strategy&tbm=isch&source=iu&ictx=1&fir=TPUdH6CkVhimVM%253A%252C7fP9B4LEXkHNcM%252C_&vet=1&usg=AI4_Qi1t_5rWTMzyW1ZItQvA

The phase1 includes the study of adaptive UIs for normal and colour-blind users. Ontology engineering is done in phase2 for user context and interfaces by using UCD approach to map user context for mobile performance optimization. The phase3 involves experimentation which focuses on iterative refinement to the usability and optimization of mobile interface according to the context of user. The phase4 includes evaluation and conclusion of adaptive models.

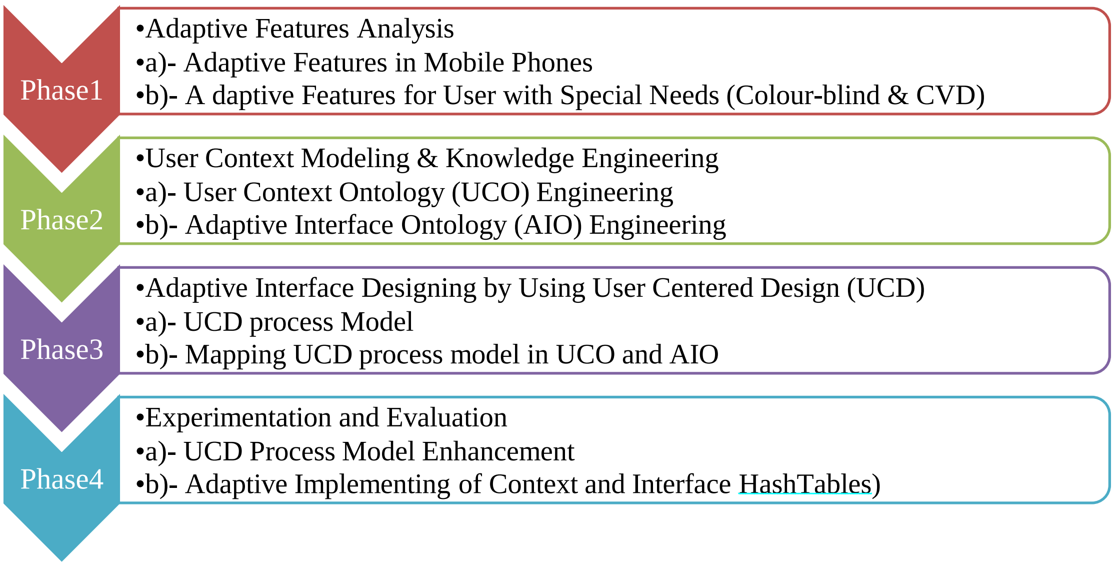

Figure 4.3: Research plan

The adaptive interface design models will be evaluated by experimental interfaces. The next chapters of thesis will provide execution and validation details of the stated research plan.

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Chapter 5. USABILITY OF ADAPTIVE FEATURES IN MOBILE PHONES

At the initial phase of research methodology, the adaptive features analysis is performed over the current mobile interfaces. These adaptive features (screen rotation, LED notifications, voice commands, kid mode) are provided by the mobile usage platform for OS of the device. Two famous operating systems such as Android and iOS are studied in this regard. Many mobile Apps still have UI issues which may cause to create difficulties for users. The limitation in the mobile devices are not only in the screen display area but also in the interactivity with mobile Apps. The AUIs give adaptivity by focusing on "which data is to be presented", "in which way this data is displayed" and "in what way there is to get connected with current information" UI to look into the complexities of using devices.

5.1 Understanding and Adaptation of Mobile Phone Features

HCI is the practice that focus on the interactivity between user, digital devices specifically on user responses and the time of interactivity by user actions (Wesson et al., 2014). Every design built for interactivity has its focused on the contextual needs by looking on knowledgeability, protection, usage, efficiency and quality of being effective in user point of view. Usability main focus relies on context up the support for user to handle the problems, generally face during interaction with devices. All the operational rules or standards are made to learn about progress in between different versions to locate the competition, to measure the strength, to assess personal quality and to enhance the performance (Hussain & Utara, 2012). There are three kind of UI problems (i) ability to use functionality in the network to handle device screen display size and power consumption time of battery (ii) looking into the hurdles of using the mobile phones related to location, psychology, surrounding, temperature and light quality (iii) user ease of adapting or using device according to his own satisfaction, ease of use and style of working (Looije et al., 2007).

The research related to the adaptivity options exist in smart phones like screen rotation, voice commands, LED notifications and kid mode. Problems related to auto display swapping of screen to handle portrait as well as landscape viewing of user, where wrongly shifting of screen orientation on slight movement are researched. These factors may effect upon users pace of working, accuracy and ease of use (Cheng et al., 2012). Speech recognition-based instructions gets run without any issue to locate an object on screen. One of the few top mobile Apps are Apple's virtual assistance program Siri and on the other hand from Google they have also built a voice instruction program that performs working on command (Zhong et al., 2014) (Carlini et al., 2016). For constant rise in the smart device usage in the public due to the reason which requires a UI regarding screen and device based alert system. Such alerts are vital for engaging user without getting them distracting their day to day working. Frequent disturbances may cause hyperactivity in modern digital community (Kushlev et al., 2016). Contrary to this there are multiple users who wants to have alert system and actually praise its availability (Pielot & Rello, 2015). Further, the kid mode creates a unique proposition which control children access to certain App in the mobile devices. This feature is extremely good for parental management without using password authentication (Anthony et al., 2012).

AUIs are known as procedure to analyse user behaviour in interacting with different kind of devices for context of acts to gain user necessary requirements. In general, these AUIs require acceptance to understand user behaviours and adaptation of interfaces accordingly (Lavie & Meyer, 2010). The purpose of AUIs is to enhance the usage of UI to interact better. (Peissner & Edlin-White, 2013). The AUI promises to change contexts automatically according to the contextual behaviour of user (Karray et al., 2008) (Jung & Hahn, 2011). If we look inside adaptable structure, in which each of the user requires to set their needs and preferences themselves in the device using only the interface available. If we tries to define context aware interface it would be the changes in any UI according to user likings either adaptive or adaptable (Hanumansetty, 2004) (Holzinger et al., 2012) (Zheng et al., 2016). Every App that has the ability to adjust itself according to the user requirements can be termed as adaptive. The adaptation can be information, visualization and UI of device with adaptivity.

Following are the four main adaptive factors (Cena et al., 2006):

1. All user choices are always adapted by the device interface.
2. Managing user last activity related to his adaptive needs.
3. Adjusting mobile functionality according to adaptive requirements.
4. If we look from contextual point it states to be context exactly what user needs.

5.2 Associated Work of Adaptive Features

It was in 1980s when the concept of user-based system formulated to provide guidance in making Apps with ease of use for the user. Such testing was made in a way to analyse the situations formally and informally. Smart Apps have been very prominent in modern world however the benchmark in current UI raise doubts (Ahmad, Boota, & Masoom, 2014).

The dissertation has been made to drawn conclusive evidence regarding the usability, its related problems and also gives insights regarding user's usage of smart devices. UCD model is used as centre of attention for easy usage of devices with cheaper cost to fully grasp the requirements of users. So AUI can indeed help in providing great contentment to user for using the interface. There are many Apps available with complex interface that not use contextual interfaces. AUIs help to increase the usage of such Apps by creating a more contextual interface for user. Research was made while building a methodology for deaf and illiterate people using UCD philosophy to measure the impact of online support usage. A raised in percentage from 52% to 94% have been seen in accomplished tasks. This suggested system allows high level usage by converting content in the native language for every user. In order to have an effective usage of UI by the user it is very important to make it according to his mind and usage ease (Nadeem Ahmad, 2014). According to the experimentation, 513 users which have used different kind of smart devices, 91% have claimed to face problems in auto orientation in the display view whereas 42% have frequently reported such issues during a week (Looije et al., 2007). Moreover, in reference to a research regarding the usage of verbal instructions with the help of black box & white box models.

Moreover, voice command generates a feedback protocol and Machine Learning (ML) methodology which can pin point attacks by 99.8% accurate results (Cheng et al., 2012). Regarding mobile alerts a research has been made for “Do Not Disturb Challenge” for 12 candidates. The outcome of this test that 11 out of 12 users found to check always their alerts on the devices. Only 4 out of 12 users accepted that alerts have a vital part of their lives (Kushlev et al., 2016). In research \$N methodology has been used to gain accurate results up to 95% to 99% to capture and movement recognition in adults as well as in children. As a result, the level of usage in adults has found 79% while in children it has predicted 63%. While going through research test tasks, the children has found to lose 50% of targets more in comparison to the adults and also face difficulty in doing small test jobs (Palsson, 2014). A study was suggested about the requirement to have adaptivity in all UIs for App with contextual understanding to enhance the usage for designed related user (Karray et al., 2008). Another usability experiment was conducted by Menthol project on smart phone usage. It was analysed that how age and gender can be affected through smart phone utilization. Therefore, the results initiated from 30,677 participants, that average usage time of female smart phone users was longer than male users (Andone et al., 2016).

All of these related works make clear about adaptive nature of various models for mobile Apps focusing on the user contextual behaviour. It is an important fact that adaptive behaviour can become a damaging factor when not used appropriately in the contextual sense. For this reason, it is very substantial to understand the usage of adaptivity with various user based contextual behaviour. Current study is related to analyse the usage of mobile phone adaptive features in the functionalities which are used most during multiple types of users and work processes.

5.3 Classification of Mobile Phone Applications

Smart devices have a lot of Apps with various adaptivity functions (Syer et al., 2013). These adaptive features give prominent functionality to reduce problems in usability of functions like ease of use, data exhibition, display problem and work process to complete the specific interaction style. Research made on top 100 Apps have provided enough data to reached to our target. These 100 Apps are divided in seven types (i) communicating (ii) social networking (iii) entertainment (iv) news and information (v) utilities (vi) service provider (vii) browser. Table 5.1 shows the selected categories and the names of available Apps.

Table 5.1: Mobile phone application categories

Communication	**Social Networking**	**Entertainment**	**News & Information**	**Utilities**	**Service Provider**	**Browser**
SMS	Twitter	YouTube	BBC	Google Drive	Uber	Google Chrome
MMS	Facebook	Daily motion	CCN	Microsoft One Drive	OLX	Safari
E-mail	Google +	SoundCloud	RT	Calendar & Scheduler	E-bay	Opera Mini
WhatsApp	LinkedIn	Mobile Games	DW	Calculator	Amazon	Mozilla Firefox
Skype	Xing	Netflix	Al Jazeera	Google Maps	PayPal	UC Browser
Facebook Messenger	Instagram	Vimeo	National Geographic	Documents & Spread Sheets	Weather For. Forecasting	

Viber	Pinterest	Dub-smash	WordPress	CPU & Memory Booster	XE Currency
Line	Tumblr		Blogger	Storage Cleaner	
	Tinder		Kindle	Dropbox	
				Trello	

However due to unavailability, access issue, both PC and mobile 45 Apps have been excluded. Moreover, 55 Apps have been found which were easily open to use and have easy availability with back to back usage from users. Obviously, many App categories are available, but we select most general used Apps in routine tasks. It does not matter that what type of App; the developer's duty is to make life easier. Either for everyone, group of people, business or fun, Apps should provide the relief to users. No doubt, each type of Apps has its strong and weak points, thus always try to cater the needs of user.

5.4 Classification of Adaptive Features

More to this, there are around 22 features specifically picked to compare with the smart phone operating system to understand the similarities. Multiple patterns have been picked with the criteria of availability, partial availability and not applicability. The population set for the sampling is presented in Appendix-A.

Table 5.2: Adaptivity features for mobile phone Apps

Display	**Notifications**	**Vocal Interface**	**Mode**
Screen Rotation	LED Notification	Voice Commands	Kid Mode
Easy Screen	Smart Alert	Ok Goggle	Night Mode
Swift Keyboard	Smart Pause	Face Recognition	Touch Disable Mode
Raise to Awake	Smart Stay	QR Code Reader	Drive Mode
S-Health	Proximity Sensor		Battery Saving Mode
	Eye Contact		Colour Blind Mode
	Air Gesture		

The complete set provides the list of adaptivity features further classified according to their behaviours. Table 5.2 shows that there are 4 features that include screen rotation, LED notifications, voice commands and kid mode are picked because of the vast pattern capacity.

5.4.1 Sample to Conduct Experimentation

Usability studies can also be successfully conducted with a small set of participants. These studies use guidelines, heuristics, and a variety of techniques to identify potential usability problems with proposed interface design. Numbers can vary for controlled experiments, although studies with as few as 12 users are not uncommon in HCI, results with 20 or more users are more convincing (Lazar et al., 2010).

This research contains number of users which have been using mobile phone for one year around. The devices, Samsung S6 edge and iPhone 6 have been used in experimentations. The users were aware to use these devices and were available easily in the market. For this a list of questions pre-selected have been used to pick the best candidates for the study. In the beginning, around 185 users were selected via questions list, from those 39 participants were removed from test due to less than one-year history of usage in smart devices. Few others have been removed of various reasons like 9 participants did not participate by their will, 2 have sight issue and 7 have no idea about adaptivity in smart devices. The other 128 users were finalized for the test and were grouped in 4 different sections. Every section was allotted a particular work based on 32 users with exact equal gender percentage. More to this, every work assigned was done in two different sets using adaptive and non-adaptive functionality. Every user goes through an orientation using laboratory to explain individually their work to be carried out (other than children). The practice was about the importance of the given work. Users age groups for initial 3 sets ranged from 21 to 40 and 4 to 7 years for the children mode. Assigned task details have been mentioned below:

Group A: Work given (Screen Rotation): This work instruction was based on inputting 300 words. Purpose behind was to check how the instructions were carried while the auto orientation of screen was enabled and how it impacts the effective, efficient and satisfying nature of end participants. Total time allowed for this activity was 30 minutes keeping in mind the standard time and extreme slow typing performing users. Activity was keenly analysed by keeping a list of user's speed and time to add their profile record. On average task was completed in 28.8 minutes.

Group B: Activity (Voice Commands): Various seven voice instructions were required to say (a) call someone from phone book (b) compose a message "Hi" and send to any one from smart phone (c) run a song from music gallery (d) watch photo from library (e) fix alarm to go off at 11 am the next day (f) enable/disable flight mode and (g) display calendar to book this for users to test. Participants were required to execute these voice instructions by activating and deactivating the certain options in their smart phones. Designated time was just six minutes to monitor in regards to the activity that covers finding and selecting data from mobile phone. Activity completion time as recorded for every instruction. On average a voice command was completed in 4.88 minutes only.

Group C: Activity (LED Notifications): Chosen users were asked to turn off alerts in their mobile devices for 4 hours back to back with their consent. Participants were questioned during this time and their emotional responses were recorded like feeling the need of seeing vital, required and urgent alerts. Information gathered during this test gave great deal of understanding related to screen or display alerts.

Group D: Activity (Kid Mode): To perform this activity a school was used in which kids were asked to do specific things like (a) run a video in mobile (b) play any game of their choice (c) create a sketch of a car in kid mode with pre-enabled feature.

Table 5.3: Test groups, selected features and tasks

Group A	Group B	Group C	Group D
Screen rotation feature is selected	Voice command feature is selected	LED notification feature is selected	Kid mode is selected
The activity of user is required to type a paragraph of 300 words	The activity of user is to perform 7 different commands	The activity of user is different type of notifications	The activity of user is to perform 3 different activities
Participants are 32	Participants are 32	Participants are 32	Participants are 32
Time is 30 minutes	Time is 6 minutes	Time is 240 minutes	Time is 40 minutes
ASQ post task evaluation is used	ASQ post task evaluation is used	ASQ post task evaluation is used	In kid mode the post task evaluation is not possible

In a result they passionately get the responses from children, all this were made to done for 40 minutes’ time. Table 5.3 shows the detail of groups along with selected features and defined tasks.

5.4.2 Usability Evaluation of Adaptive Features

There are three parameters to measure the performance of usability such that effectiveness, efficiency and satisfaction. ISO 9241-11 standard is used to measure the effectiveness, efficiency and satisfaction (Bevan, 1995). The components of the framework are decomposed into sub-components with computable and verifiable attributes. The usability is dependent on the given framework on the specific situations in which a product is used. ISO 9241-11 also covers the user, device, task and environment which can be impact on the usability of product. Further, Android and iOS devices are used to make this experiment significant. The Figure 5.1 (Bevan & Macleod, 1994) presents the ISO 9241-11, usability framework.

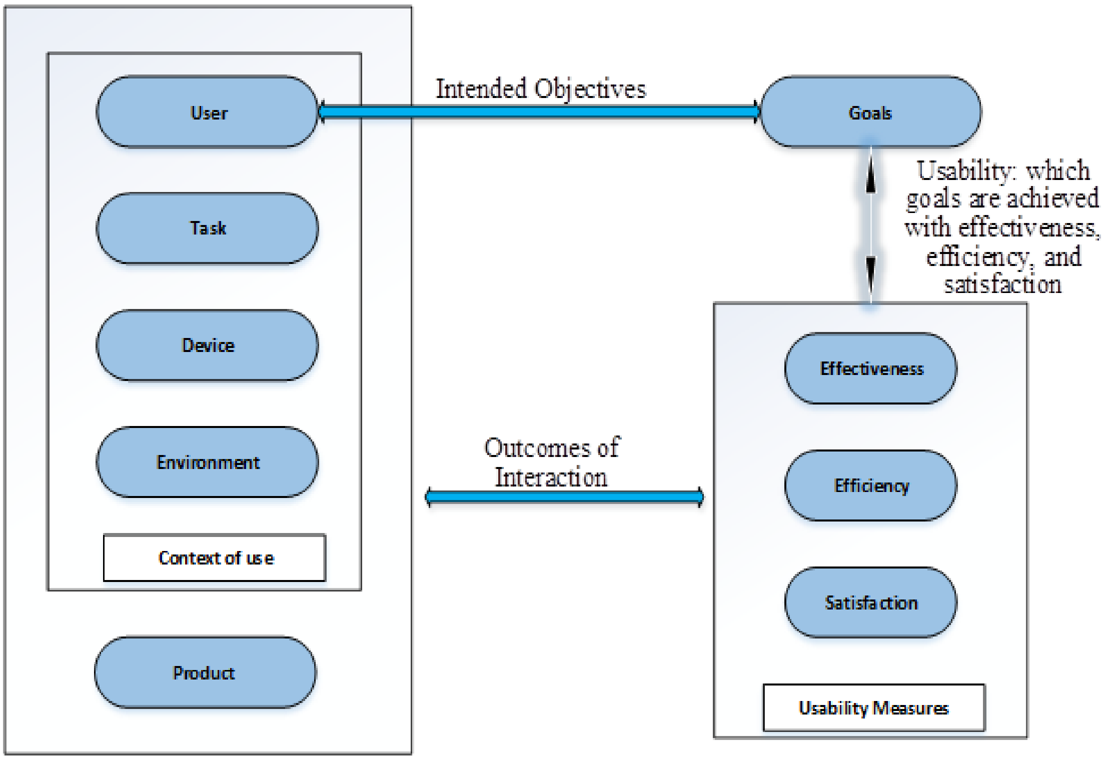


Figure 5.1: ISO 9241-11 usability framework

Effectiveness is the amount of goals to be achieved and it is measured as:

$$\text{Effectiveness} = \frac{\text{Total number of tasks completed successfully}}{\text{Total number of tasks undertaken}} * 100 \quad (1)$$

The resources such as time, money or mental efforts that have to be extended to achieve the intended goals; called efficiency and can be measured as:

$$\text{Time based Efficiency} = \frac{\sum_{j=1}^{R}\sum_{i=1}^{N}\frac{n_{ij}}{t_{ij}}}{NR} \quad (2)$$

Where
N = The total number of tasks (goals)
R = The number of users
n_{ij} = The result of task i by user j; if the user successfully completes the task, then $N_{ij} = 1$, if not, then $N_{ij} = 0$
t_{ij} = The time spent by user j to complete task i. If the task is not successfully completed, then time is measured till the moment the user quits the task

After Scenario Questionnaire (ASQ) is chosen for the post task evaluation to measure the user's satisfaction. It is defined by Lewis for IBM computer usability satisfaction questionnaires: psychometric evaluation and instructions for use. Errors may be unintended actions, slips, mistakes or omissions that a user makes while attempting a task (Lewis, 1991).

User contentment in using a product can be marked as satisfactory by looking on the frequency of usage of App. It is based on the situations of App utilized and the usage contextual pattern. This contextual behaviour requires user's work need, machine capability, app and the content. Furthermore, it can have evaluated by using various methods for example SEQ, UME and SMEQ (Cena et al., 2006) however in actual the reliability and user contentment is often calculated using ASQ methodology. The ASQ usability satisfaction questionnaire (Lewis, 1995) is presented in Appendix-B. This technique in general is based on a list of questions that requires minimum time to grasp and have great hands on potential by the user for usage analysis testing. Based on just three enquiries having a scale from 1–7, (fully disagree =1, disagree=2, mild disagree=3, disagreed =4, bit agree =5, agree =6, fully agree =7). It consists of significant points that shows level user happiness with the usage overall. Initial question shows the level of activity completeness, the next question gives idea regarding time took to finalized an activity, and the last question gave understanding of user ability regarding assistance knowledge (Roy et al., 2014).

5.5 Results for Evaluated Adaptive Features

The research depicts that AUIs are helpful in solving App usage problems for smart devices. The effectiveness, efficiency and satisfaction are shown below for features such as screen rotation, voice commands, LED notifications and kid mode. Following are the details for the above three functionalities.

5.5.1 Effectiveness

Following Figure 5.2 indicates the level of adaptivity by showing its value by its effectivity keeping in view the situation and environmental factors. If look on the effective display orientation functionality, it is indicated that as a whole its adaptivity is low. There is a significant amount of overall gap related to adaptivity and effective usage from 56% to 81%. Also, this difference is highlighted when we consider its effective score by looking on the gender and found females have comparatively low effect than males. It is also found that female users had clear gap of 25% (adaptive=50% and non-adaptive=75%) in both kinds of modes. Users were found in bit discomfort because of the auto orientation of display view while using keyboard in smart devices. Similarly, for verbal instruction test female users also found overall gap of 18.75% in both kinds of situations. As a whole the non-adaptivity scores contained more effective value at 88% in comparison to adaptive feature 69%. The voice commands were tested without any interruption still the level of effective processing decreased.

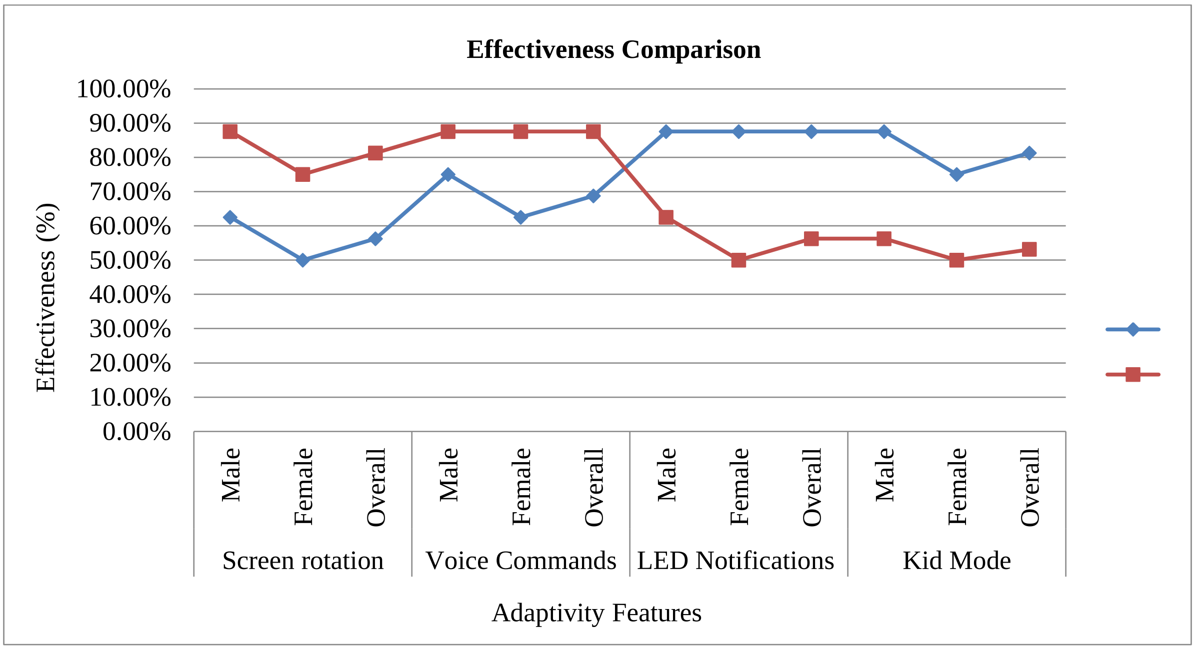


Figure 5.2: Effectiveness between various adaptivity functionalities

On screen alerts functionality testing shows a score of 88% in effectivity in both male and female groups and has raised adaptive functionality. The effectiveness in general is marked at 31% in these 2 situations. Additionally, the users were fully informed by the significance of alerts in their day to day operations. Also, it is analysed that the adaptive score of effective usage is higher in male and female in kid mode and gives a clear range or gap between 53% non-adaptive and 81% adaptive. Kids remained enthusiastic while performing the test in kid mode which also is a great thing related to parent checking and control.

5.5.2 Efficiency

Following score in Figure 5.3 indicates the screen rotation feature did not create much impact on user’s efficiency. As a whole adaptivity was low in terms of efficiency for all genders using display orientation. Further, efficiency was recorded quite lower in value for adaptive display, it was 23% and for non-adaptive display raised to 41%. This has been evidently found during study that participants have been less efficient in using keyboard on expanded in landscape or horizontal display. The average value of efficiency found in voice commands goes up as 89% where adaptivity is performing low. Men users have not huge variation between two modes of working. Similarly, efficient behaviour varies with rest of the functionality.

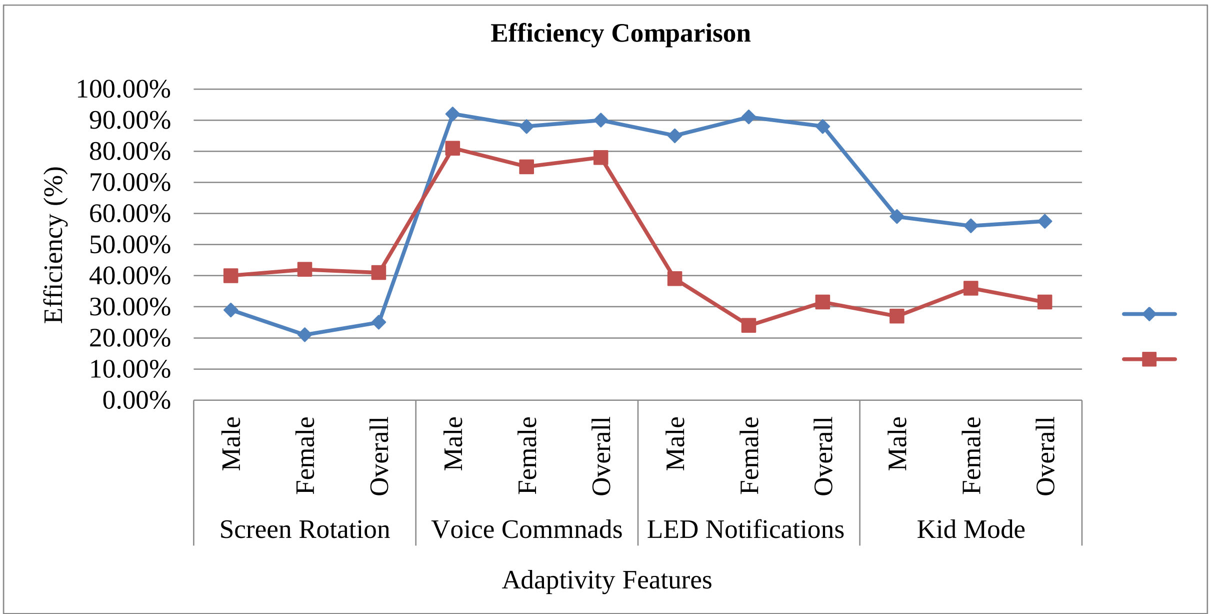


Figure 5.3: Efficiency comparison for adaptive and non-adaptive features

Whereas, a big variation has been found for on screen alerts in these two working modes (for adaptive score went to 89% and for non-adaptive it was 26%). Female users have shown great efficient behaviour towards adaptivity in device during experimentation. While working in kid mode, efficient behaviour or responses went to higher score with adaptive feature. Children have also been very much enthusiast during the research because of the adaptivity. Figure shows that voice commands, LED notifications and kid mode scoring high in efficient response for adaptive behaviour.

5.5.3 Satisfaction

Figure 5.4 depicts a comparative study based on users ease of use and his level of happiness with adaptive and non-adaptive modes. For this purpose, data has been picked through ASQ related to screen rotation, voice commands and LED notifications to check how much user is satisfied. Kid mode have been excluded in this study through ASQ because of narrow App in kids. If we talk about as whole level of satisfaction for screen rotation functionality in non-adaptive mode goes near 5.8 that exceeds in comparison to adaptive mode which is near 4.1. Female users do respond well with display orientation in regard to male users. A higher level of comfort in typing was observed when screen rotation feature was disabled.

Similarly, voice commands functionality gave great acceptance in the adaptive mode. Male group have shown 5.6 comfort score while the female group have kind a similar score of 6. Also, LED notifications have been greatly appreciated in adaptive mode. Its comfort score goes between 6.3 to 6.6 among men and women groups. Every user group have claimed to find it efficient to use voice commands and on-screen alerts in the adaptive mode. For verbal instructions due to automatic usage and operation every group find it easy to use to perform different tasks. Furthermore, LED notifications also provide higher user comfort and satisfy his or her needs in adaptive mode due to person's daily routine in interacting with it. Usability evaluation data of adaptive features for the experiments of effectiveness, efficiency and satisfaction is presented in Appendix-C.

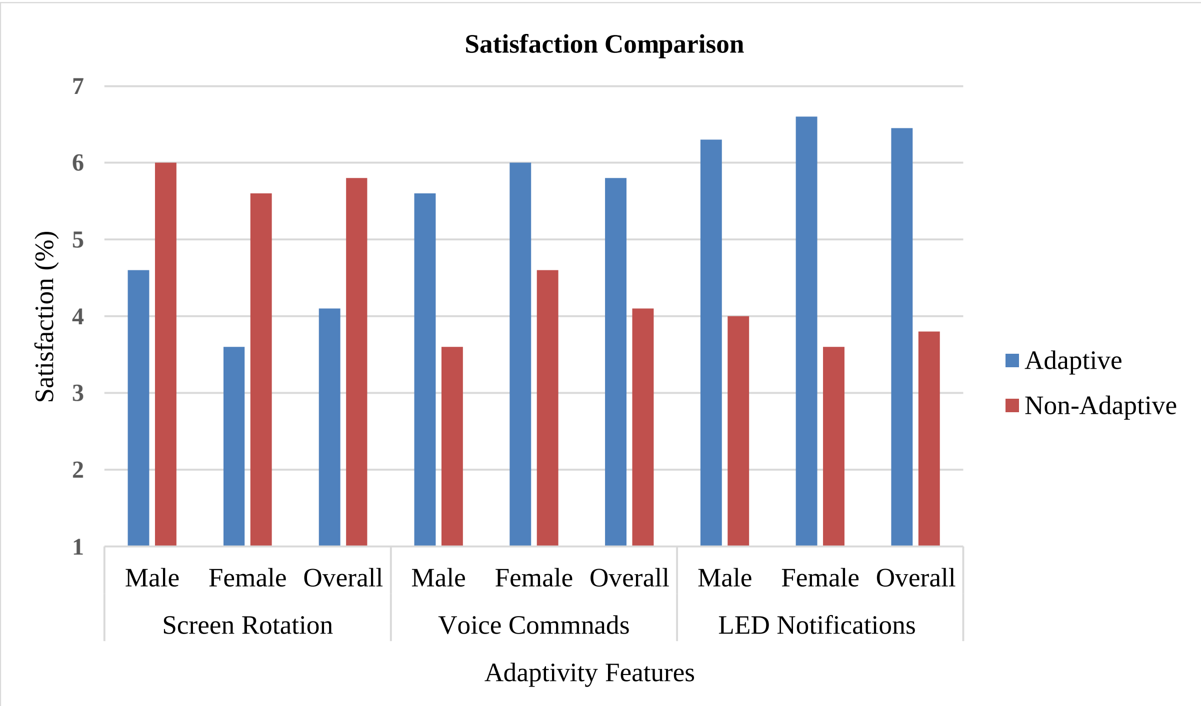


Figure 5.4: Comparative study for adaptivity and non-adaptivity score by user

5.6 Discovered Limitations and Outcomes

In this chapter, considerable limitations of different studies are presented as an argument in support of the significance of adaptive features usability in smart phones.

Previously, a study was conducted by Constantinides (Constantinides et al., 2015) through android news App (Habito) for AUIs. The comments on satisfaction level for three categories were shown as i) 71% trackers chosen adaptive interface for reading ii) 80% of the reviewers preferred the baseline for navigation and iii) dippers given a neutral preference on both interfaces with 33% for each. The study was presented only in the context of news readers specifically with limited contextual properties. Another research was performed using mobile-map based App “Media Maps” (Wesson et al., 2014) to handle the adaptive nature of the user and their contextual needs. Due to this level, user relaxation and contentment in using the interface become very much positive, the information was obtained with 76 to 78% accurate value at average. The presented study was shown good results for adaptive environment but contained limited features, context and user properties. Hartmann (Hartmann, 2009) has given a declaration in research regarding the MS Office software that its hidden intelligent menus earlier than 2007 had raised many usage problems at user end. At that stage it was considered complex and difficult to use. However, after 2007+ releases had got it fixed and hence there was no such issue left after using AUIs. Further, many adaptive features (e.g. screen rotation, voice commands, LED notifications, kid mode) were developed with limited user context and complex contexts. These modes and features were developed in specific environment for specific class of users (Looije et al., 2007) (Cheng et al., 2012) (Palsson, 2014) (Kushlev et al., 2016).

The outcomes of the current study during the usability evaluation of adaptive and non-adaptive features are presented for effectiveness, efficiency and satisfaction. It has been evidently found that users like to utilize portrait mode of keyboard for inputting text because of its adaptivity and only one hand is required to operate it. Display orientations adaptivity is 25% which is much less effective in adaptive mode. However, the voice commands in the adaptive mode scores around 6% above in efficiency but down to 19% when comes to effectiveness. The problem behind is the variation of accent found in all kind of users. If we look regarding LED notifications, the adaptivity is dominant from all the rest features and goes up to 88% being effective and 89% being efficient. For kid mode the adaptivity is shown more effective of 28% and efficiency in compare to the regular mode. A clear level of comfort was not possible to collect due to kids lack in ASQ, however they did finish all the activity in best way. For this reason, it can be said that adaptivity in kid mode outperforms than other mode and shows higher score.

The comparison between existing studies and the current usability evaluation is shown significance of adaptivity. The existing evaluations were made for specific environment, context and purpose. But the current usability evaluation is performed for adaptive and non-adaptive features. This study is evaluated effectiveness, efficiency and satisfaction through UCD process model. The positive results of adaptive features, encourages us to proceed our research towards AUI. In wider perspective, the aim of this study is to provide adaptivity according to user's context. Furthermore, there are some problems to address in the adaptive nature of the smart devices because manufacturers have not yet set customization guidelines considering diversity of context. At the moment the adaptation strategy requires user's selection only, regardless the context, to either enable or disable any adaptive functionality.

5.7 Summary

The usability evaluations are performed to analyse the impact of adaptive features provided in widely used mobile device operating environments (android and iOS). The different features such as screen rotation, voice commands, LED notifications and kid mode are selected for evaluation based on frequency of use from four different categories. The comparative usability evaluations are performed for adaptive and non-adaptive mode. The ISO standard 9241-11 is used to measure the usability in terms of effectiveness, efficiency and satisfaction for selected tasks in specified time frame. After Scenario Questionnaire (ASQ) is used to judge the satisfaction level excluding kid mode. The results prove the significant margin of improvement in mobile device usability with the proper use of adaptive features. In this chapter the usability evaluation of adaptive features in mobile phone devices is conducted for normal users. Next chapter analyse the influence of adaptive features on mobile device usability for user requiring special assistance like colour-blind and colour vision deficient users.

Chapter 6. ADAPTIVE FEATURES FOR COLOUR-BLIND & VISION DEFICIENT USERS

This chapter of dissertation provides an insight on the colour-blindness and Colour Vision Deficiency (CVD) in which user feels difficulty in comprehending different colours. It can have an adverse effect on users. This research explores the transformation of static interfaces into dynamic interfaces for automatic adjustment of user's context. The experiments are conducted to find out the deficiency of colour-blind and CVD users. Further, the effect of adaptive mode in mobile phone usability is made for both colour-blind and CVD users.

6.1 Colour-Blind and CVD Interfaces

Colour-blindness and Colour Vision Deficiency disables the patients to differentiate among some basic colours i.e. red, green, and blue (Ohkubo & Kobayashi, 2008) (Lau et al., 2015). This disability can restrict the colour-blind patient to distinguish between different types of colours (Poret et al., 2009). Colour-blindness is usually occurred with lack of decision making from low-ground contrast colour schemes (I. P. Oliveira et al., 2015).

The fault in retina of the eye is main reason of colour-blindness which has two smarts like cone and rod. Both Rods and Cones judge the colours while the cones are named as photoreceptors which provides colour vision to the eyes. Three types of cone smarts such as L, M and S cones have been identified for absorption of colour spectrum. If there is any fault or disability in each of these, then it will lead us to colour-blindness which produces inappropriate results related to identification of wide range of matching colours (Harwahyu et al., 2013).

Table 6.1: Test groups, selected features and tasks

Kind of Cone	Cause	Frequency in Female	Frequency in Male
Monochromic	Missing all cones	0.00001%	0.00002 %
Dichromacy Protanopia Deuteranopia Tritanopia	Missing L cone M cone S cone	 0.02 % 0.1 % Very rare	 1.0% 1.1 % Very rare
Anomalous- Trichromacy Protanomaly Deuteranomaly Tritanomaly	Abnormal L cone M cone S cone	 0. 02% 0. 04 % Very rare	 1.0% 4.9% Very rare

The frequencies of cone types (L=large, M=medium, S=small) has been quickly depicted in Table 6.1. There are two fundamental conceivable outcomes in shading distinctive

pieces of proof (i) Trichromats are effectively definable for example orange, yellow, blue coral and canary yellow (ii) Dichromats are not definable i.e. red and green (Ananto et al., 2011). The vast majority of patients are influenced by Dichromacy which are partitioned into three after sub-classifications, for example, Deuteranopia, Protanopia and Tritanopia. Further, there are 0.02% female and 1.0% male populace is prompted by the deficiency of the L cone in Protanopia (J. Bin Huang et al., 2009) (Ranjani, 2015). It is uncovered in the table that, Deuteranopia includes around 0.1% female and 1.1% male populace and it is generally brought about by the insufficiency of M cone (Jefferson & Harvey, 2007)

In certain range of spectrum, the patient thinks that it's hard to comprehend the ID of specific sort of hues that are red, blue and green hues. Third kind of visual deficiency (Tritanopia) that is discovered more every now and again in males than females which is because of the inadequacy of S cone (Manhas & Sarwar, 2012) (Chua et al., 2015). Worldwide, well known portable administrators for example iOS and Android (almost 98% market share) have implanted capacity for CVD to help partially blind users. Ease of use issues still continue for such users because of unbending modes, low usefulness alternatives and complex interfaces to approach offices to defeat CVD (Jindal & Jain, 2012). The ColorFind interface has been created by the Golden Shores innovations LLC with the unique component containing a quit switch and one camera see. Amidst the camera see, there is a yield of line on which the spectrum name is composed. There are various interfaces exist that give diverse highlights and capacities to battle shading insufficiency. These endeavours are great regarding functionalities yet don't bolster outsider Apps (Schmitt et al., 2012).

The AUIs can be utilized to overpower the limitations forced by interfaces utilized in CVD. To mimic the typical shading vision inadequacies, the ordinary camera of smart phone is utilized. Notwithstanding, still needs an incredible work to distinguish such hues that are easy to use for CVD watchers (Fahrul Muttaqin & Suwandi, 2011). The AUI recognizes the user context to adjust an alternate presentation, for example, activity and representation to deal with the user objectives as indicated by necessity. Such interfaces are being upheld by AUI that are adaptive according to users need rather than the interfaces that make the user adaptive in like manner. Essentially, AUI furnishes a stage with vast potential to improve intuitiveness with frameworks (Akiki et al. , 2014). Individuals are confronting numerous challenges because of complex component, for example, substantial data framework, office suits and facilitated Apps with static interfaces, more diminutive screens and ability to manage the user’s analysis. These troubles in the smart phone interfaces can cause the low fulfilment level among the general population (Dostal & Eichler, 2011). An investigation has been led on the ease of use of smart phone Apps. It demonstrated 59% errand consummation inside given example measure. Also, there were three ease of use issues recognized, for example, productivity, content inclusion and screen measure (Wesson et al., 2014).

In adaptive interface for a successful ease of use, the arranged errands must be adjusted in agreement to client's reasoning example. (Anthony et al., 2012). Still there are numerous Apps confronting ease of use issues in light of their non-relevant UIs. In this manner, keeping in view the dimension of capacity of the users, adaptive UIs endeavour to improve the ease of use of users.

6.2 Related Work for Users with Special Needs

Visual weakness is the variation from the norm because of which an individual can't perceive specific or entire hues. Individuals having ordinary shading vision are considered as Trichromats and can perceive different kinds of hues, for example, yellow, naval force blue, coral, orange, blue and canary yellow. Any of these hues is recognized by red-green Dichromats. Appropriately, red-green Dichromats are not reasonable absolutely shading lacking, however they are visually challenged (Byrne & Hilbert, 2010). At the point when the subjects have complete partial blindness, they can experience the ill effects of diminished visual sharpness. Thus, brilliant conditions can cause distinctive issues (Ohkubo & Kobayashi, 2008). The study was proved the trouble of guide perusing for partially blind users. The outcomes announced that the 96% of entire members were ordinary in CVD while just 8% men were vision shading disabled (Jenny & Kelso, 2006).

Pearson depicted that 8% of Caucasian men are partially blind. Specifically, the Protanopia (red visually impaired) are just 1% and the Deuteranope (green visually impaired) are just 1. 1%. The Dichromats (red heartless) are just 1% just as the Trichromats (green obtuse) have the most astounding level of 4.9%. The creator likewise expressed that 0.003%

men were found totally partially blind and blue-dazzle were just 0.002%. It has been demonstrated that simply 0.4% females were described by the issue of survey any kind of shading, where the red or green structures are transcendent (V. C. Smith & Pokorny, 1986). Another fascinating investigation was performed to assess by three devices so as to improve the visual quality as indicated by adaption of fluffy rationale alongside the reproduction of the red just as green visual impairment. Histogram adjustment in RGB has examined all amendment varieties. As needs be, there were 46% better individuals found in the assessment while 14% were discovered tried most unfortunate. Likewise, histogram evening out in L, M, S shading model was performed. The outcome assessed that there were 17% individuals discovered better amid testing and just 7% recorded as most noticeably awful (J. Lee & Santos, 2010).

Lastly, a picture recovery task dependent on highlights of shading co-event was examined in where two cases were talked about for ordinary vision and three for partial blindness. The change of 12000 pictures into 3 Dichromatic forms was performed by Vischeck re-enactment device to find the aftereffects of 48000 inquiries asked from partially blind clients. The outcome demonstrated the examination was 32% to 35% for initial 20 re-established pictures and the typical vision containing normal for shading (Kovalev, 2004). As needs be, display was structured and actualized a physiological based model for recreating shading recognition. A confinement of this model is that it just considers the conditions roughly up to 99. 38% for all CVD cases in Dichromacy and Anomalous Trichromacy (MacHado et al., 2009). To overpower the prohibitive capacities of CVD, the examination understood another model of separation of the human shading, called ICD-2. Shading space embraced by another model was better altered to the human shading vision versus the RGB shading space utilized by old circumstance explicit models. From an observational correlation of the two models, it was found that the old model was multiple times slower than the new ICD-2 demonstrate (Flatla &Gutwin, 2011).

Additionally, a shading pay vision framework for CVD subjects was proposed dependent on Gaussian Mixture Model (GMM) for displaying the picture shading circulation. A picture of 300×300 pixels was re-hued in under 5 seconds by proposed approach without strain to improve the speed of streamlining. Another investigation was proposed a quick re-shading approach for CVD individuals which depended on safeguarding the picture data. In the meantime, re-coloured picture was kept as very characteristic by proposed shading change for a subject with ordinary view. The outcomes gotten by analysis demonstrated that proposed methodology had the capacity to keep pictures as normal for an ordinary watcher. In the meantime, it had capacity to make increasingly justifiable pictures for experiencing CVD individuals (Jeong et al., 2011). A re-colouring instrument (SSMRecolor) in view of idea of circumstance explicit displaying was produced for re-colouring process. An investigation was performed where execution of SSMRecolor and other two strategies were assessed in various ecological contexts. The acquired outcomes demonstrated that proposed instrument was increasingly exact and quicker in shading coordinating errands (Flatla & Gutwin, 2012). Additionally, the creator built up another calculation of video re-colouring for individuals influenced by Dichromacy. All the more explicitly, the test was made out of 11 subjects with one subject influenced by Protanopia to which the first recordings were indicated first. An assessment dependent on complexity, instinctive nature and execution was performed on the four recordings by the Protanopia subject. The PC based adaptation of the Ishihara shading plate test has been assessed through calculations dependent on adaptive interfaces (C. R. Huang et al., 2011).

An examination was coordinated with 18 subjects which were picked with the goal according to image and engraving for the clicking of hopeful coordinating. An aggregate of 72 tasks were looked and pointed by each subject. In 56% of the investigations a general blunder of ±40% and a normal relative mistake of 16% with standard mistake of 54% with connection of 0.7 were secure as a finish of examination. For 90% of the analyses where display worked suitably, a normal relative blunder of 6% alongside a standard deviation of 42% was procured (Biswas & Robinson, 2013). App was exhibited for expanding the convenience of portable union in context with CVD. Sort of shading lack could be effectively perceived by the proposed App. For mimicking the shading vision issues to typical individuals, the smart phone's camera caught the picture (Schmitt et al., 2012). A proposed system was appeared through the advancement of models and diverse situations. Accordingly, from the system, the most appropriate re-shading methodologies could be resolved and consequently utilized so as to adjust the interfaces for CVD individuals (De Araujo et al., 2016).

The aforementioned works analysed and studied the CVD accessibility and adaptivity in mobile Apps. It has been noted that a number of approaches, models, algorithms and Apps have been outlined for re-colouring, labelling and diversity of colours for CVD people.

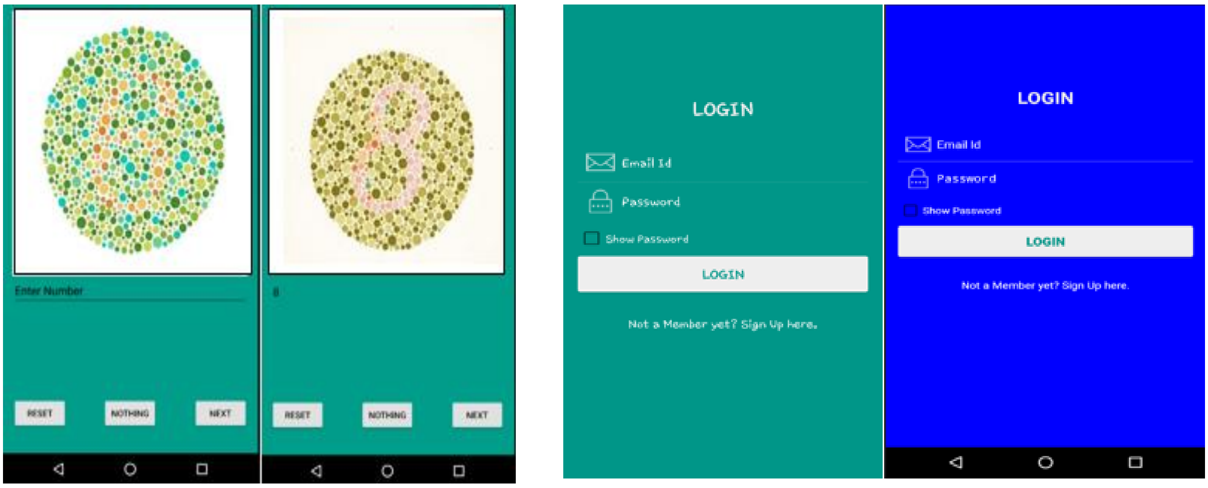
Nonetheless, the versatile models are not especially centered around the user requirement. In fact, for CVD viewers still the choice of colours that are visually friendly takes too much struggle. Likewise, the adaptive highlights are intended for special purpose/context and special environments.

6.3 Usability Evaluation Method

Various investigations are performed to break down the ease of use parts of adaptive portable interfaces for partially blind and shading insufficient users. To conquer the inabilities an App with versatile highlights was created for visually challenged clients. This App peruses the user context with some underlying partially blind tests and change to the particular mode individually. Ishihara test was utilized to recognize the partially blind users that will change UI consequently. The ease of use assessment was cultivated to quantify the productivity, viability and fulfilment for adaptive and non-adaptive condition. Moreover, the similar ease of use investigation between visual impairment and shading vision insufficiency was exhibited for both adaptive and non-adaptive conditions.

6.3.1 Adaptive Environment for Colour-Blind Users

For communication between devices and users, the mobile device interface provides a comfortable medium. A dynamic situation was imitated through an overlay App to perform ease of use assessment. This App gives different styles of UIs having explicit shading palettes. In contrast to later adaptive static advancements, this dynamic condition changes to explicit context just by detecting it. To detect the client context, each user needs to perform Ishihara test at any rate once with the goal that gadget can get recognizable to the client and their visual capacities.



(a) (b)

Figure 6.1: Ishihara test login screens for normal and colour-blind user

Figure 6.1 (a) demonstrates the case of test, that is being performed for client's vision types ID. It exhibits the visual perceptions of test screen for typical vision user and for user having partial blindness. Contingent upon the Ishihara test results, App changes to particular interface style. This App utilizes a shading plan that can be effectively worked by users with any sort of partial blindness. All the realized users don't have to play out the test however will be legitimately signed in to their particular interface style. The difference between the login screens for normal and colour-blind users has been depicted in Figure 6.1 (b).

6.4 Sample to Conduct Experimentation

The inspecting for a convenience assessment needs straightforward gathering of clients from focused area. Here the objective area of client is populace of partially blind and shading vision lacking clients. The experimentation with 30 users is a standard and satisfactory example estimate for the users from explicit geographic region having explicit vision disablement (Lazar et al., 2010).

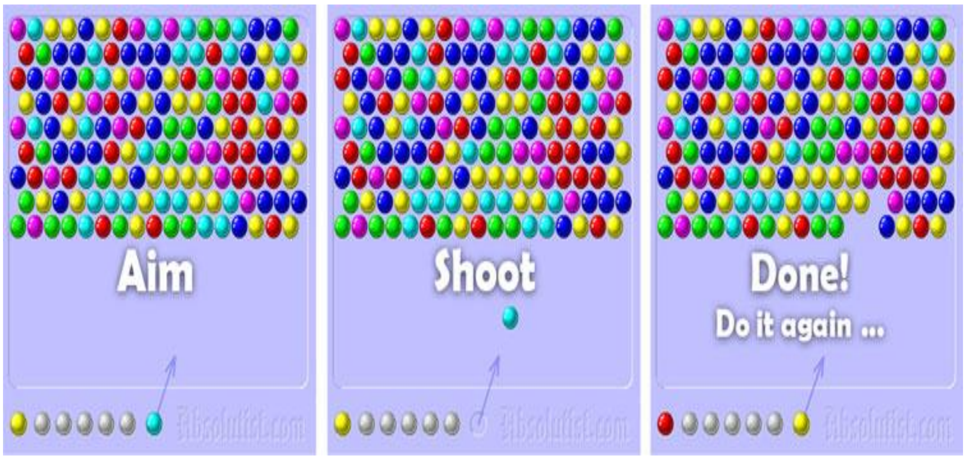
The example about gatherings of users having visual impairment and shading vision inadequacy with over one-year experience of advanced smart utilization. Thirty individuals including 23 boys and 7 girls are picked based on worldwide proportion of male/female populace with shading vision debilitation. In the trial, members were 18 to 30 years old for non-adaptive and adaptive environment where every member went to a little instructional meeting. These diversions were chosen dependent on two reasons for given time of 5 minutes, first extraordinary shading mixes are utilized in these recreations and second user needs to distinguish hues to play in evolving blends.

Task1-Color Switch: In this game the player needs to take a jumping ball across multi-colour, rotating, matching through colour region of the shape. The jumping ball changes its colour with every new shape. Figure 6.2 (a) shows some sample combination and shapes used in Color Switch game.

Task2-Bubble Shooter: In this game, the player has to shoot different colours of balls and balls will keep on increasing until they come at the bottom of screen. User has to shoot them only with matching balloon provided in the canon. Some screenshots are showing in Figure 6.2 (b).

Task3-Baby Xylophone: User has to play two specific tunes using a rainbow coloured Xylophone by hitting colour music notes appearing on different keys shows in Figure 6.2 (c).

(a) Colour Switch



(b) Bubble Shooter

(c) Baby Xylophone

Figure 6.2: Applications for the experimentation

6.4.1 Usability Evaluation for Users with Special Needs

As discussed in chapter 5, usability evaluation is performed according to the ISO 9241-11 standard with the same measurement factors. ASQ is used to measure the satisfaction level.

6.5 Interpretation of Evaluated Results

In this section the results of effectiveness, efficiency and satisfaction have been calculated for colour-blind and CVD people. The usability has been computed for colour-blindness (Protanopia, Deuteranopia, Tritanopia) and colour vision deficiency (Protanomaly, Deuteranomaly, Tritanomaly).

6.5.1 Usefulness of Colour-Blind and CVD Users

The Figure 6.3 shows the comparison of effectiveness in adaptive and non-adaptive environment for Protanopia, Deuteranopia and Tritanopia with the impact of 80%, 60% and

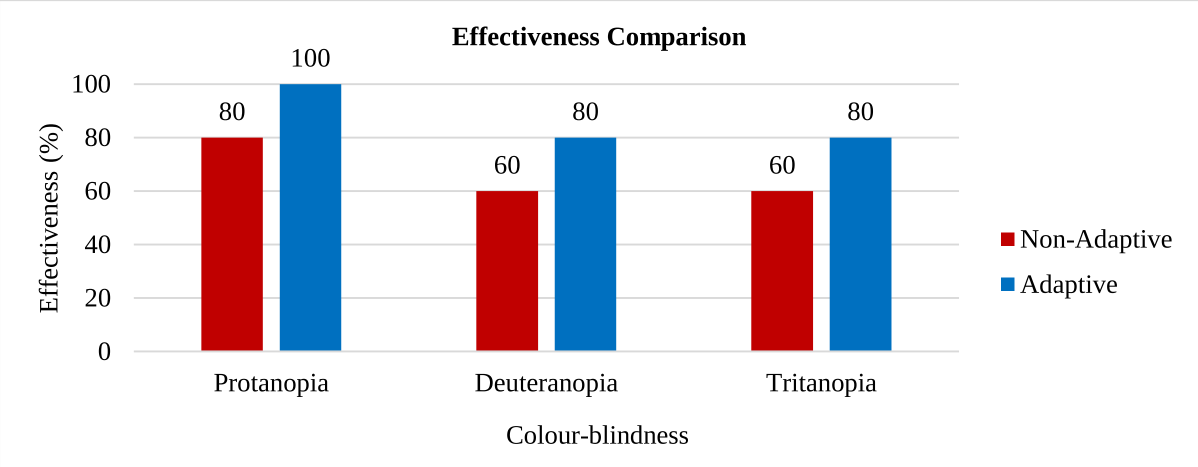


Figure 6.3: Effectiveness of colour-blindness for both environments

60% accordingly. In adaptive condition the viability of Protanopia, Deuteranopia and Tritanopia is 100%, 80% and 80% individually. Protanopia has versatile condition for adequacy while it is near great in non-versatile condition as for viability. The outcome demonstrates that for non-versatile and versatile condition, Deuteranopia and Tritanopia has square with adequacy. As a rule, the consequence speak to that the fittingness of versatile condition is more famous than non-versatile condition.

The adequacy of CVD is intricated in Figure 6.4 for non-adaptive and adaptive condition. For non-adaptive condition the effect of Protanomaly and Deuteranomaly determined 80%. Moreover, the non-adaptive and adaptive condition show same impact in Deuteranomaly. In any case, the effect of adaptive condition has remarkable separation with the non-adaptive condition. Other than this, the effect of Protanomaly and Tritanomaly in CVD displays exceptional qualification (20%) in non-adaptive condition.

The significant contrast has been appeared in the consequences of viability for visually challenged and CVD clients in non-adaptive and adaptive mode. The adequacy is good in normal to all sort of visual weakness in adaptive condition while it fluctuates for CVD. The distinction among Protanomaly and Tritanomaly is estimated 20% and 40% among the two modes in CVD. The above outcomes speak to that the clients of smart phones with partial blindness and shading vision inadequacy feel great with versatile condition.

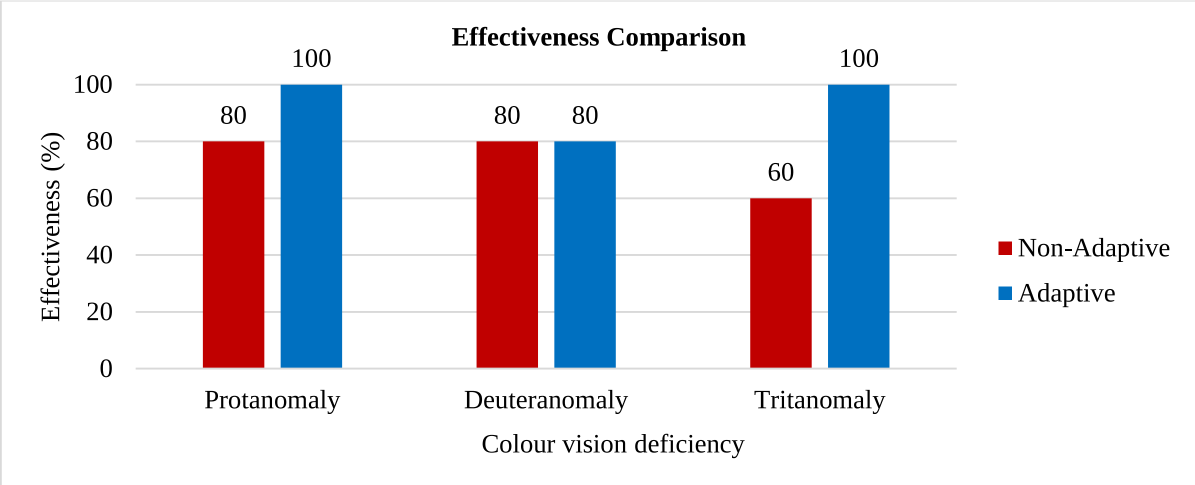


Figure 6.4: Effectiveness of colour vision deficiency for environments

6.5.2 Efficacy for Colour-Blind and CVD Users

The efficiency of non-adaptive and adaptive modes has been proven in the Figure 6.5 by using N=goals in formula. Moreover, it depicts the efficiency of colour-blind community in as much as non-adaptive and adaptive environment.

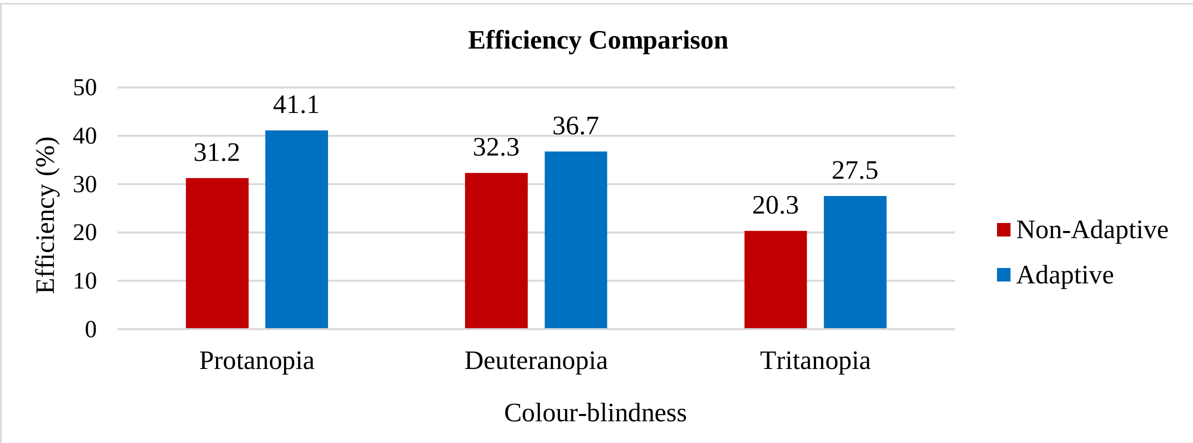


Figure 6.5: Efficiency of colour-blindness for both environments

The above figure shows the features of higher Protanopia efficiency of adaptive features. It illustrates that the efficiency of Protanopia, Deuteranopia and Tritanopia is lesser in non-adaptive environment (31.2%, 32.3%, 20.3%). Overall the effectiveness in adaptive environment is exceptional than non-adaptive environment.

Figure 6.6 exemplifies the efficiency of colour vision deficiency in non-adaptive and adaptive atmosphere. It is clear from the result that the adaptability of colour vision deficiencies (Protanomaly, Deuteranomaly, Tritanomaly) is higher for adaptive features. Moreover, highest efficiency is 39.4% for adaptive and lowest is 17.7% for non-adaptive environment in Tritanomaly. The Deuteranomaly CVD type has not much difference between the efficiency of adaptive and non-adaptive mode.

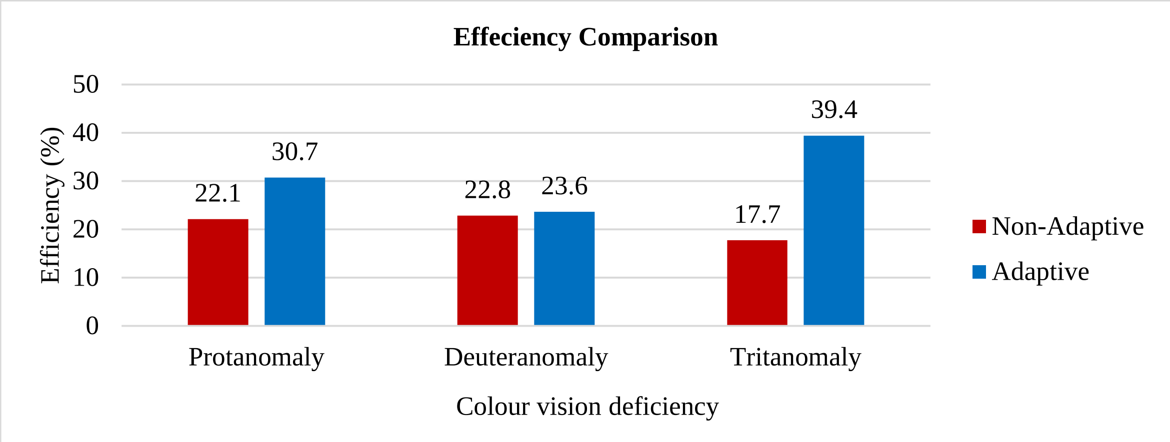


Figure 6.6: Efficiency of colour vision deficiency for both environments

In adaptive environment proficiency and competence indicates exceptional results in accordance with colour-blindness as well as with CVD. There is 9.9% difference in efficiency and proficiency of Protanopia for colour-blind persons. Highest efficiency for adaptive features is reported 41.1% in protanopia for colour-blindness while 39.4% in tritanomaly for CVD. Thus, in adaptive environment, the efficiency of colour-blind users is improved.

6.5.3 Satisfaction for Colour-Blind and CVD Users

Comparison of adaptive and non-adaptive atmosphere considering the user contentment is illustrated in Figure 6.7. To measure the contentment status of candidates, tests has been carried out by ASQ for Protanopia, Deuteranopia and Tritanopia. It interprets the ranks of satisfaction of Protanopia, Deuteranopia and Tritanopia as 3.7, 4.3 and 4.1 accordingly for non-adaptive atmosphere which is lesser than adaptive atmosphere. Similarly, the Protanopia users contain minimum satisfaction in non-adaptive (3.7) and adaptive (5.2) atmospheres. Highest satisfaction rate is 5.6 which gained for Tritanopia in adaptive environment.

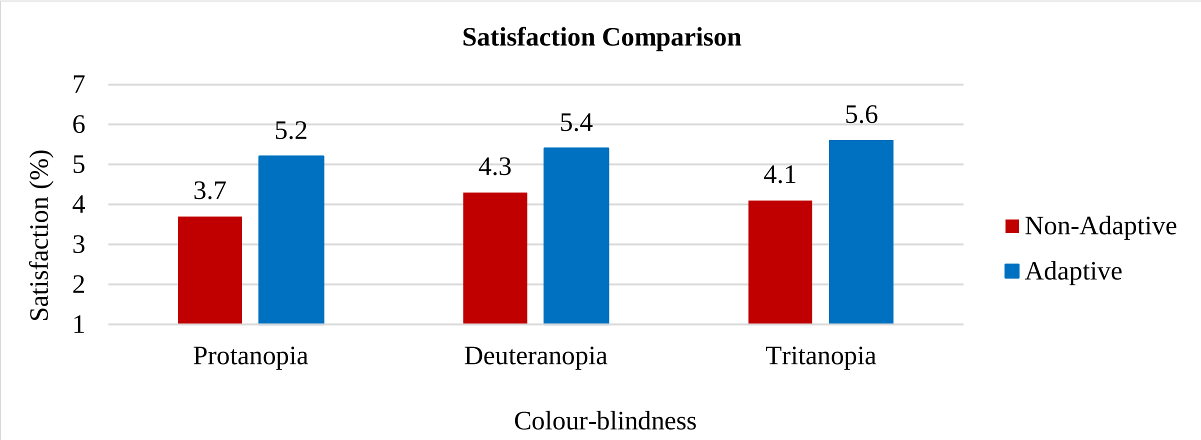


Figure 6.7: Satisfaction of colour-blindness in both environments

Satisfaction of colour vision deficient persons for Protanomaly, Deuteranomaly and Tritanomaly is illustrated in Figure 6.8. The result further clarifies that satisfaction is greater in adaptive environment than non-adaptive atmosphere. Satisfaction level of Protanomaly, ranked 5.9 in adaptive environment which is higher while 5.5 is lower in protanomaly. Protanomaly and Deuteranomaly shows equal satisfaction level which is 4.1 in non-adaptive mode. Appendix-D describes the usability data for colour-blind and CVD users. It also represents the summarised data for non-adaptive and adaptive environments.

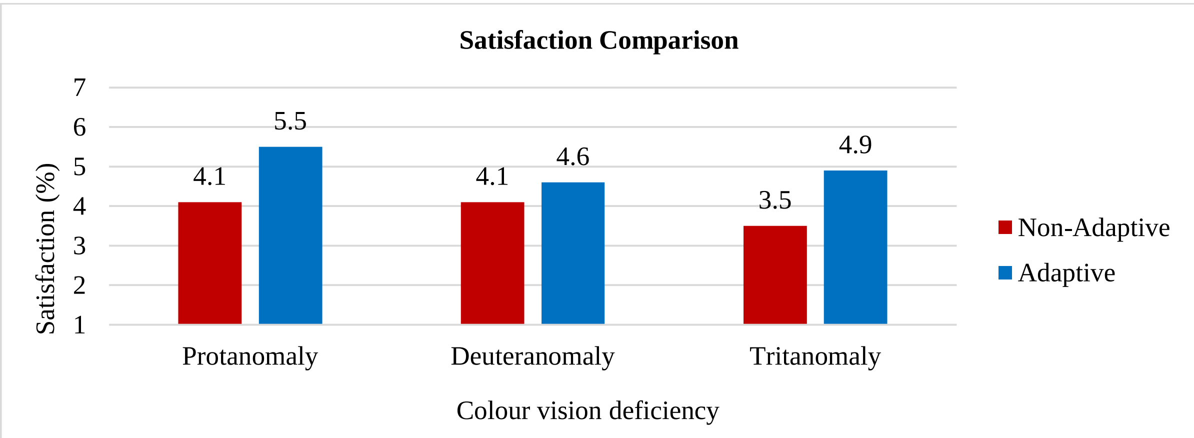


Figure 6.8: Satisfaction of colour vision deficiency in both environments

6.6 Effects of Adaptive Mode on Mobile Phone Usability

As indicated by the outcomes, it is uncovered that adaptive condition has preferred ease of use measures over non-adaptive condition. This segment ascertains the expansion rates of ease of use measures with complexity to the non-adaptive condition. It presents similar outcome investigation for clients with partial blindness versus clients with shading vision inadequacies. The general outcomes demonstrate that the adaptive condition has blend preferences for the clients with visual impairment and CVD. The expansion in adequacy, proficiency and fulfilment is gathered by utilizing following equations.

$$Increase\ in\ Effectiveness = \frac{Effectiveness_{(Adaptive)} - Effectiveness_{(Non-Adaptive)}}{Effectiveness_{(Non-Adaptive)}} \times 100 \quad (1)$$

$$Increase\ in\ Efficiency = \frac{Efficiency_{(Adaptive)} - Efficiency_{(Non-Adaptive)}}{Efficiency_{(Non-Adaptive)}} \times 100 \quad (2)$$

$$Increase\ in\ Satisfaction = \frac{Satisfaction_{(Adaptive)} - Satisfaction_{(Non-Adaptive)}}{Satisfaction_{(Non-Adaptive)}} \times 100 \quad (3)$$

In total the satisfaction level of adaptive atmosphere is better than non-adaptive atmosphere for colour-blindness and CVD. The difference of usability satisfaction between Protanopia and Tritanopia is 1.5. Further, for colour vision deficient users is at highest limit which is 4.9 while for adaptive while in Tritanomaly the lowest limit is 3.5 for non-adaptive environment. Furthermore, the result discusses the feeling, comfortability and usability of participants during the experimentation in an adaptive environment.

The Figure 6.9 shows the increase in effectiveness. It presents the effective comparison to identify the effectiveness between mobile users who are colour-blind and colour deficient.

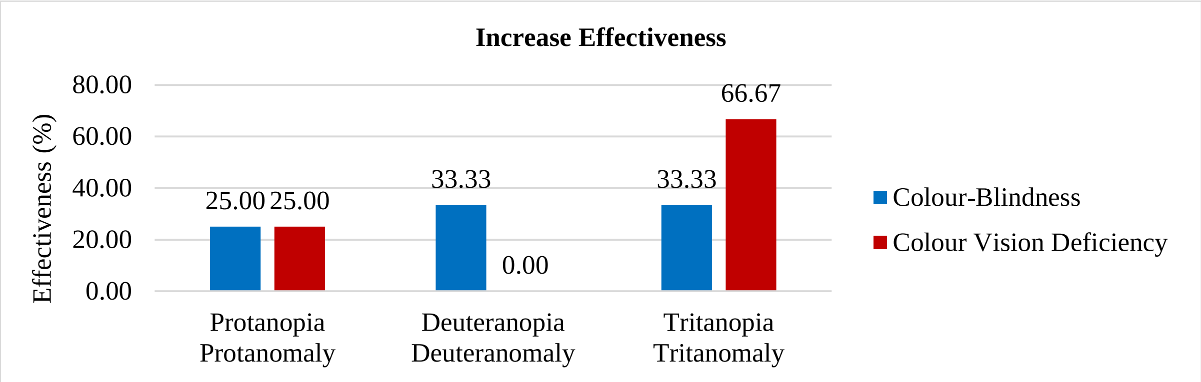


Figure 6.9: Increase in effectiveness of colour-blindness and CVD

The major difference recognizes in Tritanopia and Tritanomaly for colour-blind and CVD users. It shows that colour-blindness in Deuteranopia people has 33.33% increase in effectiveness while there is no increase in effectiveness for colour vision deficient in

Deuteranomaly. Furthermore, the equal increase in effectiveness is noticed for colour-blindness in Protanopia and CVD in Protanomaly.

The Figure 6.10 shows the productive condition of Tritanomaly in adaptive mode for mobile users while the efficiency of Protanomaly is 38.91% and Deuteranomaly has minimum productivity for CVD. It gives the most noteworthy efficiency of visually challenged clients in Tritanopia is 35.46%. In like manner, Protanopia has proficiency 31.73% while Deuteranopia has lower productivity for partially blind users. Additionally, significant distinction shows up in Tritanopia and Tritanomaly for visually challenged and CVD clients. The examination between visually challenged and CVD individuals gives an understanding to the outflow of adequacy in the adaptive users.

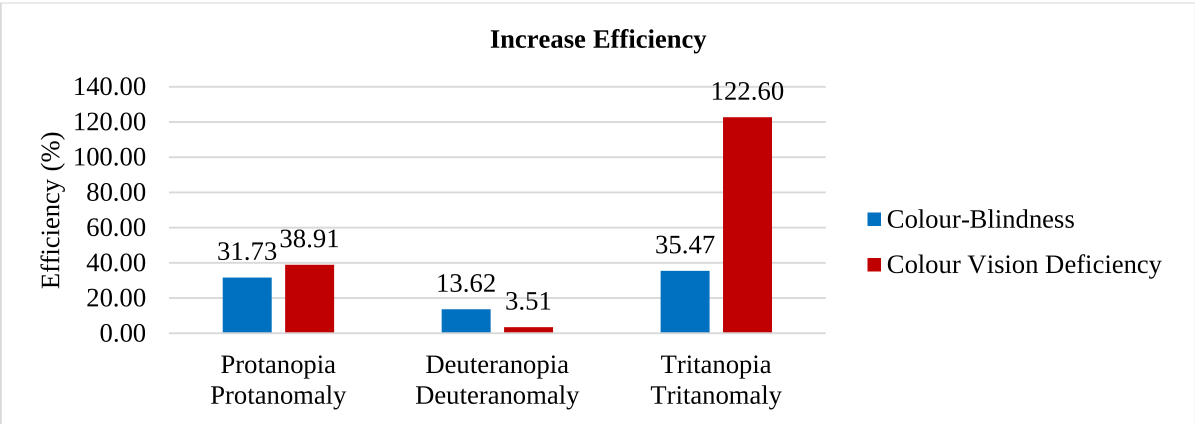


Figure 6.10: Increase in efficiency of colour-blindness and CVD

The comparison is shown in Figure 6.11 for the satisfaction of colour-blindness and CVD users. The 40.54 percent satisfaction is found for Protanopia and 34.14 percent for Protanomaly. The major difference is shown in results between the satisfaction of Deuteranopia and Deuteranomaly. Moreover, the users are significantly satisfied for Protanopia in colour-blindness and Tritanomaly in CVD.

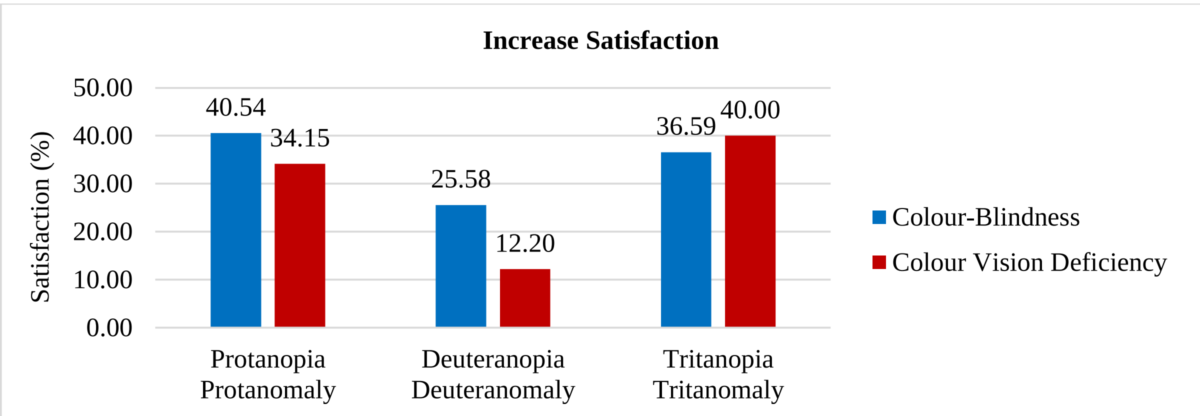


Figure 6.11: Increase in efficiency of colour-blindness and CVD

6.7 Evaluation Findings and Discovered Limitations

Numerous ICT Apps provide accessibility options for the individuals who have vision deficiency. There are also adaptive features provided in mobile devices for users with disabilities. The evaluated features in this chapter are provided by two major mobile OS including Android, iOS for colour blind users.

ColorBless and PatternBless are two quant-basics visually challenged modes which were presented in a critical report. The investigation is really the examination of these models and other current strategies. It has been led with 10 partially blind just as 10 typical shading seeing subjects with the age 21 to 30 years. ANOVA measures were embraced to assess the effect of hues just as the differentiation extremity on three dependent factors (Chua et al., 2015). In unique situation, the work was produced for the Tukuchiy system for consequently creating AUIs, which was depicted by a standard structure and got a progressively vital usability dependent on the tendency of the users. Then again, this framework considered visual weakness and near-sightedness instead of physical troubles. For testing the guidelines, the Midiku App was intended for supporting the analytic procedure kept running by radiologist. Gadget surveys the principles utilizing the forerunners of advanced Mock-ups. The screen affiliation and data fields see were emphatically surveyed, while the catches, characters perception and phrasing were contrarily assessed (Barrera et al., 2014). Another wearable improved vision framework dependent on expanded the truth was presented for expanding the shading vision in a subject influenced by CVD. The analysis was led on 24 subjects with CVD, specifically 18 male and 6 female subjects with normal time of 37.4 years. The acquired outcomes from proposed framework decided an improvement in the Ishihara Vision Test, with a mean an incentive from 5.8 without amendment to 14.8 with adjustment (Melillo et al., 2017).

The outcome of research displays a novel methodology in which the users conduct is not shaped by the advanced smart App rather the smart phone App is created in an approach to coordinate the necessities of the client’s versatile interface. The outcomes are compelling and demonstrated a critical improvement in undertaking finishing rate which is expanded 40% if there should be an occurrence of Tritanomaly clients in CVD, moreover the effectiveness of clients has additionally raised up to 22%. The fulfilment rate of partially blind users in versatile interfaces are higher particularly if there should be an occurrence of Protanopia and Tritanopia which is additionally clear by their execution. It is appropriate to specify here that if there should be an occurrence of Deuteranomaly in CVD the adequacy and proficiency of clients in adaptive condition is very little improved whenever contrasted with different sorts of shading insufficiencies however by and large fulfilment on versatile interfaces demonstrated them favoured decision. Above figure, demonstrates that expansion in effectiveness if there should be an occurrence of Tritanomaly in CVD is twofold while if there should be an occurrence of Protanomaly which is found up to 38.91%. The versatile interfaces are given consistent joining in which the clients feel progressively sure and less frightened.

6.8 Summary

This chapter discovers the possibility to change static UI into dynamic which automatically change its behaviour according to user context. The study is focused for experiments in colour-blind and colour vision deficient users. Different categories of colour-blindness (i.e. protanopia, deuteranopia, tritanopia) and colour vision deficiency (i.e. protanomaly, deuteranomaly, tritanomaly) are identified clearly. A working App is developed which detects the colour-blindness types and automatically switch to respective colour mode. To simulate the visual abilities of user, the Ishihara test is performed in start. The comparative usability evaluation with working App (adaptive) and without it (non-adaptive) are performed by selecting three different tasks. The usability framework (ISO 9241-11) is used to measure the effectiveness, efficiency and satisfaction in defined time for selected tasks. ASQ is used to check the satisfaction level of colour-blind and CVD users. The results demonstrate that the adaptive mode is leading than non-adaptive mode.

The studies of mobile device adaptive features for normal and special users have proved significance of adaptive interface with improved usability. These features have also provided some negative results due to compatibility issues of adaptive features and context. The voice commands feature couldn’t perform well due to the user’s culture and linguistic features (non-English speaking community) and adaptive features requirement (English accent fluency). The screen rotation couldn’t perform well in writing text tasks. These adaptivity features are either mismatched to user demography or selected task. Similarly, effectiveness in deuteranomaly for adaptive and non-adaptive mode is same. Thus, adaptivity of mobile device interface must be aware of usage context. Next section will discuss the methods to create machine understandable model of context and consequently incorporation of the context with adaptive interface.

Chapter 7. MOBILE PHONE USAGE CONTEXT ONTOLOGIES

The adaptivity features analysis, in previous chapters, have proven the role of adaptive interfaces in level of usability conditional to its harmonisation with the usage context. A detailed context analysis is required to adapt interface accordingly. Different situations exhibit variety of context patterns which are directly influencing on usability of tasks to be performed at mobile devices by users. In this chapter, the user context modelled through knowledge engineering process to handle the contextual complexity faced by mobile phone interfaces.

This chapter covers the second phase of research methodology, in which User Context Ontology (UCO) modelling is performed that leads towards Adaptive Interface Ontology (AIO). The major participants, including user, task, environment and device, are defined as base concepts of the usage context. The ontology, engineered here, adopted many context concepts from well matured and widely used ontologies presenting standard definitions (Appendix-E). As discussed in literature review these concepts are defined in many disjoint ontologies. Here we have joined these formal definitions with some additional concepts studied through adaptive features analysis to provide a comprehensive mobile device usage context.

The User Context Ontology (UCO) enables to capture all the information according to the context of user. It changes the UI characteristics automatically according to the situation. The UCO is responsible to discover the dependencies and semantic relations amongst the classes and attributes. The target here is defined in this chapter by the competency questions that we can define, store and retrieve user context with its semantic relations and constraints.

7.1 Usage of Context and Ontologies

The context is any data that can be utilized to portray the circumstance of a substance identified with association among App and user (Dey, 2001). It is difficult to check the vital parts of all circumstances that will change as per conditions. Some relevant data, for example, restriction, time, date and close-by individuals is expected to translate something in context (Amar et al., 2008). To show the context of user, people have diverse ways of life with their individual or aggregate needs. There is a need to improve client profile to accomplish the customized administrations with the capacity to adjust client's specific situation (Jiang & Tan, 2009). The ordinary and basic data that in the long run prompts an assessment of user's inclinations is the present circumstance. For instance, client may be "driving a vehicle" and the context changes constantly. In like manner, the circumstance "taking selfie" is the user context where smart phone use can't change amid certain time interim (Weißenberg, Voisard, & Gartmann, 2004). These kinds of circumstances may see user context to adjust changeability of activities and presentations to accomplish the objectives of user which will make the interface increasingly adaptable.

The context can be estimated a specific sort of learning which can be displayed as an ontology. An ontology-based context models are powerful methods for sharing and combination of context data (Dey, 2001) (Amar et al., 2008). A client context ontological model can be created based on client's qualities, for example, individual data, aptitudes, inclinations and context to give customized administrations (Skillen et al., 2012). For the most part, people comprehension and ideas are diverse for different circumstances, for example, at-home or in-kitchen. Computationally it is required to characterize these ideas through induction rules or semantic relations or classes on a philosophy (Moore et al., 2010). As of late, various association styles and methods of smart phones make complexity of interface communication (Peissner & Edlin-White, 2013) (Feng & Liu, 2015).

Over the most recent couple of years the examination on user profiling and context has been supported for the improvement of adaptive frameworks that are to be utilized by heterogeneous clients (Kobsa, 1993). In such manner, ontological displaying on user profiles is by and large App explicit that has been made for explicit area or assignment. These arrangements have given versatile UIs to explicit contexts yet ailing in clever basic leadership, not programmed changing to the particular mode and failure to adapt new contexts. The adaptive interface request to be a keen arrangement that can adapt new contexts, sense existing contexts and alter itself as per any obscure context. Formal ontology is a strategy to grow such context knowledgebase. It has capacity to keep all the context picture steady, institutionalized, shared and versatile (Gruber, 1993).

Competency Questions: In this manner, by thinking about the issues, some competency questions are characterized to create user context psychology for adaptive smart phone interfaces.

CQ-1. How usage of context can be formally defined for Mobile Phones?

CQ-2. What are the context properties effecting Mobile Phone interfaces?

CQ-2.1. What are the User properties effecting Mobile Phone interfaces?

CQ-2.2. What are the Device properties effecting Mobile Phone interfaces?

CQ-2.3. What are the Environment properties effecting Mobile Phone interfaces?

CQ-2.4. What are the Activity properties effecting Mobile Phone interfaces?

CQ-3. How different context properties are related semantically?

This research shows a context based ontological model utilizing Web Ontology Language (OWL) for versatile smart phones. It shows the users context, gadget parameters, condition (area and time) and movement. Classes and sub-classes have been made for the offered parameters to build up the connections between these ideas (Korpipaa & Mantyjarvi, 2003). Our ontological model catches the contexts by utilizing the plan of characterization, relationship catching between various data of context, conditions of properties related with explicit context class and catches nature of context with extensible quality requirements.

In the bigger point of view, this examination is a piece of UCD approach for versatile UI plan and advancement (Salah et al., 2014). The significant objective of UCD is to offer improved, proficient and easy to use items which builds the convenience and fulfilment of users (Hartmann, 2009) (Da Silva et al., 2011) (Sfetsos et al., 2016).

7.2 Mobile Phone User Context Studies

Fine-Grained adaptive UI created for OpenOffice. organization essayist word processor. It endeavoured full adjustment and were anything but difficult to learn in personalization of word processor. In this examination 12 members were occupied with which 9 were guys and 3 were females, matured from 21 to 53 years (M=28.75 years). In subjective measures, clients could choose their ideal directions in instances of toolbars, menus and avenue amid first endeavour around 62.7%, 53.3% and 66.4% individually. Be that as it may, clients neglected to choose order amid 30 seconds (most extreme time) in 20 cases for toolbar, 67 cases for menus and 11 cases for road part of examination (Dostal & Eichler, 2011).

In 1999, Dey et al expressed that context can be utilized to characterize the situation of an element. The examination portrayed the four context types and three context mindful highlights to the Apps. The chose frameworks contain diverse uses of context mindful and context's conduct. For instance, digital guide, context toolbox, dynamic identification, NETMAN and augmentable reality have context types (personality, area) and context mindful sorts (introduction and labelling) (Dey et al., 1999). Open Service Gateway Initiative (OSGi) gave secure administration conveyance and dependable remote administration of context mindful versatile administrations. The SOCAM middleware was created to give the help to context mindful frameworks on the highest point of OSGi. For usage reason, the ontologies of vehicle area were created comprising 19 classes and 30 properties. Context mediator approved and parsed OWL articulations into Resource Description Framework (RDF) triples while context inquiry got. The outcome explained that the runtime is worthy for running context mindful versatile administrations and Interpreter performed thinking (5000 triples) for context learning in unavoidable registering condition (Gu, 2004). The sensor-based context metaphysics for smart phone was determined with the blend of various sensors embedded in a smart phone. The metaphysics underpins the fast-versatile Apps advancement, utilization of assets effectively, learning reusability and data sharing between imparting substances. Likewise, the idea of model for the showcase of adaptive data was talked about and delineated in conceivable methods for utilizing cosmology (Korpipaa & Mantyjarvi, 2003). UI cosmology approach for GUIs was talked about in 2011. The final product of the procedure is only an ordinary GUI for a vCard, yet principle focused on result is User Interface Model (UIM) portrayed as RDF/XML documents containing the labels of space philosophy and UIO. It was obvious that UIs properties and their connections can be characterized through semantic and ontological system as UIO (Shahzad, Granitzer, & Helic, 2011).

Diverse ontologies have been produced in various contexts yet at the same time there is have to make philosophy for smart phones in user's specific circumstance. The Composite Capabilities/Preference Profile (CC/PP) is a W3C activity display that proposed a foundation to express the inclinations of user and capacities of gadget. It very well may be utilized to direct the substance adjustment displayed to the gadget. The CC/PP is profile-based design which utilizes RDF dialect for execution. It comprises of a progressive structure of segments which is separated into three regions like equipment, programming and App (Buriano et al., 2006). Context Broker Architecture (CoBrA-ONT) characterizes a portion of the regular ascribes and connections identified with spots, individuals and exercises. The fundamental target of this metaphysics is to empower information sharing and cosmology thinking inside the CoBrA framework. CoBrA-ONT characterizes key cosmology classifications, for example, activity, specialist, time, space, and gadget (Strimpakou et al., 2006). The CoDAMoS metaphysics use to fathom the difficulties of programmed code age, code portability, App adjustment and age of gadget explicit UIs. It characterizes four primary centre elements, for example, client, condition, stage and administration (Poveda-Villalon et al., 2010). Context Ontology (CONON) decides the general ideas about individual, area, action or computational substance, whose terms are believed to be extensible progressively by including space explicit ideas.

In addition, "Upper Ontology" is an abnormal state cosmology which characterizes the subtleties of general ideas alongside their highlights in each sub-space. This particular cosmology catches the nonexclusive highlights of fundamental relevant elements (Ahmed & Parsons, 2011). The "Conveyance Context Ontology" gives a formal model of the earth qualities in which diverse gadgets cooperate with solid administrations. The real substances displayed in this cosmology are equipment, programming, condition and area. Standard Ontology for Ubiquitous and Pervasive Apps (SOUPA) is structured and model to help unavoidable processing Apps. It is separated into SOUPA-Core, which characterizes such ideas that shows up in numerous situations (e.g. time, individual, space) and SOUPA-Extensions that underpins explicit ideas in smaller areas (e.g. office, home) (Arechiga et al., 2009) (Poveda-Villalon et al., 2010). DOLCE upper dimension philosophy was created inside the WonderWeb venture. It demonstrated that how DOLCE utilized Onto-Clean procedure and saw some real WordNet's semantic restrictions (Borgo & Masolo, 2010).

7.3 User Context and Usage Environment

Variable with respect to user's condition are accessible in wide range, for example, demography, psychological aptitudes, foundation, training, identity and inclinations. The elucidation of various user may not be coordinated for commands, names, icons and displays which is one of the significant difficulties in HCI (Lavie & Meyer, 2010). In knowledge world, there is a fast increment in user connection with interfaces and direct impact of the context on the client's assignment in a situation. The unique situation and undertaking characterize the change that should be performed at a particular development on UI's (Riahi & Moussa, 2015). In versatile registering, the context mindfulness or physical condition incorporates surroundings of a client and gadget (e.g. area and time) (Holzinger et al., 2012).

Client displaying, in the zone of portable Apps can be performed by observing client’s past practices or profiles. This kind of prescient learning has an impact on App interfaces and its substance. Context demonstrating for utilization learning has been characterized into three classes, for example, (i) in light of area information (ii) regulated learning methodologies and (iii) unsupervised learning approaches. Managed learning approaches require littler sum space information while unsupervised learning do not require area information (Klaassen et al., 2013) (J. Hussain et al., 2018). It is exceptionally hard to gather applicable data from users in light of the fact that majority of the users do not know which data is essential. This issue may make troubles for App engineers to create adaptive Apps as per user's logical data (Dey et al., 1999).

7.3.1 Context Entities

The characterized context entities are spoken to through semantic relations and their limitations (Arechiga et al. , 2009). In our model the contexts are dynamic that are removed from condition which help to distinguish the circumstance of a user at certain time or area. All things considered a "circumstance" is an unpredictable thought that might be seen at various granularities. The user context has been considered in our examination as a lot of parameters, for example, gadget, user, condition and movement. Context's factors are available in which the grouping connected to context which characterizes the level of fluctuation. There are two expansive classes (i) static context is user driven (customization) in which substance are given and controlled by user chiefly (ii) dynamic context (personalization) isn't user driven in which client is basically dormant or has less control (Iqbal et al., 2017).

In ontologies, the context data is for the most part spoken to in static shape while dynamic qualities of users are excluded. Despite the fact that a metaphysics allows the presence of different occasions of classes that may change with the progression of time (e.g. living states of user) (Golemati et al., 2007). There are numerous ontologies grown already as indicated by user explicit contexts. There is no cosmology exist explicitly for versatile UIs for smart phones in user's unique situation. Following are the parts of ontological model to context adjustment for portable users.

1. Device Context: Devices are utilized in different sorts of circumstance which changes powerfully as indicated by specific context. Little screen measure, show, adaptability, sensor, limit, processor, memory, illustrations, information and

produce functionalities impacts the utilization of interfaces and association (Klaassen et al., 2013). The gadget ought to be keen enough to comprehend the user's needs to settle on choices and continuing of satisfactory activities without interfering with the user (Weibenberg et al. , 2004) (Lim & Dey, 2011).

2. User Context: User's context may contain demographic data (e.g. name, age, nation, city, state, gender, instruction) and have the capacity to speak to the inclinations of either a gathering of users or a solitary individual. User profiles are commonly spoken to assets of weighted catchphrases, semantic systems, or weighted ideas, or affiliation rules. User's readiness and his time are required for the improvement of individual profile. User displaying can be depicted as the way toward building the individual inclinations of users as far as client's learning about the world, social viewpoints, objectives, different preferences (Weibenberg et al. , 2004) (Bolchini et al., 2007) (Bhowmick et al., 2010) (Shahzad, 2011).
3. Environment Context: The earth context has four sorts such as (i) physical (ii) social (iii) virtual and (iv) computational condition. To accomplish the adjustment, App must have capacity to detect earth to decide current movement, for example, climate, temperature, noise, time, and area (Gu et al., 2004) (Bhaskar et al., 2013) (Iqbal & Ahmad, 2018).
4. Activity Context: User demonstrating is required to keep up and refresh the user's profile while undertaking displaying alludes to specific client's exercises to induce additional data. A user's movement may have a particular area, time and context (Skillen et al., 2012). The movement context is utilized to depict data about the users, assignments and objectives (Ahmed & Parsons, 2011).

7.4 Ontological Representation of Context

The ontologies have ability to impart data and the capacity to speak to substances to name the ideas in machine intelligible frame. It can characterize these ideas in various classes and explicit cases. People have ideas, in view of learning comprehension including framework gadgets, detects, encounters and context (B. Smith, 2004). These ideas are conceptual, obscure, composite or genuine. People make mental model and expect framework and gadget conduct likewise. All robotized framework contained programming and equipment give a computational model of real-world ideas. Ontologies are utilized to express these ideas formally to characterize a computational model. Metaphysics driven data frameworks approach is being utilized to plan the App in human's point of view (Gruber, 1993) (K. M. De Oliveira et al., 2013). Along these lines, we are mistreating the advantages of ontologies to formally express the utilization context of versatile UIs. This ontology might be involved illustrative terms for the components of the versatile use context. This sort of philosophy speaks to relationship among substances known to man of talk (e.g. classes, relations, capacities, items or imperatives) with comprehensible content interpretation.

7.5 Ontology Engineering for User Context

Ontology Engineering is utilized to create cosmology to formally characterize the ideas of use context in detail. The context components can be perused and comprehended by any machine or computational framework with these formal definitions expressed in OWL/RDFs.

Story Boarding: Some preliminary situations are worked for various contexts in smart phone use. Smart phone is an example device utilized in this examination; it is chosen because of assortment of capacities and utilization situations, for example, official Apps, amusement recordings or geospatial administrations and so forth. These situations are worked for various classes of clients, condition and exercises utilizing diverse assignments (e.g. a child is taking selfie in the park at noon, an illiterate person is listening news in TV lounge, unskilled individual utilizing smart phone on roadside at twelve, driver is disallowed to take selfie amid driving etc).

Use-Case (UC) Scenarios: Some sample use-cases are defined.

UC-1. A child is recording rain fall video by using mobile phone in the room window at night.

UC-2. An illiterate person is listening news by using mobile phone in TV lounge at night.

UC-3. An office worker is doing video conferencing on mobile phone in office at noon.

UC-4. A student is downloading lecture slides through mobile phone at class room in morning.

UC-5. An elderly person is using social networks on mobile phone in drawing room at night.

UC-6. A driver is searching for nearest ATM on mobile phone at road side in morning.

Vocabulary: Various ontologies have been studied to extract the already available knowledge about context. Appendix-E provides the selected ontologies to render the terminologies and class definition for vocabulary building. The vocabulary constituted for ontological model is presented in Table 7.1.

This vocabulary is constructed over the recognized elements of context, especially considerable for interface design. These elements are identified by many of the past research work performed in last three decades and discussed in the literature review section previously (Gruber, 1995) (Korpipaa & Mantyjarvi, 2003) (Gu et al., 2004) (Heckmann, Schwartz, Brandherm, & Kroner, 2005) (Poveda-Villalon et al., 2010) (Bhaskar et al., 2013) (Wiens & Lohmann, 2018).

Table 7.1: Vocabulary representation for the development of ontological model

Classes	Sub Classes	Object Property	Data Property	Individuals	Data Types
Device	Camera, Display, Internet Connectivity, Navigation System, Touch screen	Has Camera, Has Display, Has Internet Connectivity, Has Navigation System, Has Touch Screen Has Device	Camera Quality, Display Colour, Display Size, Screen Size	Auto Brightness Back Camera Front Camera High Brightness Low Brightness Maps Mobile Internet Wifi Mobile Phone Touch Screen	xsd: integer xsd: string
User	Activity	Has Device Has Location Has Activity	Age	Illiterate Person Child Driver House Wife Office Worker Sportsman	xsd: integer xsd: string
Environment	Location Time	Has Location, Has Time		Office Park Road Side Kitchen Garage Gym Morning Night Noon	xsd: integer xsd: string

Activity	User	Has Location Has Time Has Context		Meeting Searching Nearest Petrol Pump Searching Nearest Hospital Taking Selfie Using Web services Workout	xsd: integer xsd: string

7.6 Taxonomy

The taxonomy of all ideas examined in past writing by the specialists where a few ontologies have been distributed (Buriano et al., 2006) (Strimpakou et al., 2006) (Arechiga et al., 2009) (Poveda-Villalon et al., 2010) (Ahmed & Parsons, 2011). The taxonomy improvement is executed as the second step after vocabulary working for ontology engineering. The Table 7.1 has given every one of the ideas introductory relations of classes and subclasses alongside information and article properties. The taxonomy was created utilizing Protégé (version 5.2.0). The progressive system is framed based on every context sort having diverse estimations of the measurement like user, movement, time, area (classes, cases, properties). Semantic questions will be utilized for learning procurement while the information sharing is cultivated through the occasions of concerned parts of context tree (Korpipaa & Mantyjarvi, 2003). There are four fundamental ideas of context properties, for example, user, condition, gadget and movement. These ideas are the essential classes of ontology taxonomy.

Device Taxonomy: Device scientific classification is explained in Figure 7.1 where device properties give the situation as part of entire context class. The properties are made by the example situation necessities. Camera: object property and Display: information property represents device properties. The occasions for the situations incorporate Mobile Phone (device itself), Touch Screen (components), Internet Connectivity (device status) and so on.

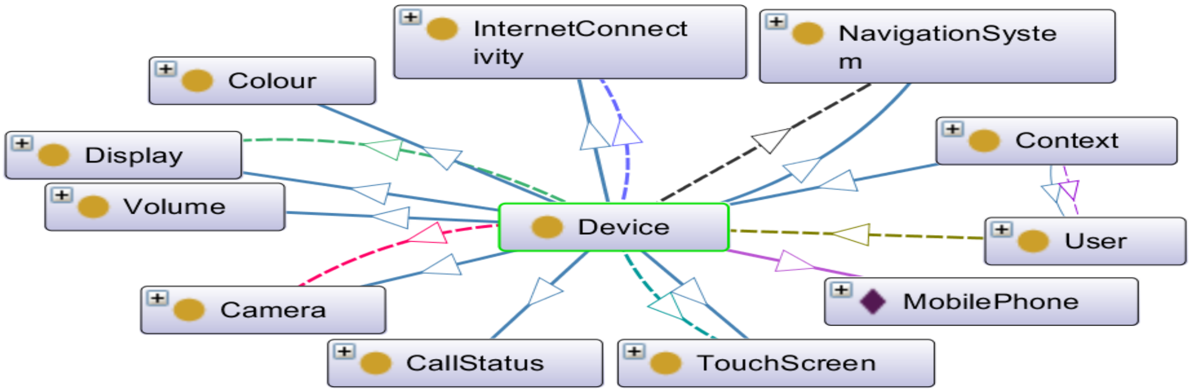


Figure 7.1: Device taxonomy

User Taxonomy: Figure 7.2 shows the user taxonomy in which user properties give the

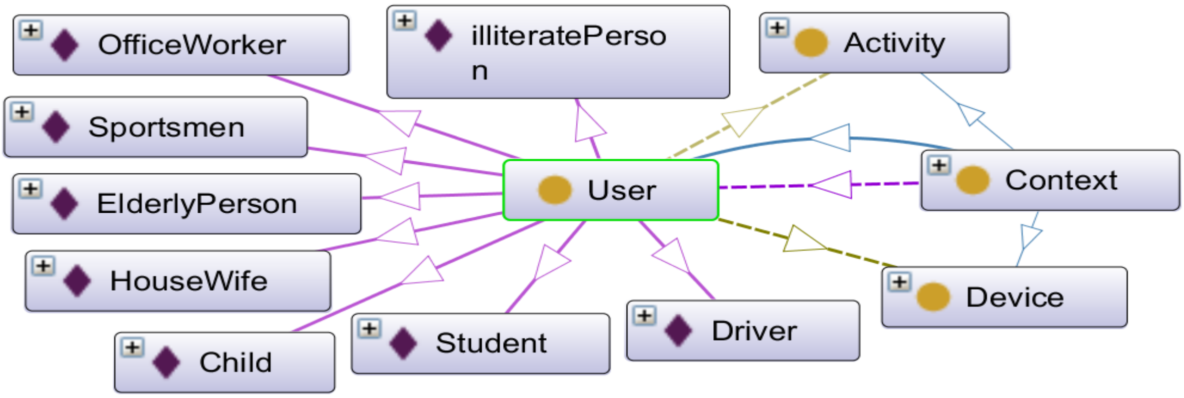


Figure 7.2: User taxonomy

user background as part of defined class. The properties are made by the requirements of example situation. Device: object property and Activity: information property are instances of the user properties. The examples for the situations incorporate Office Worker, Driver, Child and so on. Like some other philosophy these properties and classes may develop with new ideas for concerned context.

Environment Taxonomy: Environment taxonomy is portrayed in Figure 7.3 where condition properties give natural context as a feature of entire context class. The properties are made by the example situation necessities. Location: object property and Time: information properties are instances of the earth properties. The people for the situations incorporates Road Side, Gym, Morning and so on.

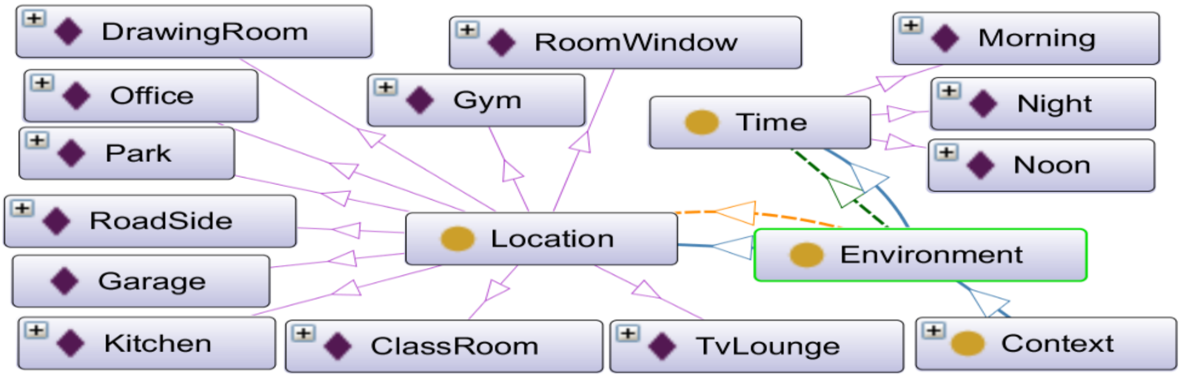


Figure 7.3: Environment taxonomy

Activity Taxonomy: Activity taxonomy provides the action situation as part of entire defined class which is appeared in Figure 7.4. The properties are made by the example situation prerequisites. Meeting: object property and Downloading Lecture Slides: information property are instances of the undertaking properties. The events for the situations incorporate Workout, Taking Selfie, Searching Nearest Hospital and so on.

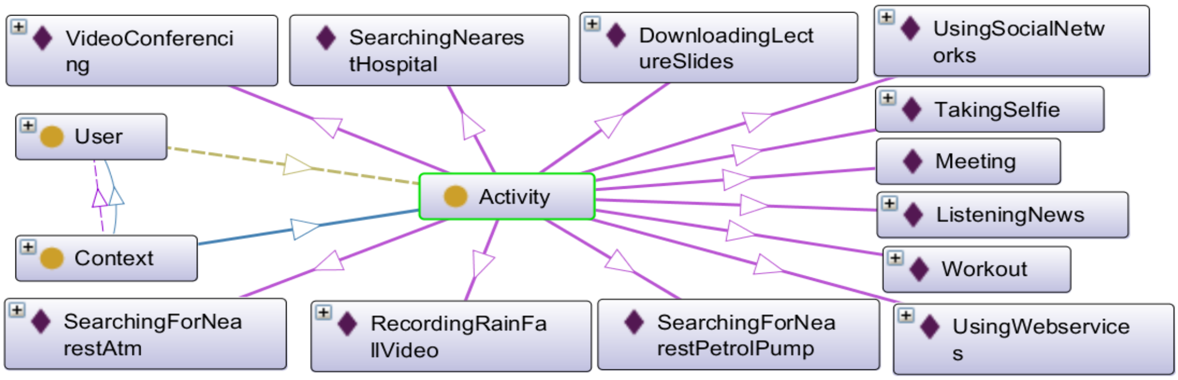


Figure 7.4: Activity taxonomy

7.7 Semantic Relations

The idea of semantic relations is appeared in Figure 7.5 where these relations are characterized by the client necessities of chosen situations. Here every idea has its semantic relations with the created taxonomy.

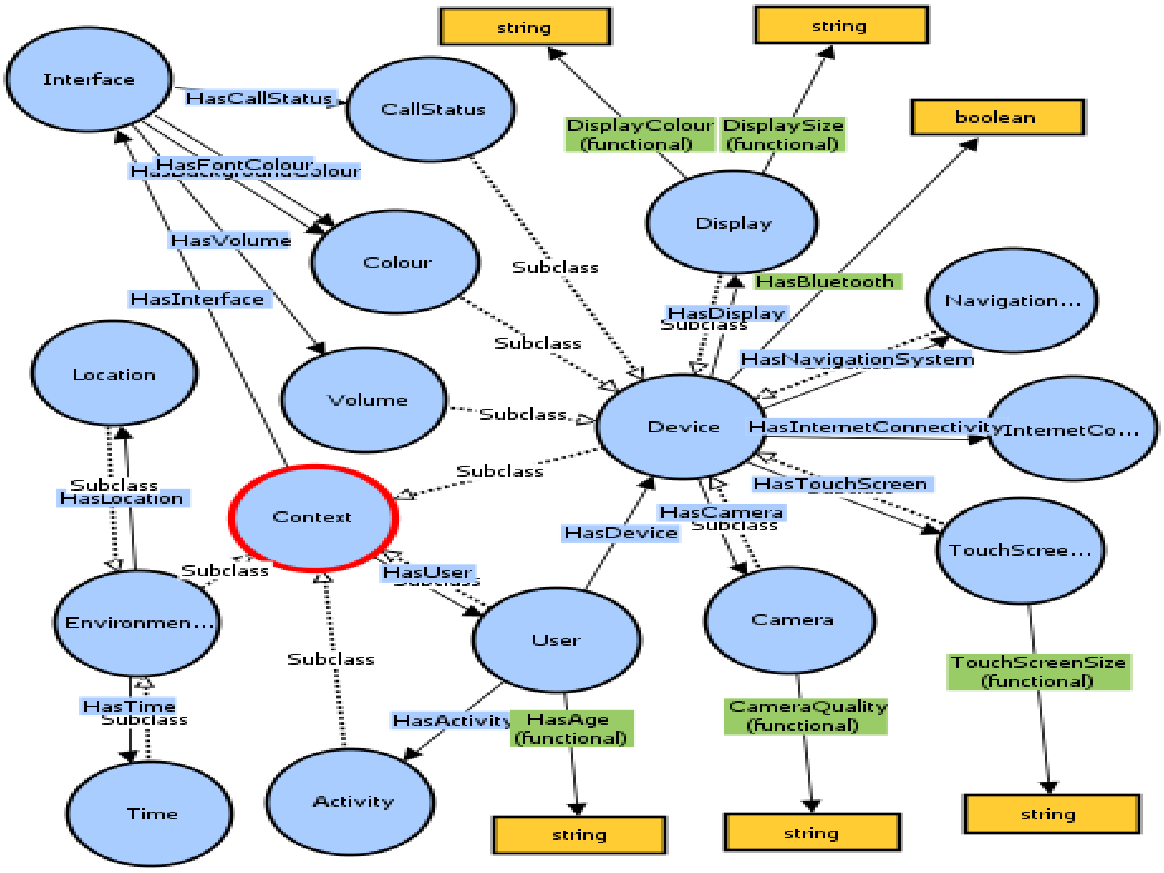


Figure 7.5: Semantic relations

7.8 Constraints of Scenarios

In Figure 7.6 the given situation demonstrates that child Has Location: Room Window, Has Activity: Recording Rain fall Video, Has Device: Mobile Phone, Has Time: Night and Has Age: 15 years. The characterized requirements are connected on several people permitting them to be in a connection with explicit scope of qualities. For instance, from the practiced situation, the individual child has essentials over the age, area and exercises. Constraints are demonstrated that Has Activity: Meeting, Workout, Searching Nearest Hospital, Kitchen, Using Web Services, Searching for Nearest Petrol Pump and Has Location: Office, Road Side, Garage, Gym.

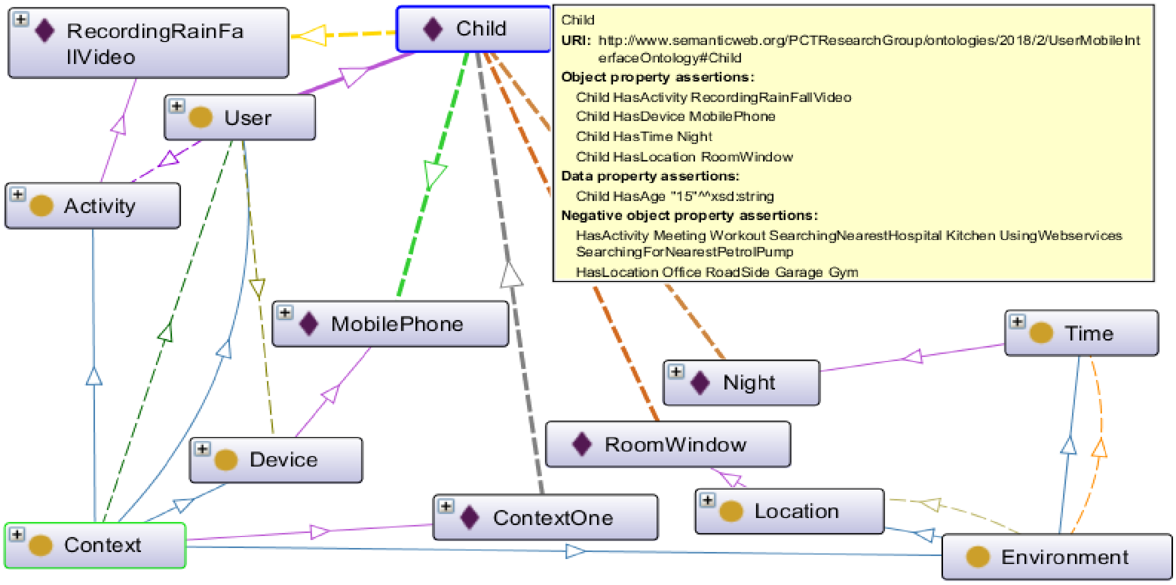


Figure 7.6: Child constraints scenario

The circumstances determine in Figure 7.7 that driver Has Location: Road Side, Has Activity: Searching for Nearest ATM, Has Device: Mobile Phone, Has Time: Morning and Has Age: 35 years. The defined constraints are applied on different individuals allowing them to be in a relation with specific range of values. As an example, from exercised scenario, driver has

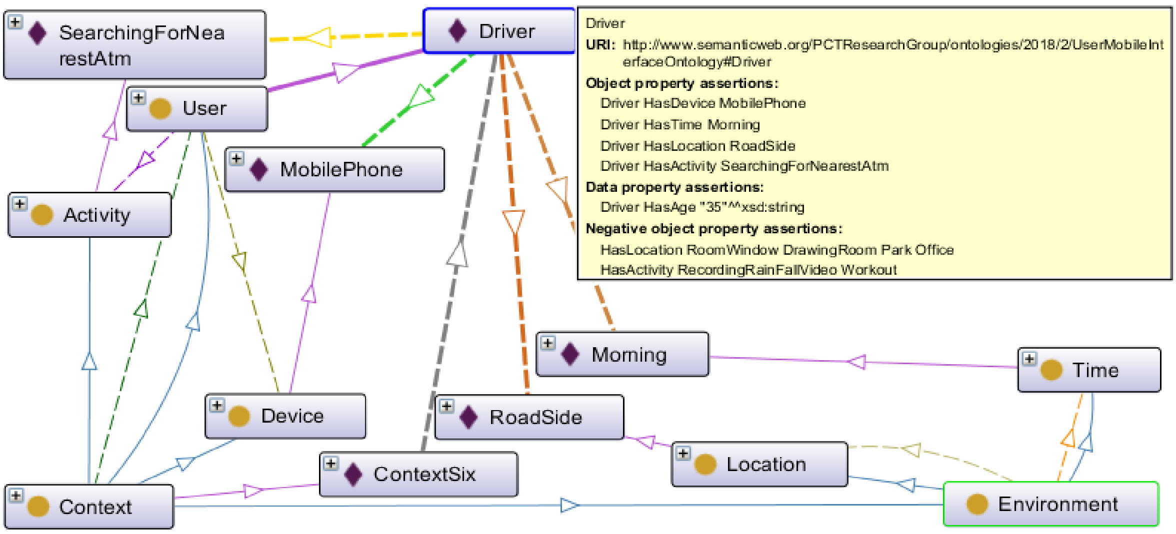


Figure 7.7: Driver constraints scenario

constraints over the age, location and activities. Constraints are shown that Has Activity: Recording Rain Fall Video, Workout and Has Location: room Window, Drawing Room, Park, Office.

The properties of elderly person are determined in Figure 7.8. It contains Has Location: Drawing Room, Has Activity: Using Social Networks, Has Device: Mobile Phone, Has Time: Night and Has Age: 40 years.

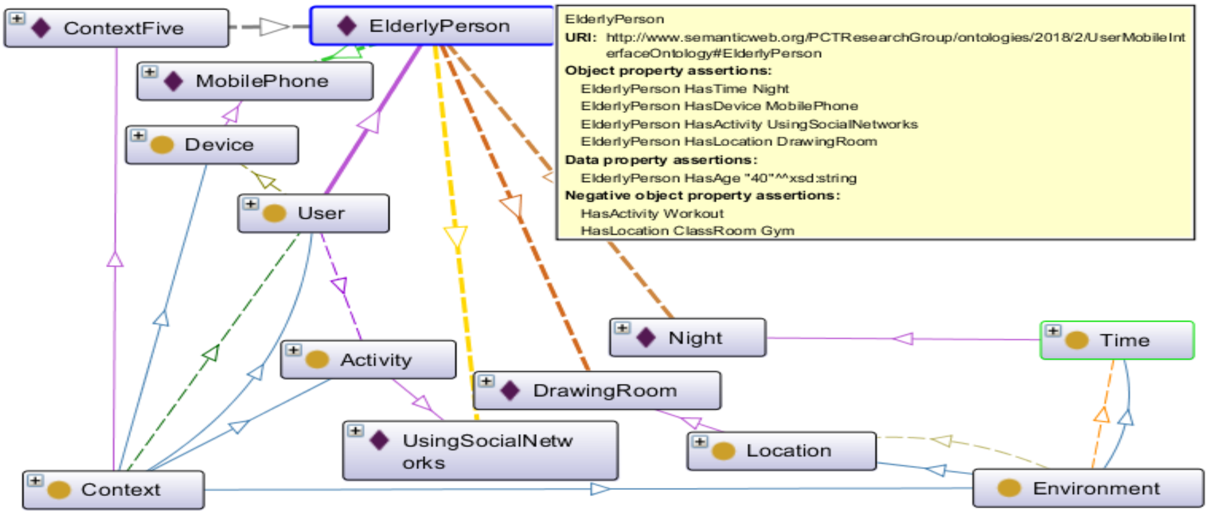


Figure 7.8: Elderly person constraints scenario

Every individual has different properties and constraints, so it can be applied on specific range of values. The work out scenario shows that elderly person has constraints over the age, location and activities. The constraints are shown that Has Activity: Workout and Has Location: Class Room, Gym.

The Illiterate Person comprises the properties in Figure 7.9 such as Has Location: TV Lounge, Has Activity: Listening News, Has Device: Mobile Phone, Has Time: Night and Has age: 30 years. The limitations are appeared in this situation that Illiterate Person Has Activity: Meeting and Has Location: Office.

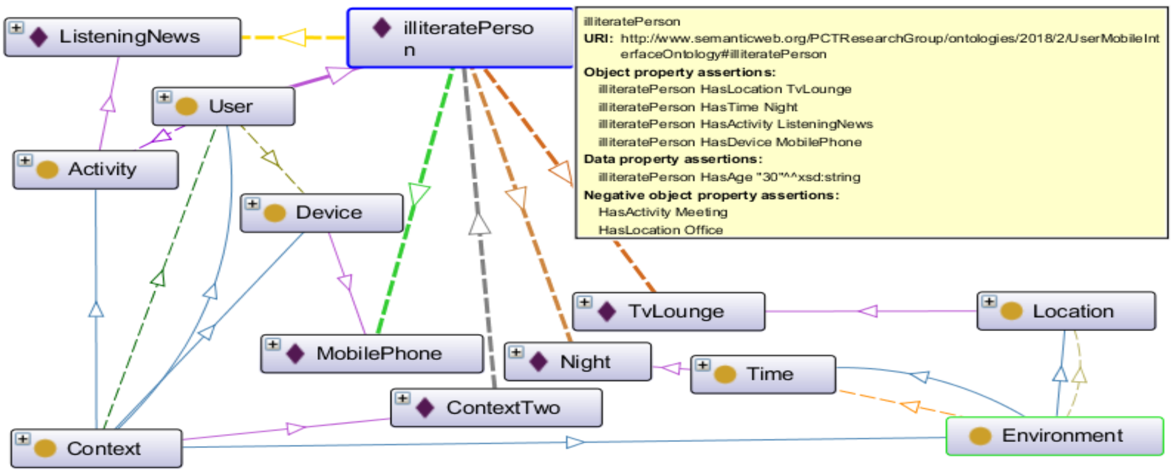


Figure 7.9: Illiterate person constraints scenario

7.9 Verification Through Reasoner

In particular, thinking over principles is monotonic where expansion of new bit of perception can't change previously deduced information. There is a solid connection between context demonstrating and thinking to deliver compelling and effective outcomes (Alirezaie et al., 2017). Be that as it may, the proposed ontological model is inferred for non-monotonic principles in which dynamic perception can be dealt with. The Pellet [http://pellet. owldl.com/] and HermiT [http://www. loner reasoner. com/] Reasoner used to confirm the principles, relations and imperatives to evade the irregularity between classes.

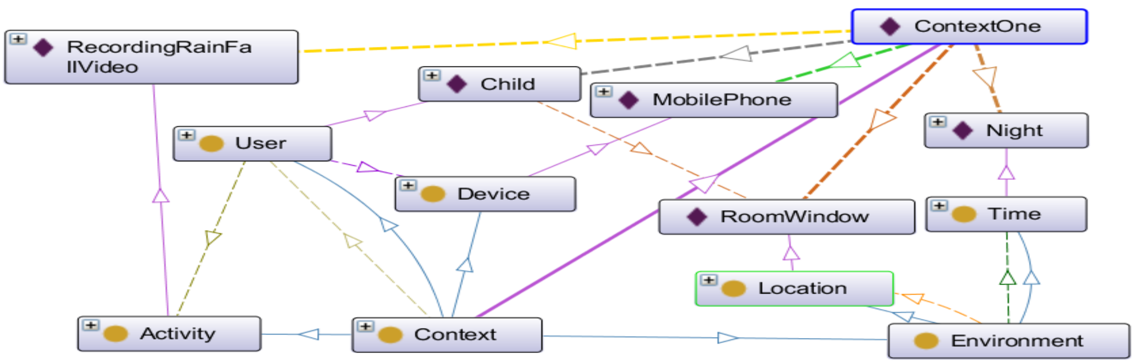
Context Knowledge Representation Through Ontology: The created context philosophy formally characterizes the use context. It gives reply to the principal competency question that requires a formal portrayal for the utilization context of keen gadgets. It comprises of the considerable number of classes and people for the given contexts. These classes and people incorporate Device, User, Environment and Activity properties that mirror the answer for CQ2 and sub-questions CQ2.1 to CQ2.4. This Ontology likewise safeguards the semantic relations and imperatives among characterized classes and occurrences. With the gave outcomes through consistency checking by the Reasoner, the appropriate reaction to the CQ3 is additionally guaranteed in created philosophy. Besides, the philosophy has been created and confirmed through SPARQL inquiry dialect. Ensuring the consistency of ontologies is an important part of ontology development and testing. Here, we launch a reasoner whether the ontology is logically consistent and codified in OWL. Further, whether the ontology is coherent with domain knowledge we check its formal structure (relationships, taxonomy, axioms etc). Then some test use cases are given to check the ability of goals fulfilment of ontologies.

The OWL DL and OWL2 are ontology dialects to catch the context of components of intrigue (e.g. people, occasions, exercises, areas) and their suitable relations by mapping the data to particular class properties (Meditskos et al., 2016). The RDF data in Web is characterized the sentence structure and semantics of the SPARQL inquiry dialect. SPARQL can be utilized to express inquiries crosswise over various information sources, discretionary diagram designs alongside their conjunctions and disjunctions. SPARQL likewise bolsters collection, sub-inquiries, nullification, making esteems by articulations, extensible esteem testing, and obliging questions by source RDF chart. The consequences of SPARQL questions can be result sets or RDF diagrams [https://www. w3. organization/TR/2013/REC-sparql11-question 20130321/]. The example sets of inquiries performed through SPARQL has been taken from the characterized semantic relations.

7.10 Context Querying Through SPARQL

Context has been characterized with their semantics through the given context of users. The Figures 7.10 to 7.16 demonstrated the SPARQL queries of characterized use case situations. The adaptive condition can alter the operations and can use parameters as indicated by the unique situations. Adaptivity manages mechanized procedures which require perusing the unique circumstances and choosing about the tasks of connection demonstrate. Generally, the calculation needs machine readable and processable components of situations. The SPARQL here have recovered the situation refinements that are required for the improvement of versatile interface. For example, AUI modify the cooperation style appropriately e.g. the portable interface of a driver, youngster or office labourer, area and so forth.

The question, in Figure 7.10 (a), represents the data about use case 1 one where "A child is recording rain fall video by using mobile phone through room window at night".



(a) Description using context ontology

SPARQL query:

```
PREFIX rdf: <http://www.w3.org/1999/02/22-rdf-syntax-ns#>
PREFIX owl: <http://www.w3.org/2002/07/owl#>
PREFIX rdfs: <http://www.w3.org/2000/01/rdf-schema#>
PREFIX xsd: <http://www.w3.org/2001/XMLSchema#>
SELECT DISTINCT *
WHERE {
 <http://www.semanticweb.org/PCTResearchGroup/ontologies/2018/2/UserMobileInterfaceOntology#Child> ?predicate ?object
}
```

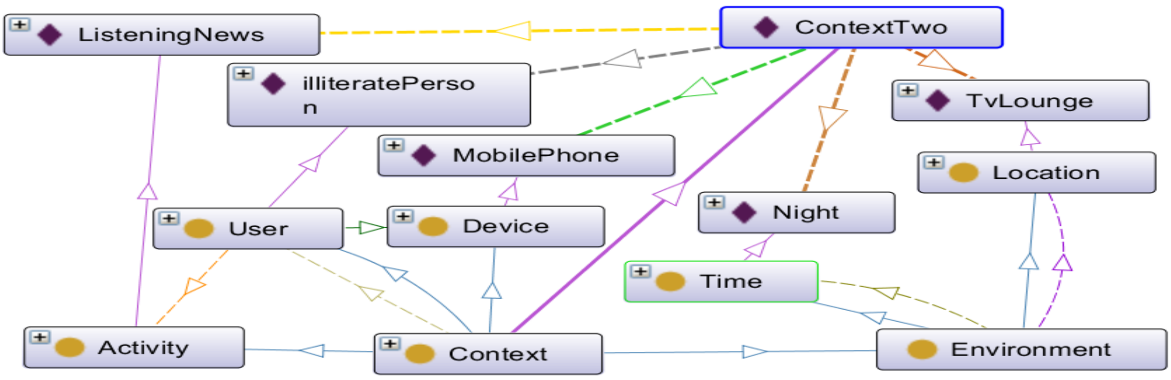
predicate	object
rdf:type	owl:NamedIndividual
HasAge	"15"^^<http://www.w3.org/2001/XMLSchema#string>
HasDevice	MobilePhone
rdf:type	User
HasActivity	RecordingRainFallVideo
HasTime	Night
HasLocation	RoomWindow

(b) Context extraction using SPARQL

Figure 7.10: Use case 1, definition & extraction

The Figure 7.10 (b) shows the extraction of context through SPARQL that child alongside the properties and articles give relations like he Has Location: Park, Has Device: Mobile Phone, Has Activity: Recording Rain Fall Video and Has Time: Night.

Use case 2 represent in Figure 7.11 (a) for the description of context ontology, "An illiterate person is listening news by using mobile phone in TV lounge at night".



(a) Description using context ontology

SPARQL query:

```
PREFIX rdf: <http://www.w3.org/1999/02/22-rdf-syntax-ns#>
PREFIX owl: <http://www.w3.org/2002/07/owl#>
PREFIX rdfs: <http://www.w3.org/2000/01/rdf-schema#>
PREFIX xsd: <http://www.w3.org/2001/XMLSchema#>
SELECT DISTINCT *
WHERE {<http://www.semanticweb.org/PCTResearchGroup/ontologies/2018/2/UserMobileInterfaceOntology#ContextTwo>
?predicate ?object
}
```

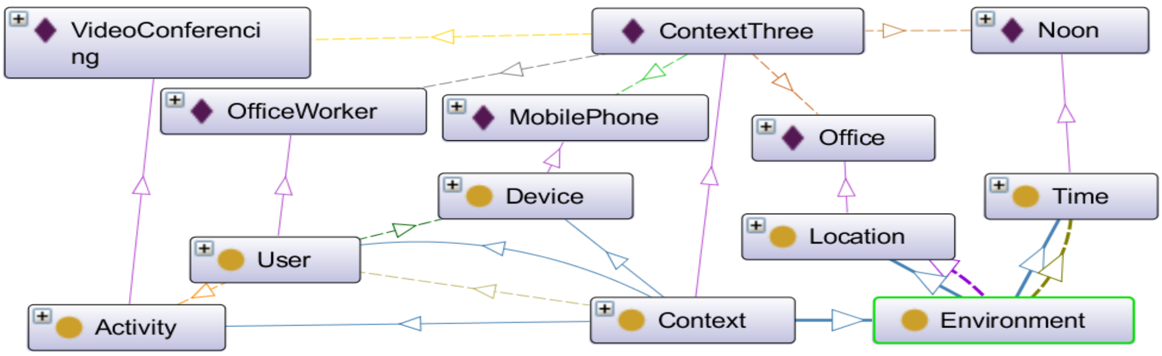
predicate	object
rdf:type	Context
rdf:type	owl:NamedIndividual
HasTime	Night
HasActivity	ListeningNews
HasLocation	TvLounge
HasDevice	MobilePhone
HasUser	illiteratePerson

(b) Context extraction using SPARQL

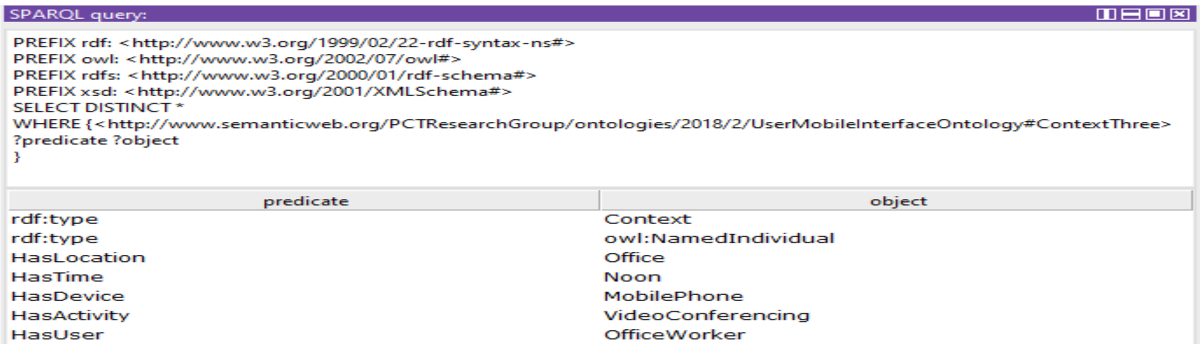
Figure 7.11: Use case 2, definition & extraction

Context extraction is shown in Figure 7.11 (b) by using SPARQL queries. The execution shows that the subject "Illiterate Person" combined with the properties and articles give relations such as the individual Has Location: TV Lounge, Has Device: Mobile Phone, Has Activity: Listening News and Has Time: Night.

The Figure 7.12 (a) demonstrates the consequences of interpretation for utilizing the situation in use case 3, where "An office worker is doing video conferencing on mobile phone in office at noon”.



(a) Description using context ontology


SPARQL query:

```
PREFIX rdf: <http://www.w3.org/1999/02/22-rdf-syntax-ns#>
PREFIX owl: <http://www.w3.org/2002/07/owl#>
PREFIX rdfs: <http://www.w3.org/2000/01/rdf-schema#>
PREFIX xsd: <http://www.w3.org/2001/XMLSchema#>
SELECT DISTINCT *
WHERE {<http://www.semanticweb.org/PCTResearchGroup/ontologies/2018/2/UserMobileInterfaceOntology#ContextThree>
?predicate ?object
}
```

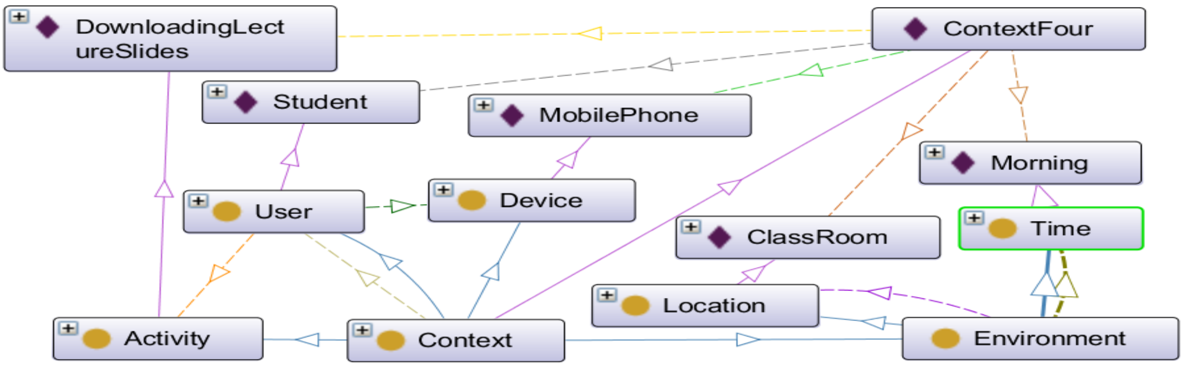
predicate	object
rdf:type	Context
rdf:type	owl:NamedIndividual
HasLocation	Office
HasTime	Noon
HasDevice	MobilePhone
HasActivity	VideoConferencing
HasUser	OfficeWorker

(b) Context extraction using SPARQL

Figure 7.12: Use case 3, definition & extraction

The outcome traversing given question demonstrates in Figure 7.12 (b) that the subject "Office Worker" alongside the properties and articles give relations like he Has Location: Office, Has Device: Mobile Phone, Has Activity: Video Conferencing and Has Time: Noon.

The question given in Figure 7.13 (a) concentrates the data about use case situation 4, where "A student is downloading lecture slides through mobile phone at class room in morning".



(a) Description using context ontology

```
SPARQL query:
PREFIX rdf: <http://www.w3.org/1999/02/22-rdf-syntax-ns#>
PREFIX owl: <http://www.w3.org/2002/07/owl#>
PREFIX rdfs: <http://www.w3.org/2000/01/rdf-schema#>
PREFIX xsd: <http://www.w3.org/2001/XMLSchema#>
SELECT DISTINCT *
WHERE {<http://www.semanticweb.org/PCTResearchGroup/ontologies/2018/2/UserMobileInterfaceOntology#ContextFour>
?predicate ?object
}
```

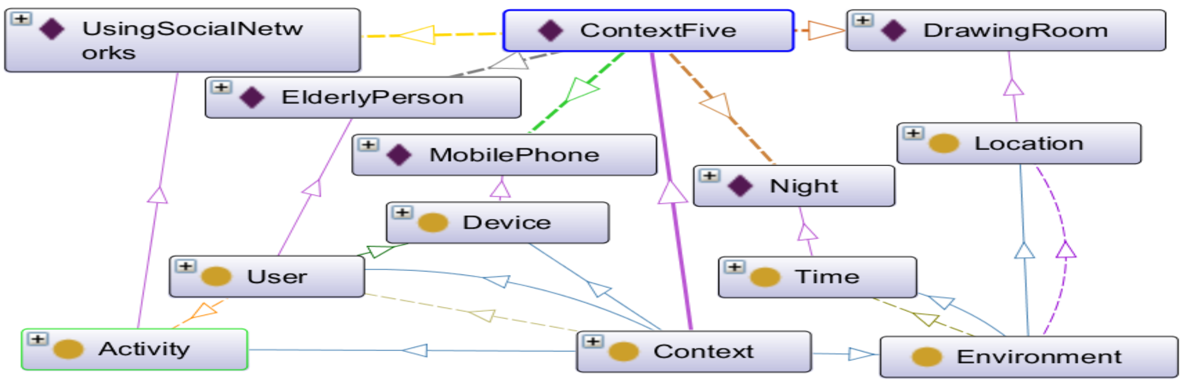
predicate	object
HasTime	Morning
rdf:type	owl:NamedIndividual
HasActivity	DownloadingLectureSlides
HasDevice	MobilePhone
HasLocation	ClassRoom
HasUser	Student
rdf:type	Context

(b) Context extraction using SPARQL

Figure 7.13: Use case 4, definition & extraction

The result of above use case demonstrates in Figure 7.13 (b) that the subject "Student" along with the properties and items give relations like he Has Location: Class Room, Has Device: Mobile Phone, Has Activity: Downloading Lecture Slides and Has Time: Morning.

"An elderly person is using social networks on mobile phone in drawing room at night" for use case 5 in Figure 7.14 (a).



(a) Description using context ontology

SPARQL query:

```
PREFIX rdf: <http://www.w3.org/1999/02/22-rdf-syntax-ns#>
PREFIX owl: <http://www.w3.org/2002/07/owl#>
PREFIX rdfs: <http://www.w3.org/2000/01/rdf-schema#>
PREFIX xsd: <http://www.w3.org/2001/XMLSchema#>
SELECT DISTINCT *
WHERE {<http://www.semanticweb.org/PCTResearchGroup/ontologies/2018/2/UserMobileInterfaceOntology#ContextFive>
?predicate ?object
}
```

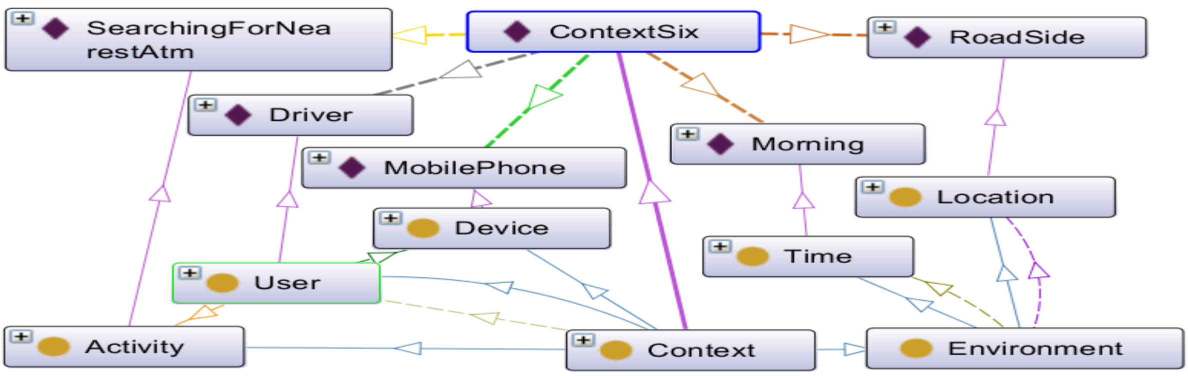
predicate	object
rdf:type	owl:NamedIndividual
HasActivity	UsingSocialNetworks
HasUser	ElderlyPerson
HasTime	Night
HasLocation	DrawingRoom
rdf:type	Context
HasDevice	MobilePhone

(b) Context extraction using SPARQL

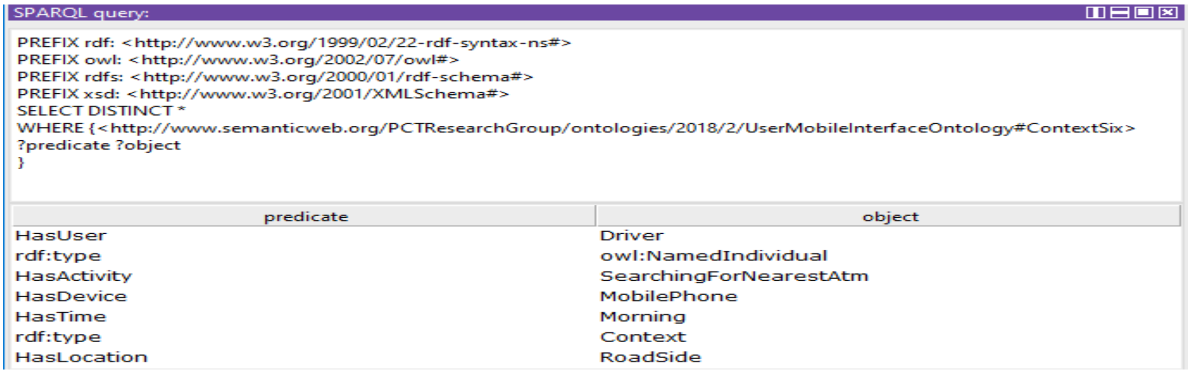
Figure 7.14: Use case 5, definition & extraction

The inquiry given in above figure demonstrates the outcome that the subject "Elderly Person" has properties and objects that provide relations like Has Location: Drawing Room, Has Device: Mobile Phone, Has Activity: Using Social Networks and Has Time: Night presented in Figure 7.14 (b).

"A driver is searching for nearest ATM on mobile phone at road side in morning" speaking to utilize the use case 6. The inquiry given in Figure 7.15 (a) demonstrates the context extraction using SPARQL for the subject "Driver" alongside the properties and items give relations such as Has Location: Road Side, Has Device: Mobile Phone, Has Activity: Searching for Nearest ATM and Has Time: Morning.



(a) Description using context ontology



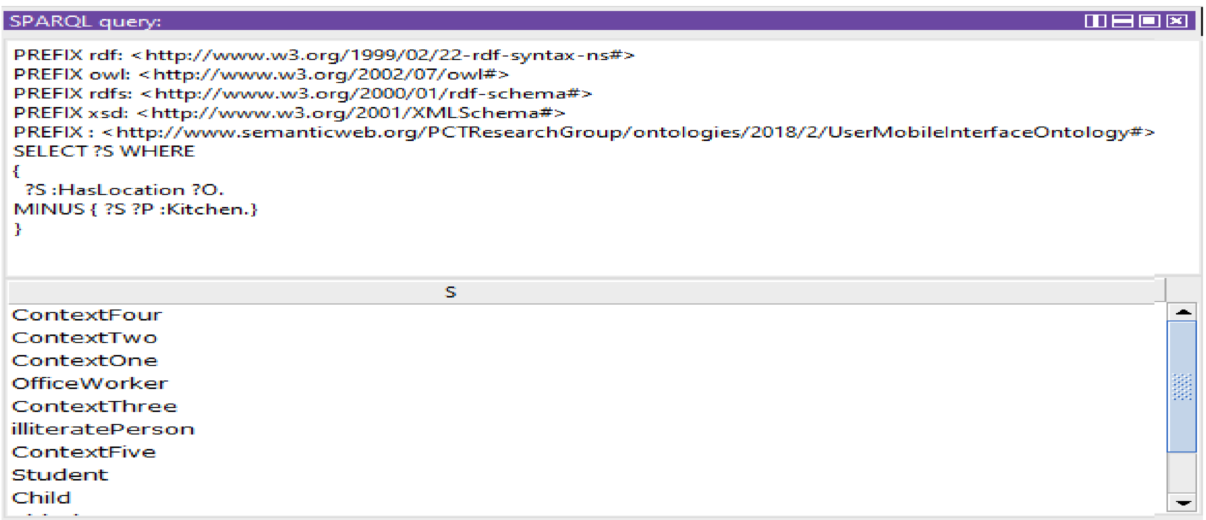
(b) Context extraction using SPARQL

Figure 7.15: Use case 6, definition & extraction

Users context explained the refinements formally to encourage AUIs to characterize client collaboration modes and styles as needs be. Determination of communication should be possible powerfully, for example, in the event that it recognizes the utilization use case 6 in Figure 7.15 (b) circumstance, the device may go to quiet mode or any specific contexts for the unique situation.

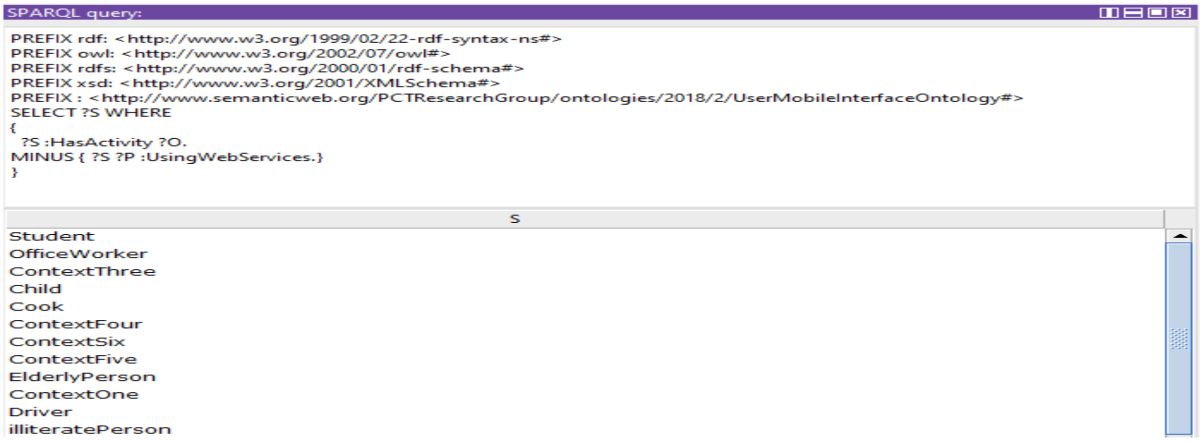
7.11 Constraint Extraction Through SPARQL

The Figure 7.16 (a) shows the users who are not in specific location according to the studied use cases. The all retrieved subjects (OWL:Individuals) through SPARQL query cannot retrieved in this scenario because of constraints applied on subjects. We have taken a specific scenario cook from use case six which has location kitchen. The query executed and validate the results of subjects (Officeworker, Illiterateperson, Student, Child) which has constraints that they do not have location kitchen.



(a) Constraint extraction for location

The Figure 7.16 (b) shows the users who are not in specific activity according to the studied use cases. The query executed and validate the results according to ContextTwo which has constraints that they do not have activity.



(b) Constraint extraction for activity

Figure 7.16: Constraint extraction through SPARQL

7.12 Mobile Usage Context Model

As of now, there are a huge number of smart phone users accessible all around because of the quick adjustment of adaptive processing. Unreasonable ease of use of smart phones has massive information of user inclinations. User profiles, contexts, circumstances and depiction of semantics give the premise to an interest driven customized data and administration co-ordinations. Every one of these portrayals depend on various levelled set of properties that describe a substance, instantiated as user profiles, circumstance profiles and administration profiles. Sensors accumulate context estimations of all users naturally and at whatever point a user altogether changes his or her unique circumstance, the (new) circumstance is determined powerfully by the induction motor. At last, the administration coordinating gives all appropriate context qualities to the user's circumstance and profile, gathered into classifications. This refresh the real arrangement of suggested administrations at the user’s PDA. The majority of this is finished utilizing semantic principles characterized based on various classes e. g. gadget, user, undertaking and condition.

7.13 Summary

Currently, many mobile devices provide various interaction styles and modes which create complexity in the usage of interfaces. The context offers the information base for the development of AUI frameworks to overcome the heterogeneity. For this purpose, the ontological modelling has been made for specific context and environment. This type of philosophy states to the relationship among elements (e.g. classes, relations, or capacities etc) with understandable satisfied representation.

The context mechanisms can be examined and understood by any machine or computational framework with these formal definitions expressed in OWL/RDFs. The Protégé is used to create taxonomy in which system is framed based on four contexts such as user, device, task and environment. Some competency questions and use-cases are utilized for knowledge obtaining while the information is refined through the instances of concerned parts of context tree. The consistency of the model has been verified through the reasoning software while SPARQL querying ensured the data availability in the models for defined use-cases. The semantic context model is focused to bring in the usage of adaptive environment. This exploration has finished up with a versatile, scalable and semantically verified context learning system. This model can be mapped to individual UI display through smart calculations for versatile UIs.

In next chapter, Adaptive Interface Ontology (AIO) is defined which enables all the interfaces to change its behaviour according to the user needs. It deals with the interface features that has to be presented such as adjustable display voice, interaction styles, sound levels, brightness and colour levels etc. The subsequent context knowledge can be stored for interface style selection of similar contexts through context-aware frameworks.

Chapter 8. CONTEXT AND INTERFACE MAPPING

AUIs are known for more than a decade for providing context fitting interfaces for mobile devices. It is desirable that interfaces may adapt their behavior when circumstances change rapidly according to context. The context can be read through the ontological model presented in previous chapter. This chapter provides the interface modeling over studied context as a subsequent ontology, Adaptive Interface Ontology (AIO). In the third phase of this research plan, AIO is developed through the standard ontology engineering incorporating UCO instances. The interface model, presented through AIO, merges the context knowledge and depicts the reflective interface through context to interface mapping knowledge.

8.1 Adaptive Interface Context Modelling

This chapter of dissertation discusses the methods to inculcate the user context to adaptive interface development. It includes the mapping of user context ontology to interface ontology resulting in a merged adaptive interface ontology. As per requirements of UCD process model the UCO specifies the user context, mapping functions provide the impact of user context on interface development and the resultant product is tested against the user requirements. The complete ontology engineering process for adaptive interface ontology is followed here. To conclude the research, complete path proposed in research methodology is verified and an enhanced UCD model is presented. The UCD model is enhanced by providing further depth in terms of context specification, adaptive interface modelling and verification using ontologies.

8.2 Ontology Driven User Centered Design

After the need analysis, user context study is the second phase in UCD. The proposed model here used ontological modelling for user context specification.

8.2.1 User Context Ontology (UCO)

Previous chapter has provided complete ontology engineering process, verification through logical reasoners and testing according to user requirements. The user context ontology provides a base classes and semantic relational structure for instantiation of any mobile usage context. The plea here is to read and formally describe the usage context containing relevant details about user, environment, device and task. Adaptation of a UI style is dependent on the context knowledge presented by the UCO.

8.2.2 Adaptive Interface Ontology (AIO)

The adaptive interface development is modelled and verified by AIO that merges UCO with adaptive interface elements. It takes context as input and prescribe adaptive interface model using semantic relations over provided mapping functions. These mapping functions are executed over the context instances and available device interface elements. These mapping functions are built against the provided user requirements stating the specific interface style for a specific context.

8.2.3 User Context Ontology Mapping to Adaptive Interface

Rendering the previous use cases described in UCO engineering process for different context, respective interfaces styles are followed. In this research, the functions are made on individual context and corresponding interface style basis. In future the usage context can be categorised (based on combination of different dimension like user, task, environment and device) mapped to interface styles according to the respective categories.

8.3 Adaptive Interface Ontology Engineering

The adaptive interface ontology has been engineered considering its integrated existence with user context ontology. The aim of the engineering process is to design and develop device interface model well connected with the interaction context.

8.3.1 Competency Questions

The competency questions to design ontology focuses on AUI modelling based on the context read through user context ontology. The questions are listed as follows:

CQ1: How usage of context can be associated with the Interface Elements?

CQ2: How context properties effect the mobile interface?

CQ3: How mobile interface model can be affected by its usage context?

8.3.2 Defining Context and Interface Parameters

Sample use cases for model verification are shown in following tables (Table 8.1 to 8.6). The different contexts and their interface parameters are defined according to user requirements. Table 8.1 presents the context of use case 1: “A child is recording rain fall video by using mobile phone in the room window at night”. It shows the context of user “Child” where it comprises that Has Time: Night, Has Device: Mobile Phone, Has Interface:

Interface One, Has Activity: Reading Rain Fall Video and Has Location: Room Window. According to context the behaviour of interface is mapped on the parameters such as Flashlight: On, Mobile Data: On, Camera: On, Wifi: On, Brightness: medium and Background Image: Image 1.

Table 8.1: Use case 1, mapping table

Context			Interface	
Has Time	Night		Flashlight	On
Has Device	Mobile Phone		Mobile Data	On
Has Interface	Interface One		Camera	On
Has Activity	Recording Rain Fall Video		Brightness	Medium
Has Location	Room Window		Background Image	Image 1
Has User	Child		Wifi	On

"Use case 2 is defined for Interface Two as "An illiterate person is listening news by using mobile phone in TV lounge at night" in Table 8.2. The context of user "Illiterate Person" is given and the mapping values set the behaviour of interface as per desires.

Table 8.2: Use case 2, mapping table

Context			Interface	
Has Time	Night		Wifi	On
Has Device	Mobile Phone		Vibration	On
Has Interface	Interface Two		Mobile Data	On
Has Activity	Listening News		Brightness	Medium
Has Location	TV Lounge		Volume	10
Has User	Illiterate Person		------------	---------

An office worker is doing video conferencing on mobile phone in office at noon" is a specified use case 3 shown in Table 8.3. It shows the context for user "Office Worker" where it includes specific context which mapped the values at Interface Three.

Table 8.3: Use case 3, mapping table

Context			Interface	
Has Time	Noon		Flashlight	On
Has Device	Mobile Phone		Message Status	On
Has Interface	Interface Three		Brightness	Low
Has Activity	Video Conferencing		Bluetooth	On
Has Location	Office		Wifi	On
Has User	Office Worker		Call Status	On
--------	---------		Volume	10

The mapping Table 8.4 is plotted the instances selected by the context for user "Student" in use case 4 "A student is downloading lecture slides through mobile phone at class room in morning". The Interface Four is drawn according to user's preferences such as Font Size: 14, Volume: 05, Wifi: On, Mobile Data: On and Brightness: Medium.

Table 8.4: Use case 4, mapping table

Context			Interface	
Has Time	Morning		Font Size	14
Has Device	Mobile Phone		Volume	05
Has Interface	Interface Four		Wifi	On
Has Activity	Downloading Lecture Slides		Mobile Data	On
Has Location	Class Room		Brightness	Medium
Has User	Student		---------	---------

"Elderly Person" is a user in use case 5 "An elderly person is using social networks on mobile phone in drawing room at night". The context is defined to perform the interface mapping interpretation to user's mental model in Table 8.5.

Table 8.5: Use case 5, mapping table

Context			Interface	
Has Time	Night		Message Status	Auto Generated
Has Device	Mobile Phone		Mobile Data	On
Has Interface	Interface Five		Volume	10
Has Activity	Using Social Networks		Bluetooth	On
Has Location	Drawing Room		Wifi	On
Has User	Elderly Person		Call Status	On

The use case 6 "A driver is searching for nearest ATM on mobile phone at road side in morning" presents in Table 8.6. It shows the context that Has User: Driver, Has Time: Night, Has Device: Mobile Phone, Has Interface: Interface Six, Has Activity: Searching for Nearest ATM and Has Location: Roadside.

Table 8.6: Use case 6, mapping table

Context			Interface	
Has Time	Night		Message Status	On
Has Device	Mobile Phone		Wifi	On
Has Interface	Interface Six		Brightness	High
Has Activity	Searching for Nearest ATM		Bluetooth	On
Has Location	Roadside		Volume	10
Has User	Driver		Mobile Data	On
			Call Status	On

8.3.3 Taxonomy

The interface taxonomy is described in Figure 8.1 where condition properties give ordinary contexts as a feature of entire context class. The properties are made by the example situation necessities. For example, interface one generated against context one which has medium brightness etc. Similarly, other interfaces are recognised according to their given context elements.

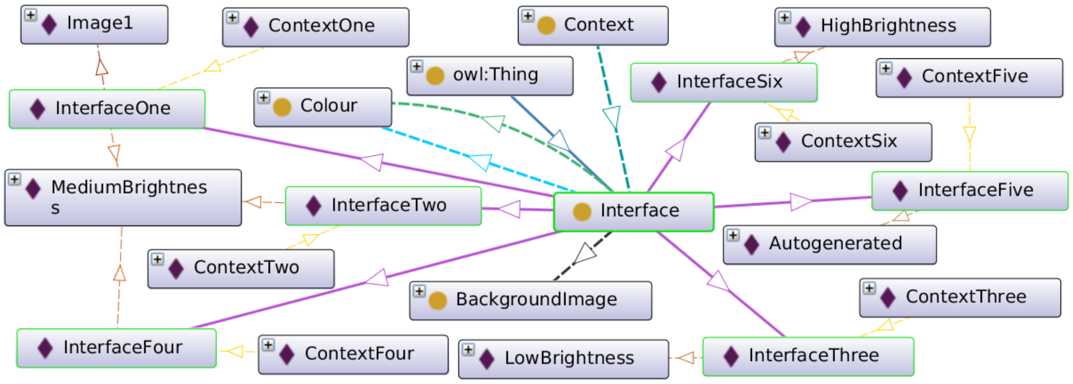


Figure 8.1: Adaptive interface taxonomy

8.3.4 Semantic Relations

The Figure 8.2 demonstrations the concept of adaptive interface ontology semantic relations. It characterized the relations according to user's preferences for specified context. Semantic relations show the properties, classes, subclasses and functions for device contextual interface. Here every idea has its semantic relations with the created taxonomy.

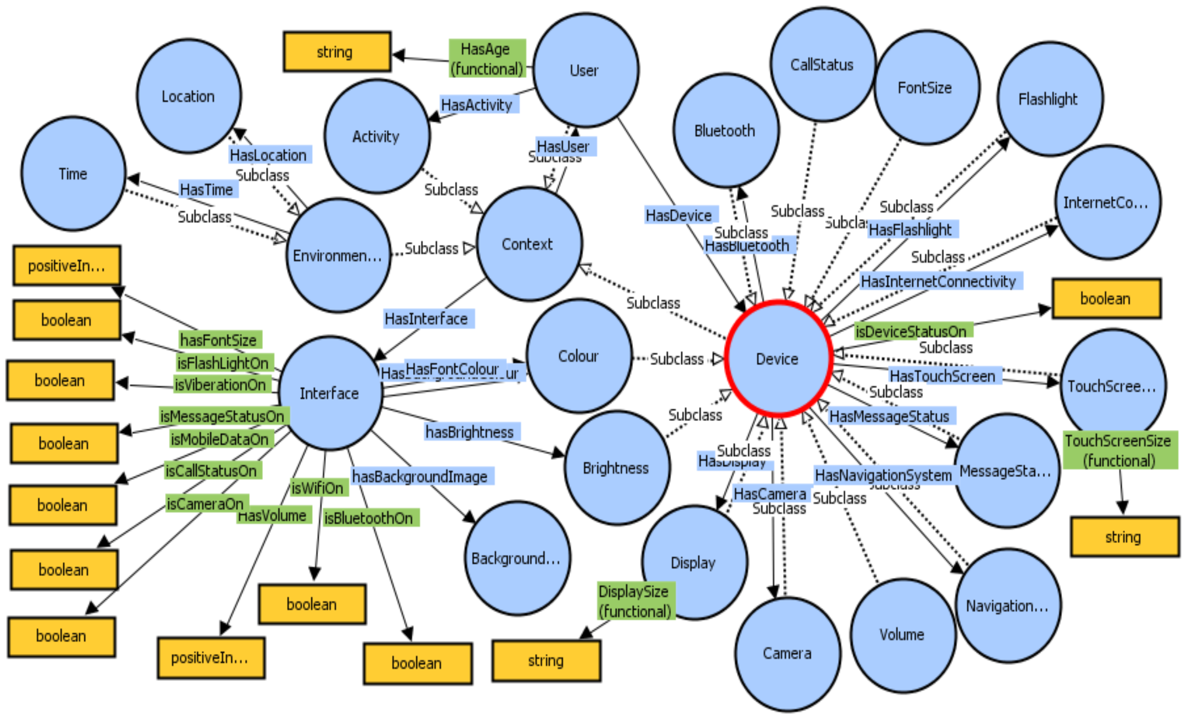


Figure 8.2: Adaptive interface ontology semantic relations

8.3.5 Constraints

In Figure 8.3 the given situation determines that "Interface One" for "Context One" contains object properties Has Background image: Image 1 and Has Brightness: Medium.

The interface data properties are defined as is Flash light On: true, is Mobile Data On: false, is Camera On: true and is Wifi On: true. The characterized requirements are connected on several users allowing them to be in association with obvious choice of qualities. The constraints are demonstrated that "is Wifi On: false, is Flashlight On: false and is Camera On: false".

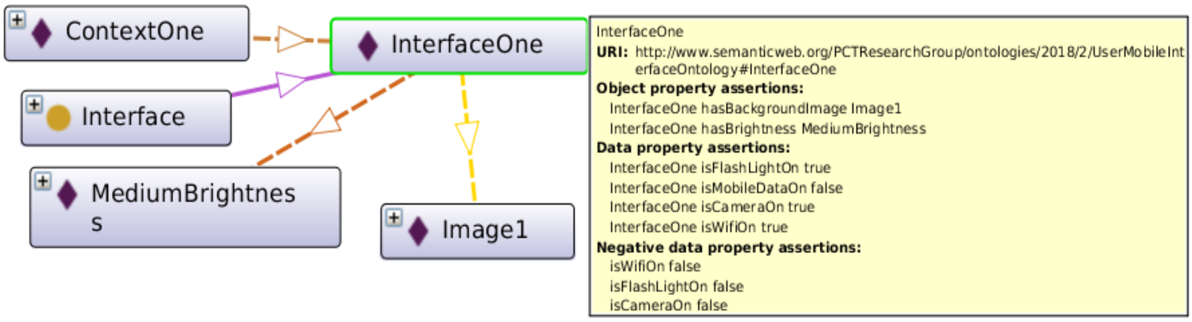


Figure 8.3: Interface one constraints

The constraints, "is Wifi On: false and is Flash Light On: false" for "Interface Two" of "Context Two" are shown in Figure 8.4.

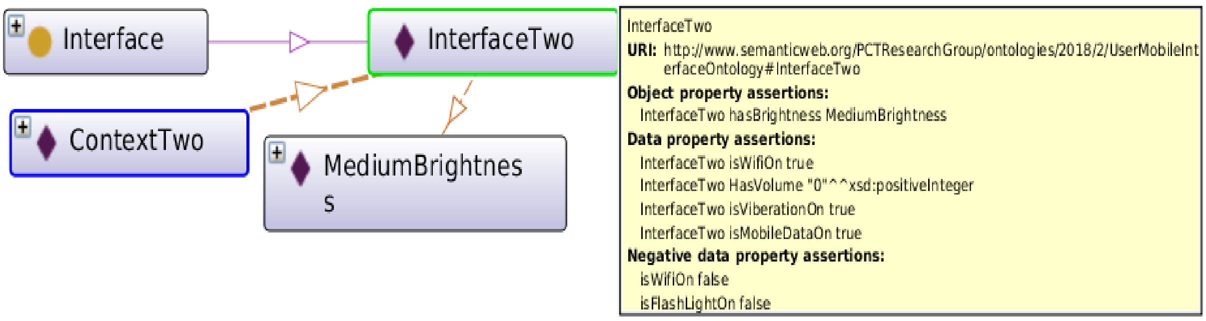


Figure 8.4: Interface two constraints

The Figure 8.5 shows the constraints for interface three, "is Flash light On: true, is Wifi On: false, is Message Status On: true and is Call Status On: true".

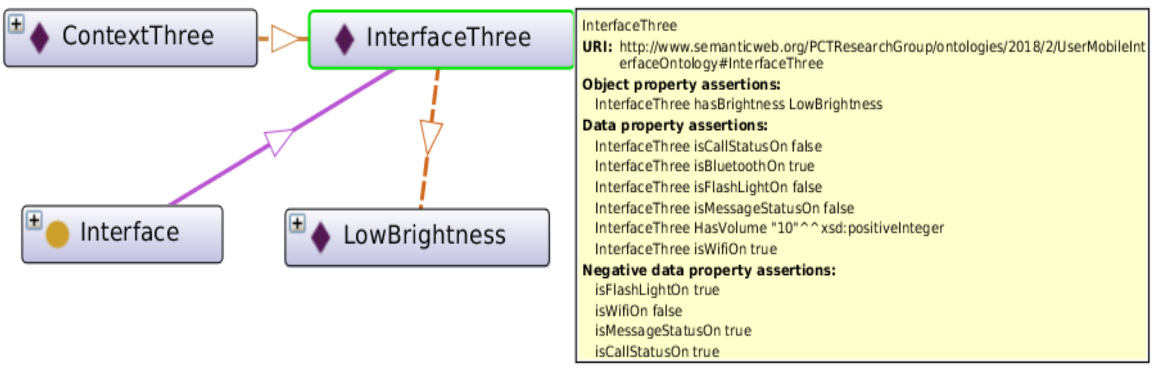


Figure 8.5: Interface three constraints

The Figure 8.6 shows object, data and negative properties for interface four in context four. The constraints for data properties in specified context are, “is Flash light On: false, is Message Status On: false and object property is Has Flashlight: On”.

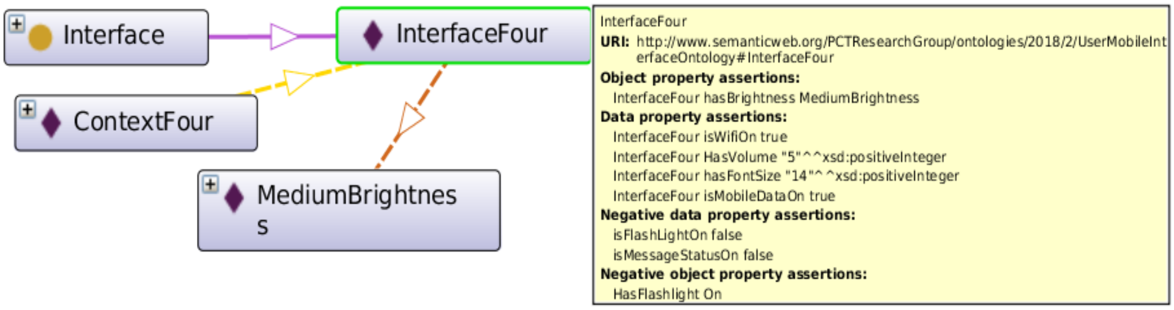


Figure 8.6: Interface four constraints

The constraints for interface five of stated context are described in Figure 8.7. The constraints for data properties are, “is Flash light On: false, is Camera On: false” and object properties are “Has Message Status: Off, Has Bluetooth: On and Has Camera: On”.

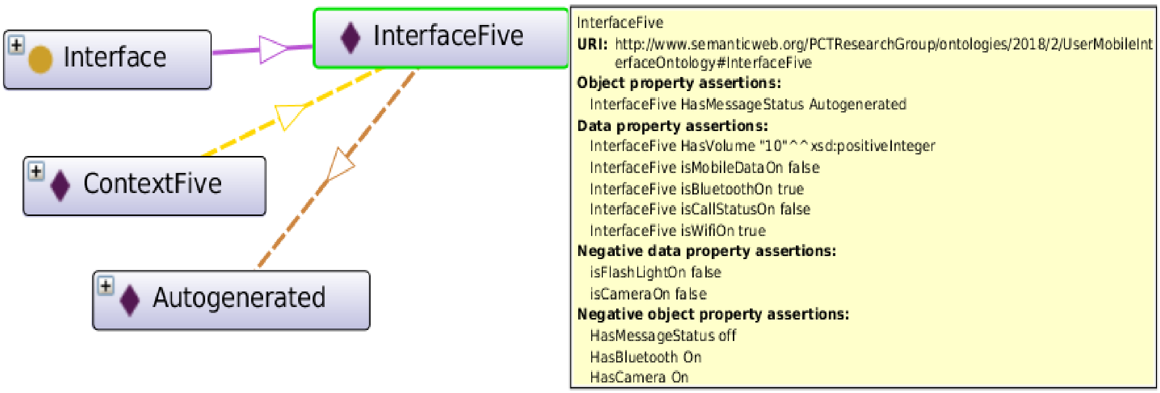


Figure 8.7: Interface five constraints

The Figure 8.8 shows the object, data and negative properties for interface six of context

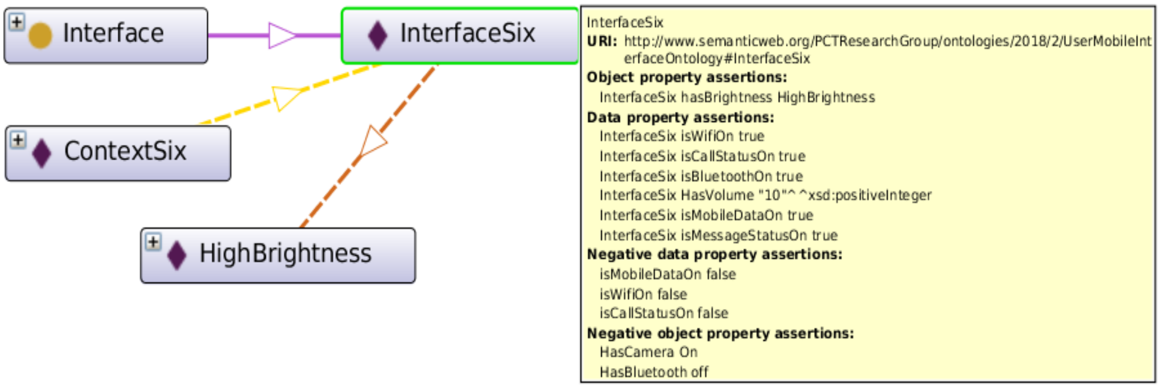


Figure 8.8: Interface six constraints

six. The constraints for data properties in specified context are, "is Mobile Data On: false, is Wifi On: false, is Call Status On: false" and object property constraints are "Has Camera: On and Has Bluetooth: Off".

8.4 Model Verification

The ontological model of AUI is verified over its logical presentation and knowledge representation in specified interface cases.

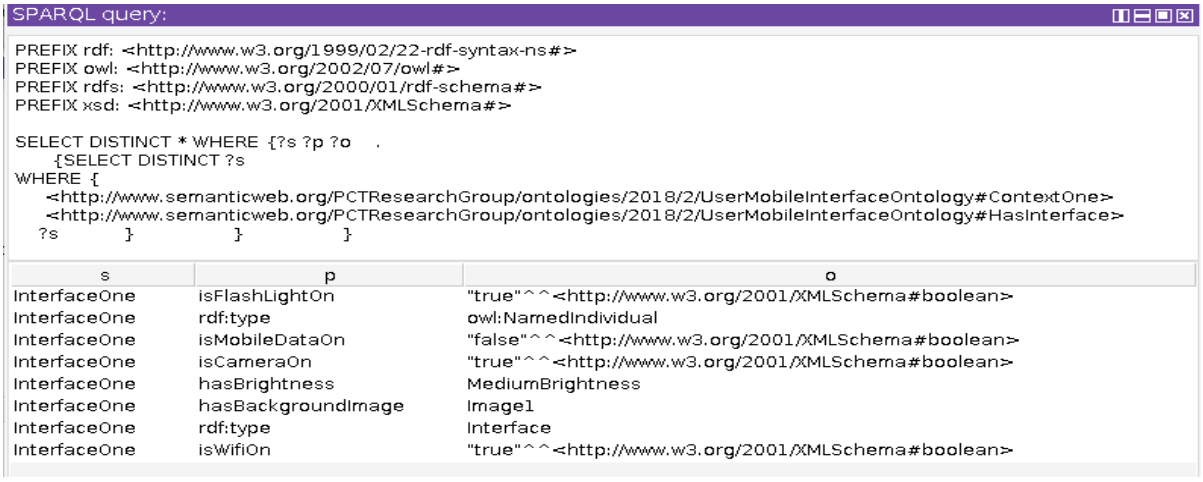
8.4.1 Logical Verification Through Reasoner

Hermit and Pellet reasoning tools were used to verify the ontological model as well as defined instances. The reasoning tools verify the consistency of semantic relations and constraints of base classes and their individuals.

8.4.2 Experimentation Using SPARQL Queries

The SPARQL querying is used to verify the storage and retrieval of interface knowledge associated with the context. The context is passed to knowledgebase as querying argument and respective interface details are inquired.

The Figure 8.9 presents the query for the interface details extraction respective to context one. The context and associated interface are defined according to user requirements in UC-1 scenario presented in Table 8.1. The query provided interface model detailing all the properties need to be set for specified context. These details of properties include "is Flash Light" with value "on", interface "brightness" is "Medium".



SPARQL query:

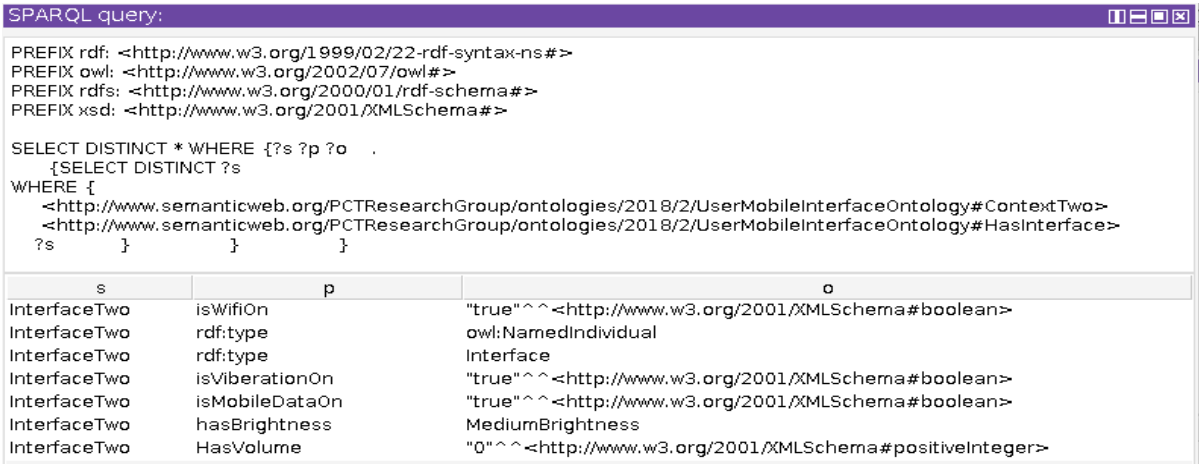
```
PREFIX rdf: <http://www.w3.org/1999/02/22-rdf-syntax-ns#>
PREFIX owl: <http://www.w3.org/2002/07/owl#>
PREFIX rdfs: <http://www.w3.org/2000/01/rdf-schema#>
PREFIX xsd: <http://www.w3.org/2001/XMLSchema#>

SELECT DISTINCT * WHERE {?s ?p ?o   .
    {SELECT DISTINCT ?s
WHERE {
   <http://www.semanticweb.org/PCTResearchGroup/ontologies/2018/2/UserMobileInterfaceOntology#ContextOne>
   <http://www.semanticweb.org/PCTResearchGroup/ontologies/2018/2/UserMobileInterfaceOntology#HasInterface>
  ?s        }           }           }
```

s	p	o
InterfaceOne	isFlashLightOn	"true"^^<http://www.w3.org/2001/XMLSchema#boolean>
InterfaceOne	rdf:type	owl:NamedIndividual
InterfaceOne	isMobileDataOn	"false"^^<http://www.w3.org/2001/XMLSchema#boolean>
InterfaceOne	isCameraOn	"true"^^<http://www.w3.org/2001/XMLSchema#boolean>
InterfaceOne	hasBrightness	MediumBrightness
InterfaceOne	hasBackgroundImage	Image1
InterfaceOne	rdf:type	Interface
InterfaceOne	isWifiOn	"true"^^<http://www.w3.org/2001/XMLSchema#boolean>

Figure 8.9: Extracting interface using SPARQL query for context one

Extraction interface using SPARQL query for context two is displayed in Figure 8.10. The context and associated interface are defined according to user requirements in UC-2 scenario presented in Table 8.2. The query provided interface model detailing all the properties need to be set for specified context. These details of properties include “is Vibration” with value “on” and Volume is “0”.



SPARQL query:

```
PREFIX rdf: <http://www.w3.org/1999/02/22-rdf-syntax-ns#>
PREFIX owl: <http://www.w3.org/2002/07/owl#>
PREFIX rdfs: <http://www.w3.org/2000/01/rdf-schema#>
PREFIX xsd: <http://www.w3.org/2001/XMLSchema#>

SELECT DISTINCT * WHERE {?s ?p ?o   .
    {SELECT DISTINCT ?s
WHERE {
   <http://www.semanticweb.org/PCTResearchGroup/ontologies/2018/2/UserMobileInterfaceOntology#ContextTwo>
   <http://www.semanticweb.org/PCTResearchGroup/ontologies/2018/2/UserMobileInterfaceOntology#HasInterface>
  ?s        }           }           }
```

s	p	o
InterfaceTwo	isWifiOn	"true"^^<http://www.w3.org/2001/XMLSchema#boolean>
InterfaceTwo	rdf:type	owl:NamedIndividual
InterfaceTwo	rdf:type	Interface
InterfaceTwo	isViberationOn	"true"^^<http://www.w3.org/2001/XMLSchema#boolean>
InterfaceTwo	isMobileDataOn	"true"^^<http://www.w3.org/2001/XMLSchema#boolean>
InterfaceTwo	hasBrightness	MediumBrightness
InterfaceTwo	HasVolume	"0"^^<http://www.w3.org/2001/XMLSchema#positiveInteger>

Figure 8.10: Extracting interface using SPARQL query for context two

The Figure 8.11 shows the extraction interface for context three. The scenario in UC-3 is accessible in Table 8.3 for context and related interface according to user necessities. The interface extraction by query describing all the properties need to be set for specified context. These details of properties include “is Flashlight” with value “on” and Volume is “10”.

```
SPARQL query:
PREFIX rdf: <http://www.w3.org/1999/02/22-rdf-syntax-ns#>
PREFIX owl: <http://www.w3.org/2002/07/owl#>
PREFIX rdfs: <http://www.w3.org/2000/01/rdf-schema#>
PREFIX xsd: <http://www.w3.org/2001/XMLSchema#>

SELECT DISTINCT * WHERE {?s ?p ?o   .
     {SELECT DISTINCT ?s
WHERE {
    <http://www.semanticweb.org/PCTResearchGroup/ontologies/2018/2/UserMobileInterfaceOntology#ContextThree>
    <http://www.semanticweb.org/PCTResearchGroup/ontologies/2018/2/UserMobileInterfaceOntology#HasInterface>
   ?s        }            }            }
```

s	p	o
InterfaceThree	isFlashLightOn	"false"^^<http://www.w3.org/2001/XMLSchema#boolean>
InterfaceThree	rdf:type	owl:NamedIndividual
InterfaceThree	isMessageStatusOn	"false"^^<http://www.w3.org/2001/XMLSchema#boolean>
InterfaceThree	hasBrightness	LowBrightness
InterfaceThree	isBluetoothOn	"true"^^<http://www.w3.org/2001/XMLSchema#boolean>
InterfaceThree	isWifiOn	"true"^^<http://www.w3.org/2001/XMLSchema#boolean>
InterfaceThree	isCallStatusOn	"false"^^<http://www.w3.org/2001/XMLSchema#boolean>
InterfaceThree	rdf:type	Interface
InterfaceThree	HasVolume	"10"^^<http://www.w3.org/2001/XMLSchema#positiveInteger>

Figure 8.11: Extracting interface using SPARQL query for context three

The Figure 8.12 illustrates the extraction interface for the context of UC-4 according to user preferences. The query provided interface model detailing all the properties need to be set for specified context. These details of properties include "is Mobile Data" with value "on" and Font Size is "14".

```
SPARQL query:
PREFIX rdf: <http://www.w3.org/1999/02/22-rdf-syntax-ns#>
PREFIX owl: <http://www.w3.org/2002/07/owl#>
PREFIX rdfs: <http://www.w3.org/2000/01/rdf-schema#>
PREFIX xsd: <http://www.w3.org/2001/XMLSchema#>

SELECT DISTINCT * WHERE {?s ?p ?o   .
     {SELECT DISTINCT ?s
WHERE {
    <http://www.semanticweb.org/PCTResearchGroup/ontologies/2018/2/UserMobileInterfaceOntology#ContextFour>
    <http://www.semanticweb.org/PCTResearchGroup/ontologies/2018/2/UserMobileInterfaceOntology#HasInterface>
   ?s        }            }            }
```

s	p	o
InterfaceFour	rdf:type	owl:NamedIndividual
InterfaceFour	hasFontSize	"14"^^<http://www.w3.org/2001/XMLSchema#positiveInteger>
InterfaceFour	HasVolume	"5"^^<http://www.w3.org/2001/XMLSchema#positiveInteger>
InterfaceFour	isWifiOn	"true"^^<http://www.w3.org/2001/XMLSchema#boolean>
InterfaceFour	isMobileDataOn	"true"^^<http://www.w3.org/2001/XMLSchema#boolean>
InterfaceFour	hasBrightness	MediumBrightness
InterfaceFour	rdf:type	Interface

Figure 8.12: Extracting interface using SPARQL query for context four

The Figure 8.13 shows the extraction interface for context five. The scenario is presented in UC-5 for context and related interface according to user necessities. The interface extraction by query describing all the properties need to be set for specified context. These details of properties include "is Call Status" with value "on" and Message Status is "autogenerated".

SPARQL query:

```
PREFIX rdf: <http://www.w3.org/1999/02/22-rdf-syntax-ns#>
PREFIX owl: <http://www.w3.org/2002/07/owl#>
PREFIX rdfs: <http://www.w3.org/2000/01/rdf-schema#>
PREFIX xsd: <http://www.w3.org/2001/XMLSchema#>

SELECT DISTINCT * WHERE {?s ?p ?o   .
     {SELECT DISTINCT ?s
WHERE {
    <http://www.semanticweb.org/PCTResearchGroup/ontologies/2018/2/UserMobileInterfaceOntology#ContextFive>
    <http://www.semanticweb.org/PCTResearchGroup/ontologies/2018/2/UserMobileInterfaceOntology#HasInterface>
   ?s        }            }            }
```

s	p	o
InterfaceFive	isCallStatusOn	"false"^^<http://www.w3.org/2001/XMLSchema#boolean>
InterfaceFive	rdf:type	owl:NamedIndividual
InterfaceFive	HasMessageStatus	Autogenerated
InterfaceFive	isMobileDataOn	"false"^^<http://www.w3.org/2001/XMLSchema#boolean>
InterfaceFive	HasVolume	"10"^^<http://www.w3.org/2001/XMLSchema#positiveInteger>
InterfaceFive	rdf:type	Interface
InterfaceFive	isBluetoothOn	"true"^^<http://www.w3.org/2001/XMLSchema#boolean>
InterfaceFive	isWifiOn	"true"^^<http://www.w3.org/2001/XMLSchema#boolean>

Figure 8.13: Extracting interface using SPARQL query for context five

The extraction interface using SPARQL query for context six is presented in Figure 8.14. The scenario in UC-6 is accessible in Table 8.6 for context and related interface according to user necessities. The interface extraction by query describing all the properties need to be set for specified context. These details of properties include “is Mobile Data” with value “on” and Bluetooth is “on”.

SPARQL query:

```
PREFIX rdf: <http://www.w3.org/1999/02/22-rdf-syntax-ns#>
PREFIX owl: <http://www.w3.org/2002/07/owl#>
PREFIX rdfs: <http://www.w3.org/2000/01/rdf-schema#>
PREFIX xsd: <http://www.w3.org/2001/XMLSchema#>

SELECT DISTINCT * WHERE {?s ?p ?o   .
     {SELECT DISTINCT ?s
WHERE {
    <http://www.semanticweb.org/PCTResearchGroup/ontologies/2018/2/UserMobileInterfaceOntology#ContextSix>
    <http://www.semanticweb.org/PCTResearchGroup/ontologies/2018/2/UserMobileInterfaceOntology#HasInterface>
   ?s        }            }            }
```

s	p	o
InterfaceSix	rdf:type	owl:NamedIndividual
InterfaceSix	isCallStatusOn	"true"^^<http://www.w3.org/2001/XMLSchema#boolean>
InterfaceSix	isMessageStatusOn	"true"^^<http://www.w3.org/2001/XMLSchema#boolean>
InterfaceSix	isWifiOn	"true"^^<http://www.w3.org/2001/XMLSchema#boolean>
InterfaceSix	rdf:type	Interface
InterfaceSix	hasBrightness	HighBrightness
InterfaceSix	isBluetoothOn	"true"^^<http://www.w3.org/2001/XMLSchema#boolean>
InterfaceSix	HasVolume	"10"^^<http://www.w3.org/2001/XMLSchema#positiveInteger>
InterfaceSix	isMobileDataOn	"true"^^<http://www.w3.org/2001/XMLSchema#boolean>

Figure 8.14: Extracting interface using SPARQL query for context six

8.4.3 Adaptive Interface Development

The Appendix-F shows the Hash Maps for contexts and interfaces defined according to use case scenarios. The developed java code contains the specification according to user preferences.

8.5 Summary

The formal ontological modelling has made context specifications, shared, standardized and machine-readable. In this chapter, it is combined with the device properties not only in logical models but also in the development environment. AIO is developed using Protégé software though the ontology engineering process. The competency questions frame the objective of the ontology while use-cases presents the scenarios of variety of UI styles for different context. The ontology presents the mobile device interface adaptivity features semantically connected with the context elements drawn from UCO. AIO is also verified for its consistency by the reasoning software and various adaptive interface styles are verified for given context use-cases using SPARQL querying. The context to interface mapping is also simulated for an android based mobile device interface in a JSON fashion with combination of context and interface. This combination of usage context model and subsequent interface model is carried forward in next chapter to be used in UCD process model.

Chapter 9. CONCLUSION AND FUTURE WORK

The last chapter of this thesis summarizes the research conducted and conclude to enhanced UCD. The context and adaptive interface ontological models combined in this enhanced UCD to represent the usage context and respective adaptive interface. The UCD model presents the need identification and context modelling at the initial phases while user requirements and solution design development are next phases. UCO is being used in the UCD for initial phases while AIO provide detailed solution design based on the context presented by UCO. This chapter also identifies the responses to the formulated research questions found in all research phases. At the end, future work in the current research directions is discussed.

9.1 User Centred Design Enhancements

Adaptive interface needs user collaboration during its designing and development for better usability. Question wise conclusion of this research is presented in below given sections.

9.1.1 Context Knowledge Representation

RQ1: How AUIs can map the context knowledge to UIs?

UCO is built to represent the context knowledge used for mobile device interface. The ontology is developed through the ontology engineering process and duly tested over its consistent formation and user requirements (Chapter 7 and 8). The ontological representation of context provides context knowledgebase that can be reused to define known contexts in interface development phases like designing and testing. Being machine readable, it also facilitates the automated development and verification process of user context driven interfaces. AIO reads user context through the ontological model and create interface instance according to the user requirements. Current chapter has discussed the AIO engineering and testing details. These context and interface ontologies are enriched with semantic relations and constraints with growth capacity. They provide a knowledge base for mobile usage context and respective interface styles. With every context read and developed interface style, its data instances will be grown. The deductive reasoning capabilities allows the knowledgebase to select interface styles for all known context patterns. The future research in this regard includes intelligent and efficient mechanism to handle massive data read by many of the mobile users switching in variety of contexts. It will require handling many issues related to bigdata analytics, communication patterns and individual's privacy.

9.1.2 Adaptive Interface Impact

RQ2: How adaptive mobile interfaces improve user efficiency and satisfaction as compared to non-adaptive interfaces?

The answer of this question shows the impact of effectiveness, efficiency and satisfaction for the environment of AUI in Chapter 5 and 6. It is identified that usability issues of adaptivity still exist due to uniform adaptive features provided by smart phone vendors regardless of user ability and task context. Currently, it is more on user's choice to turn on or off any adaptive feature while performing specific task. The experimental results advised that the interface should be more equipped with adaptive features to increase the usability of smart phones. It is also suggested that user and task context should be studied or sensed for switching to any adaptive environment. Diverse user's contextual behaviour can be used for many changes and functionalities that will help for future tasks. UCD has been found to supply relevant adaptive information for linking functions to their better contextual behaviour.

9.1.3 Enhanced UCD

RQ3: How context aware AUIs can be designed by UCD paradigm?

Current section presents enhance UCD model incorporating the ontology driven modelling of user context to develop an AUI.

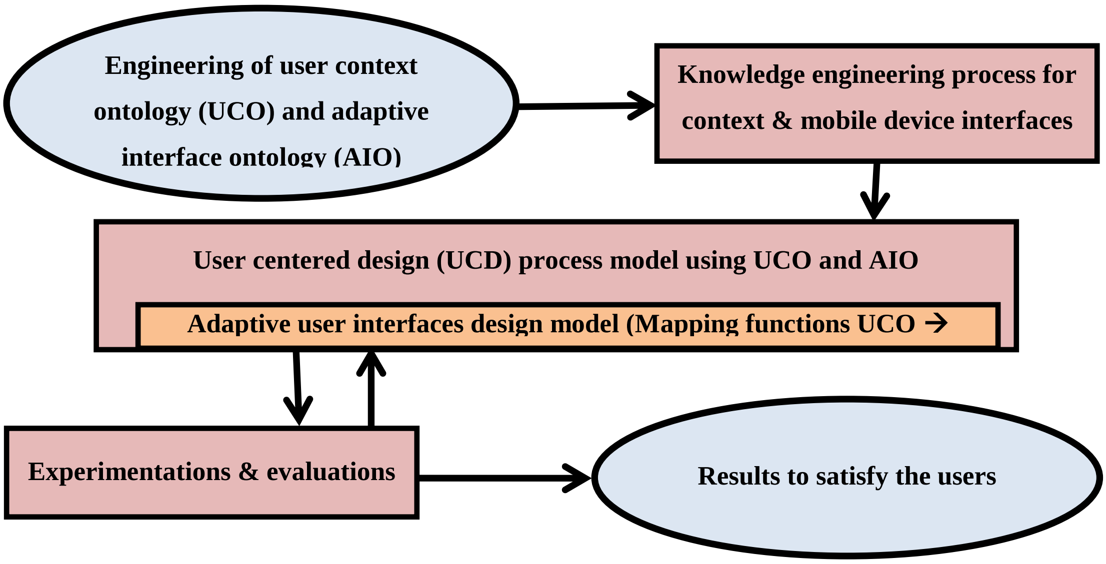


Figure 9.1: Enhanced UCD process model in terms of mapping

The phases of enhanced UCD process model are prescribed in Figure 9.1. The engineering of UCO and AIO for mobile device interfaces in user's context. In the context aware system development for mobile AUI, more detailed investigations are required including scales and value ranges etc. Elicitation of user context is a precondition for analysis and modelling of the context. Modelling user context provides the classification of user-based groups, combinations and semantic relations. Overall UCO enables to capture all the information according to the context of user. It changes the UI characteristics automatically according to the situation. The UCO discovers the dependencies and semantic relations amongst the classes and attributes. The adaptation is based on the user context which is influenced by goals and associated tasks. Interaction mode represents the information of parallel assistance for visualization and speech. It also deals with user response modes such as look and feel. AIO enables all the interfaces to change its behaviour according to the user needs. It also describes the mapping functions of UCD with UCO to AIO which leads towards the experimentation and evaluation of results for the satisfaction of users. Refinement of UCO and AIO is made on the basis of mapping rules and evaluated results. All features of UCD is provided real benefits to the user experience. It focuses on iterative refinement to the usability of interface to fulfil the needs of users. In UCD, the prototypes are very useful to translate the user requirements into contextual experience. It is used to enhance the usability, satisfaction and optimization of adaptive mobile UIs.

9.1.4 Adaptive Interface as an Intelligent Interface

Building mobile context-aware systems is inherently complex and non-trivial task. It consists of several phases starting from acquisition of context, through modelling to execution of contextual models. Today, such systems are mostly implemented on mobile platforms, that introduces specific requirements, such as intelligibility, robustness, privacy, and efficiency. Over the last decade, along with the rapid development of mobile industry, many approaches were developed that unevenly support these requirements. This is mainly caused by the fact that current modelling and reasoning methods are not crafted to operate in mobile environments (Bobek, S., Nalepa, G. J., & Ślażyński, 2018). Human activity is one of the most important pieces of context affecting an individual's information needs. Understanding the relationship between activities, time, location, and other contextual features can improve the quality of various intelligent systems, including contextual search engines, task managers, digital personal assistants, chat bots, and recommender systems (J. R. Benetka, J. Krumm, 2019). Systems capable of changing their internal functioning must take decisions according to a number of variables. These decisions could be taken on different basis and could be the output of different reasoning processes (Nicola Bicocchi, Damiano Fontana, 2019).

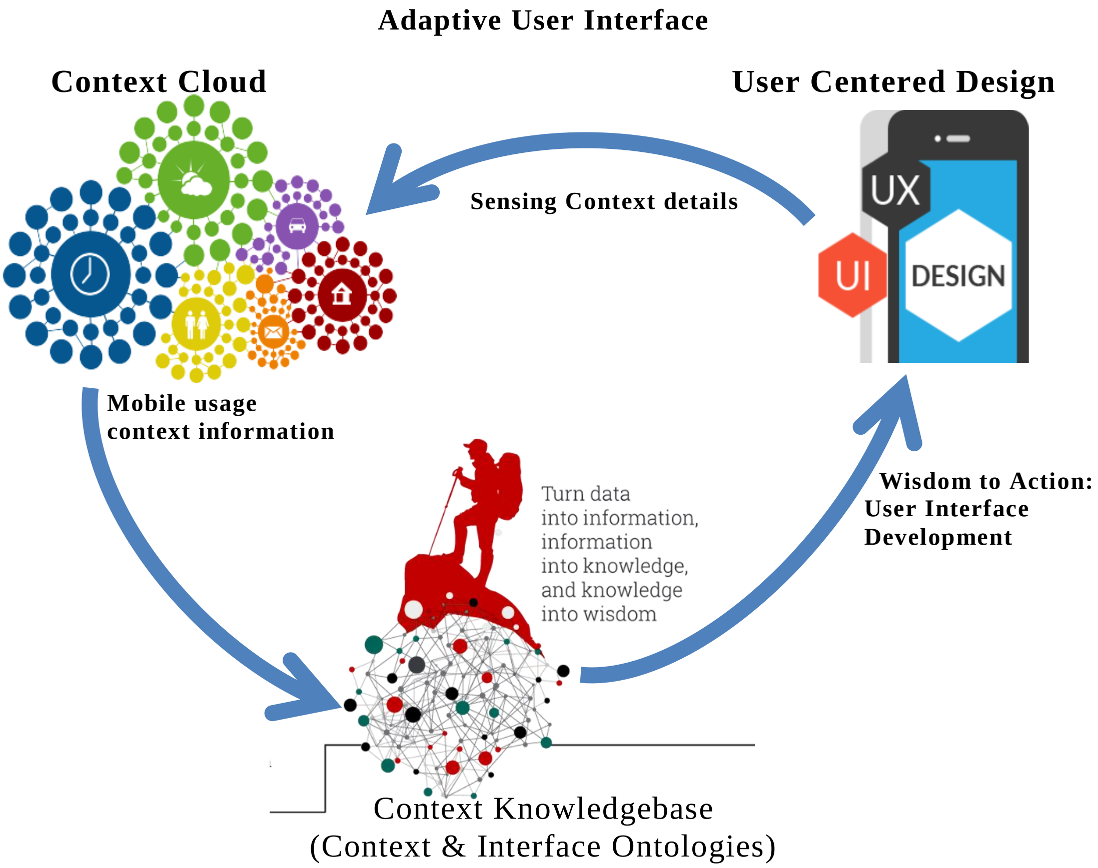


Figure 9.2: Intelligent adaptive user interface

The figure 9.2 illustrates the architecture of this intelligent adaptive UIs, sensors are used to sense the context information such as location, direction, sunlight and time etc. This model provides the connectivity and data sharing with cloud for decision making. The model also presents the adaptation strategy that can be triggered from the device with the sensing of context change. The knowledge cloud can provide the suitable interaction style on the basis of context pattern matching. New context patterns can be added to the knowledgebase with user selection of interaction styles.

9.2 Future Work

In future the devices may have strong communication with clouds in which the adaptive environment can be extended to handle the situation by using collective intelligence. For example, if some information is missing it can be acquired from other sources like mobile phones in surroundings. A rich knowledgebase can be evolved and populated for the context by experiencing various mobile device users, user preferences for the interaction styles and their combinations. Artificial Intelligence, machine learning, context knowledgebase and cloud computing may be involved to convert data into wisdom. The wisdom, as a result, is transformed into AUI development for UX through UCD process model. Currently the competitors of mobile service industry win through the most usable devices and services that requires intense consumer behaviours analysis and respective design decisions.

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Appendix-A

Mobile Adaptivity Patterns in Apps and Features Matrix

Features / Apps	Screen Rotation	Easy Screen Turn on/off	Swift Keyboard	Raise to Awake	S-Health	LED Notification	Smart Alert	Smart Pause	Smart Stay	Proximity Sensor	Eye Contact	Air Gesture	Voice Commands	Ok Goggle	Face Recognition	QR Code Reader	Kid Mode	Night Mode	Touch Disable Mode	Drive Mode	Battery Saving Mode	Color Blind Mode
Communi-cation Apps																						
SMS	Y	P	Y	X	P	Y	P	X	Y	Y	P	P	Y	P	N	X	N	Y	N	Y	Y	Y
MMS	Y	P	Y	X	P	Y	P	X	Y	Y	P	P	Y	P	N	X	N	Y	N	N	Y	Y
E-mail	Y	P	Y	X	P	Y	P	P	Y	Y	P	P	Y	P	N	P	N	Y	N	N	Y	Y
WhatsApp	Y	P	Y	X	P	Y	P	P	Y	Y	P	P	Y	P	P	P	N	Y	N	N	Y	Y
Skype	Y	P	Y	X	P	Y	P	P	Y	Y	P	P	Y	P	P	P	N	Y	N	N	Y	Y
Facebook Messenger	Y	P	Y	X	P	Y	P	P	Y	Y	P	P	Y	P	P	P	N	Y	N	N	Y	Y
Viber	Y	P	Y	X	P	Y	P	P	Y	Y	P	P	Y	P	P	P	N	Y	N	N	Y	Y
Line	Y	P	Y	X	P	Y	P	P	Y	Y	P	P	Y	P	P	P	N	Y	N	N	Y	Y
Social Networking Apps																						
Twitter	Y	P	Y	X	P	Y	P	P	Y	N	P	P	Y	P	P	P	N	Y	N	N	P	Y
Facebook	Y	P	Y	X	P	Y	P	P	Y	N	P	P	Y	P	P	P	N	Y	N	N	P	Y
Google +	Y	P	Y	X	P	Y	P	P	Y	N	P	P	Y	P	P	P	N	Y	N	N	Y	Y
LinkedIn	Y	P	Y	X	P	Y	P	P	Y	N	P	P	Y	P	P	P	N	Y	N	N	Y	Y
Xing	Y	P	Y	X	P	Y	P	X	Y	N	P	P	Y	P	P	P	N	Y	N	N	Y	Y
Instagram	Y	P	Y	X	P	Y	P	P	Y	N	P	P	Y	P	P	P	N	Y	N	N	P	Y
Pinterest	Y	P	Y	X	P	Y	P	X	Y	N	P	P	Y	P	P	X	N	Y	N	N	Y	Y
Tumblr	Y	P	Y	X	P	Y	P	X	Y	N	P	P	Y	P	P	X	N	Y	N	N	Y	Y
Tinder	N	P	Y	X	P	Y	P	X	Y	N	P	P	Y	P	P	X	N	Y	N	N	P	Y
Entertain-ment Apps																						
YouTube	Y	P	Y	X	P	Y	P	P	Y	N	P	P	Y	P	N	X	N	Y	N	N	Y	Y
Dailymotion	Y	P	Y	X	P	Y	P	P	Y	N	P	P	Y	P	N	X	N	Y	N	N	Y	Y
SoundCloud	N	P	Y	X	P	Y	P	P	Y	N	P	P	Y	P	N	X	N	Y	N	P	Y	Y
Mobile Games	Y	P	Y	X	P	Y	P	P	Y	N	P	P	Y	P	N	X	N	Y	N	N	Y	Y
Netflix	P	P	Y	X	P	Y	P	P	Y	N	P	P	Y	P	N	X	N	Y	N	N	Y	Y
Vimeo	Y	P	Y	X	P	Y	P	P	Y	N	P	P	Y	P	P	X	N	Y	N	N	Y	Y
Dubsmash	Y	P	Y	X	P	Y	P	P	Y	N	P	P	Y	P	P	X	N	Y	N	N	Y	Y
News and Information Apps																						
BBC	Y	P	Y	X	P	Y	P	P	Y	Y	P	P	Y	P	N	X	N	Y	N	N	Y	Y
CCN	Y	P	Y	X	P	Y	P	P	Y	Y	P	P	Y	P	N	X	N	Y	N	N	Y	Y
RT	Y	P	Y	X	P	Y	P	P	Y	Y	P	P	Y	P	N	X	N	Y	N	N	Y	Y
DW	Y	P	Y	X	P	Y	P	P	Y	Y	P	P	Y	P	N	X	N	Y	N	N	Y	Y
Al Jazeera	Y	P	Y	X	P	Y	P	P	Y	Y	P	P	Y	P	N	X	N	Y	N	N	Y	Y
National Geographic	Y	P	Y	X	P	Y	P	P	Y	Y	P	P	Y	P	N	X	N	Y	N	N	Y	Y
WordPress	Y	P	Y	X	P	Y	P	P	Y	Y	P	P	Y	P	N	P	N	Y	N	N	Y	Y
Blogger	Y	P	Y	X	P	Y	P	P	Y	Y	P	P	Y	P	N	P	N	Y	N	N	Y	Y
Kindle	Y	P	Y	X	P	Y	P	P	Y	Y	P	P	Y	P	N	N	N	Y	N	N	Y	Y
Utility Apps																						
Google Drive	Y	P	Y	X	P	Y	P	P	Y	Y	N	P	Y	P	N	P	N	Y	N	N	Y	Y
Microsoft One Drive	Y	P	Y	X	P	Y	P	P	Y	Y	N	P	Y	P	N	P	N	Y	N	N	Y	Y
Calendar & Scheduler	Y	P	Y	X	P	Y	P	X	Y	Y	N	P	Y	P	N	X	N	Y	N	N	Y	Y
Calculator	Y	P	Y	X	P	Y	P	X	Y	Y	N	P	Y	P	N	X	N	Y	N	N	Y	Y
Google Maps	Y	P	Y	X	P	Y	P	X	Y	Y	N	P	Y	P	N	X	N	Y	N	Y	P	Y
Documents & Spread Sheets	Y	P	Y	X	P	Y	P	X	Y	Y	N	P	Y	P	N	X	N	Y	N	N	Y	Y
CPU & Memory Booster	P	P	Y	X	P	Y	P	X	Y	Y	N	P	Y	P	N	X	N	Y	N	N	Y	Y
Storage Cleaner	P	P	Y	X	P	Y	P	X	Y	Y	N	P	Y	P	N	X	N	Y	N	N	Y	Y
Dropbox	Y	P	Y	X	P	Y	P	P	Y	Y	N	P	Y	P	N	P	N	Y	N	N	Y	Y
Trello	Y	P	Y	X	P	Y	P	P	Y	Y	N	P	Y	P	N	P	N	Y	N	N	Y	Y
Service																						

Provider Apps																						
Uber	N	P	Y	X	P	Y	P	X	Y	Y	N	P	Y	P	N	P	N	Y	N	Y	P	Y
OLX	Y	P	Y	X	P	Y	P	X	Y	Y	N	P	Y	P	P	P	N	Y	N	N	P	Y
E-bay	Y	P	Y	X	P	Y	P	X	Y	Y	N	P	Y	P	N	P	N	Y	N	N	P	Y
Amazon	Y	P	Y	X	P	Y	P	X	Y	Y	N	P	Y	P	N	P	N	Y	N	N	P	Y
PayPal	P	P	Y	X	P	Y	P	X	Y	Y	N	P	Y	P	N	P	N	Y	N	N	P	Y
Weather For. Forecasting	P	P	Y	X	P	Y	P	X	Y	Y	N	P	Y	P	N	P	N	Y	N	N	P	Y
XE Curren-cy	P	P	Y	X	P	Y	P	X	Y	Y	N	P	Y	P	N	P	N	Y	N	N	Y	Y
Browsing Apps																						
Google Chrome	Y	P	Y	X	P	Y	P	P	Y	Y	P	P	Y	P	P	P	N	Y	N	N	P	Y
Safari	Y	P	Y	X	P	Y	P	P	Y	Y	P	P	Y	P	P	P	N	Y	N	N	P	Y
Opera Mini	Y	P	Y	X	P	Y	P	P	Y	Y	P	P	Y	P	P	P	N	Y	N	N	P	Y
Mozilla Firefox	Y	P	Y	X	P	Y	P	P	Y	Y	P	P	Y	P	P	P	N	Y	N	N	P	Y
UC Browser	Y	P	Y	X	P	Y	P	P	Y	Y	P	P	Y	P	P	P	N	Y	N	N	P	Y

Legend	Y = Avail-able	N = Non-Avail-able	P = Partial-ly Avail-able	X = Not Appli-cable

Appendix-B

After-Scenario Questionnaire

This questionnaire was taken to evaluate the satisfaction level of users. It was published in 1995 in “International journal of Human-computer Interaction” written by Lewis, J. R. 7: 1, 57-78. It was based on IBM computer usability satisfaction questionnaires: psychometric evaluation and instructions for use (Lewis, 1995).

Sr.#	Statement	⟵	1	2	3	4	5	6	7	⟶	NA
1	Overall, I am satisfied with the ease of completing the task in this scenario	Strongly Disagree	●	●	●	●	●	●	●	Strongly Disagree	●
2	Overall, I am satisfied with the amount of time it took to complete the tasks in this scenario	Strongly Disagree	●	●	●	●	●	●	●	Strongly Disagree	●
3	Overall, I am satisfied with the support information (online-line help, messages, documentation) when completing the tasks	Strongly Disagree	●	●	●	●	●	●	●	Strongly Disagree	●

Appendix-C

Usability Evaluation Data of Adaptive Features

Screen Rotation Experiment Data											
Adaptive						Non-adaptive					
Gender	Task Completed	Completion Time (min)	Completed Task /min	ASQ Score	Error	Gender	Task Com-pleted	Completion Time (min)	Completed Task /min	ASQ Score	Error
M	1	4	0.25	4	Spelling	M	1	2.75	0.363636364	6.666666667	
M	1	3.5	0.285714286	4.333333333		M	1	2.5	0.4	5.666666667	
M	0	6	0	3.666666667	Calls	M	1	2.5	0.4	5	
M	0	6	0	5	Speed	M	1	2.5	0.4	6	Spelling
M	1	3.36	0.297619048	3.333333333		M	1	2.33	0.429184549	5.666666667	
M	0	6	0	6.333333333	Rotation	M	1	2.4	0.416666667	6.333333333	
M	1	3	0.333333333	6		M	0	6	0	6.666666667	Hang
M	1	3.67	0.272479564	4.666666667		M	1	2.61	0.383141762	6	
8	5	35.53	1.439146231	37.33333333		8	7	23.59	2.792629342	48	
F	1	4.75	0.210526316	3.666666667		F	1	2	0.5	5	Spelling
F	0	6	0	4	Rotation	F	1	3	0.333333333	6	SMS
F	1	4.87	0.205338809	3.333333333	Rotation	F	1	2.75	0.363636364	6.333333333	
F	1	4.67	0.214132762	3.666666667		F	0	6	0	6.333333333	Speed
F	0	7	0	2		F	1	2	0.5	5.666666667	Calls
F	0	6	0	3.333333333	Rotation	F	1	2.5	0.4	5.333333333	SMS
F	1	4.84	0.20661157	5		F	1	2.33	0.429184549	5.666666667	
F	0	7	0	4.333333333	Rotation	F	0	6	0	4.666666667	Speed
8	4	45.13	0.836609457	29.33333333		8	6	26.58	2.526154246	45	
16	9	80.66	2.275755688	66.66666667		16	13	50.17	5.318783588	93	

Voice Commands Experiment Data											
Adaptive						Non-adaptive					
Gender	Task Com-pleted	Comple-tion Time (Sec)	Completed Time/min	ASQ Score	Extra Attempt	Gender	Task Completed	Comple-tion Time (Sec)	Completed Time/min	ASQ Score	Extra Attempt
M	1	43	1.395348837	5.666666667	4	M	0	180	0	2.333333333	2
M	1	88	0.681818182	6	6	M	1	60	1	4.666666667	
M	1	38	1.578947368	5	0	M	1	68	0.882352941	4	
M	1	52	1.153846154	6.666666667	5	M	1	58	1.034482759	4.333333333	
M	1	68	0.882352941	6.333333333	2	M	1	66	0.909090909	4	
M	0	180	0	4.666666667	9	M	1	53	1.132075472	2.666666667	
M	1	36	1.666666667	5.666666667	3	M	1	72	0.833333333	3.333333333	
M	0	180	0	5	3	M	1	88	0.681818182	3.666666667	
8	6	685	7.358980149	45		8	7	645	6.473153596	29	
F	1	35	1.714285714	6	2	F	1	67	0.895522388	5	
F	0	180	0	5	10	F	1	90	0.666666667	4.333333333	3
F	0	180	0	5.666666667	4	F	1	60	1	4.666666667	
F	1	53	1.132075472	6.666666667	3	F	1	55	1.090909091	5.333333333	
F	1	53	1.132075472	5.666666667	4	F	1	82	0.731707317	5	1
F	1	36	1.666666667	6	0	F	0	180	0	4.333333333	
F	1	43	1.395348837	6.666666667	0	F	1	75	0.8	4.666666667	
F	0	180	0	6.333333333	10	F	1	73	0.821917808	4	
8	5	760	7.040452162	48		8	7	682	6.006723271	37.33333333	
16	11	1445	14.39943231	93		16	14	1327	12.47987687	66.33333333	

LED Notifications Experiment Data											
Adaptive						Non-adaptive					
Gender	Task Completed	Delay Time (Sec)	Completed Time/min	ASQ Score	Notification App	Gender	Task Completed	Completion Time (Sec)	Completed Time/min	ASQ Score	Notification App
M	1	58	1.034482759	6.666666667	Social media	M	0	300	0	4.333333333	Email
M	1	66	0.909090909	6.333333333	Social media	M	1	101	0.594059406	4	Social media
M	1	92	0.652173913	6.333333333	Email	M	1	99	0.606060606	3.666666667	Email
M	0	300	0	6.666666667	Social media	M	1	87	0.689655172	5	Social media
M	1	53	1.132075472	6.333333333	Social media	M	1	91	0.659340659	5.333333333	Social media
M	1	45	1.333333333	5.666666667	Social media	M	0	300	0	3.666666667	Email
M	1	85	0.705882353	6.666666667	Email	M	0	300	0	2	Advertisement
M	1	58	1.034482759	6	Social media	M	1	105	0.571428571	4	Social media
8	7	757	6.801521497	50.66666667		8	5	1383	3.120544415	32	
F	1	55	1.090909091	6.666666667	Social media	F	0	300	0	2.666666667	Social media
F	1	62	0.967741935	6	Social media	F	1	123	0.487804878	4.333333333	Email
F	1	55	1.090909091	6.666666667	Social media	F	0	300	0	3	Social media
F	1	74	0.810810811	7	Email	F	0	300	0	3	Social media
F	0	300	0	6.333333333	Email	F	1	131	0.458015267	4.666666667	Social media
F	1	48	1.25	7	Social media	F	1	129	0.465116279	3.666666667	Social media
F	1	60	1	6.666666667	Social media	F	1	118	0.508474576	4.333333333	Social media
F	1	56	1.071428571	6.666666667	Social media	F	0	300	0	3.333333333	Social media
8	7	710	7.2817995	53		8	4	1701	1.919411001	29	
16	14	1467	14.083321	103.6666667		16	9	3084	5.039955416	61	

Kid Mode Experiment Data									
Adaptive					Non-adaptive				
Gender	Task Com-pleted	Completion Time (Sec)	Completed Task/min	ASQ Score	Gender	Task Com-pleted	Completion Time (Sec)	Completed Task/min	ASQ Score
M	1	95	0.631578947	5.666666667	M	1	157	0.382165605	3.666666667
M	1	103	0.582524272	5	M	1	161	0.372670807	2.333333333
M	1	80	0.75	6	M	0	300	0	4
M	1	88	0.681818182	5.333333333	M	0	300	0	5
M	1	77	0.779220779	6.333333333	M	1	126	0.476190476	5.666666667
M	0	300	0	4	M	1	135	0.444444444	4.333333333
M	1	98	0.612244898	4.666666667	M	1	124	0.483870968	4
M	1	88	0.681818182	6	M	0	300	0	3.333333333
8	7	929	4.71920526	43	8	5	1603	2.159342301	32.33333333
F	0	300	0	4.333333333	F	0	300	0	5.333333333
F	1	95	0.631578947	5	F	1	96	0.625	3.333333333
F	1	75	0.8	5.666666667	F	1	80	0.75	3.666666667
F	1	78	0.769230769	4.666666667	F	0	300	0	4.333333333
F	1	82	0.731707317	6	F	1	75	0.8	2
F	1	72	0.833333333	6.333333333	F	0	300	0	3.666666667
F	0	300	0	6	F	1	85	0.705882353	2.333333333
F	1	84	0.714285714	4.333333333	F	0	300	0	4.666666667
8	6	1086	4.480136081	42.33333333	8	4	1536	2.880882353	29.33333333
16	13	2015	9.199341341	85.33333333	16	9	3139	5.040224654	61.66666667

Appendix-D

Usability Evaluation Data of Colour-blind and CVD Users

Non-Adaptive Environment									
Type	**User**	**Experiment**							
		Game	**Score**			**Time**			**Avg. Time**	**ASQ**
		Game no.1	Attempt 1	Time	Attempt 2	Time	Attempt 3	time		
		Color Switch		50		42		10	34	
Deuteranopia	1	Game no.2	Attempt 1	Time	Attempt 2	Time	Attempt 3	time		4
		Bubble Shooter		185		180		167	177.3333	
		Game no.3	Tune 1	Time	Pass/Fail	Tune 2	Time	Pass/Fail		
		Baby Xylophone	Complete	48	P	Complete	39	P	43.5	
		Game	**Score**			**Time**			**Avg. Time**	**ASQ**
		Game no.1	Attempt 1	Time	Attempt 2	Time	Attempt 3	time		
		Color Switch		65		37		66	56	
Deuteranopia	2	Game no.2	Attempt 1	Time	Attempt 2	Time	Attempt 3	time		6.33
		Bubble Shooter		260		230		215	235	
		Game no.3	Tune 1	Time	Pass/Fail	Tune 2	Time	Pass/Fail		
		Baby Xylophone	Complete	43	P	Complete	33	P	38	
		Game	**Score**			**Time**			**Avg. Time**	**ASQ**
		Game no.1	Attempt 1	Time	Attempt 2	Time	Attempt 3	time		
Deuteranopia	3	**Color Switch**		4		3		2	3	4
		Game no.2	Attempt 1	Time	Attempt 2	Time	Attempt 3	time		
		Bubble Shooter		39		30		27	32	

		Game no.3	Tune 1	Time	Pass/Fail	Tune 2	Time	Pass/Fail		
		Baby Xylophone	Complete	39	P	Complete	36	P	37.5	
		Game	**Score**			**Time**			**Avg. Time**	**ASQ**
		Game no.1	Attempt 1	Time	Attempt 2	Time	Attempt 3	time		
		Color Switch		75		50		20	48.33333	
Deuteranopia	4	Game no.2	Attempt 1	Time	Attempt 2	Time	Attempt 3	time		3.33
		Bubble Shooter		112		185		129	142	
		Game no.3	Tune 1	Time	Pass/Fail	Tune 2	Time	Pass/Fail		
		Baby Xylophone	Complete	40	P	Complete	47	P	43.5	
		Game	**Score**			**Time**			**Avg. Time**	**ASQ**
		Game no.1	Attempt 1	Time	Attempt 2	Time	Attempt 3	time		
		Color Switch		6		8		8	7.333333	
Deuteranopia	5	Game no.2	Attempt 1	Time	Attempt 2	Time	Attempt 3	time		4
		Bubble Shooter		109		78		69	85.33333	
		Game no.3	Tune 1	Time	Pass/Fail	Tune 2	Time	Pass/Fail		
		Baby Xylophone	Complete	18	P	Complete	15	P	16.5	
		Game	**Score**			**Time**			**Avg. Time**	**ASQ**
		Game no.1	Attempt 1	Time	Attempt 2	Time	Attempt 3	time		
		Color Switch		10		9		8	9	
Deuteranopia	6	Game no.2	Attempt 1	Time	Attempt 2	Time	Attempt 3	time		5
		Bubble Shooter		220		250		290	253.3333	
		Game no.3	Tune 1	Time	Pass/Fail	Tune 2	Time	Pass/Fail		
		Baby Xylophone	Complete	56	P	Complete	50	P	53	
		Game	**Score**			**Time**			**Avg. Time**	**ASQ**
		Game no.1	Attempt 1	Time	Attempt 2	Time	Attempt 3	time		
Deuteranopia	7	**Color Switch**		20		18		15	17.66667	4.33
		Game no.2	Attempt 1	Time	Attempt 2	Time	Attempt 3	time		
		Bubble Shooter		300		280		270	283.3333	

		Game no.3	Tune 1	Time	Pass/Fail	Tune 2	Time	Pass/Fail		
		Baby Xylophone	Complete	68	P	Complete	66	P	67	
Deuteranopia	8	**Game**	**Score**			**Time**			**Avg. Time**	**ASQ**
		Game no.1	Attempt 1	Time	Attempt 2	Time	Attempt 3	time		4.3
		Color Switch		6		4		4	4.666667	
		Game no.2	Attempt 1	Time	Attempt 2	Time	Attempt 3	time		
		Bubble Shooter		220		210		180	203.3333	
		Game no.3	Attempt 1	Time	Pass/Fail	Tune 2	Time	Pass/Fail		
		Baby Xylophone	Complete	38	P	Complete	40	P	39	
Deuteranopia	9	**Game**	**Score**			**Time**			**Avg. Time**	**ASQ**
		Game no.1	Attempt 1	Time	Attempt 2	Time	Attempt 3	time		5.3
		Color Switch		9		8		8	8.333333	
		Game no.2	Attempt 1	Time	Attempt 2	Time	Attempt 3	time		
		Bubble Shooter		242		221		215	226	
		Game no.3	Tune 1	Time	Pass/Fail	Tune 2	Time	Pass/Fail		
		Baby Xylophone	Complete	34	P	Complete	36	P	35	
Deuteranopia	10	**Game**	**Score**			**Time**			**Avg. Time**	**ASQ**
		Game no.1	Attempt 1	Time	Attempt 2	Time	Attempt 3	time		2
		Color Switch		32		34		38	34.66667	
		Game no.2	Attempt 1	Time	Attempt 2	Time	Attempt 3	time		
		Bubble Shooter		68		78		79	75	
		Game no.3	Tune 1	Time	Pass/Fail	Tune 2	Time	Pass/Fail		
		Baby Xylophone	Complete	29	P	Complete	31	P	30	
Deuteranopia	11	**Game**	**Score**			**Time**			**Avg. Time**	**ASQ**
		Game no.1	Attempt 1	Time	Attempt 2	Time	Attempt 3	time		3.5
		Color Switch		13		15		18	15.33333	
		Game no.2	Attempt 1	Time	Attempt 2	Time	Attempt 3	time		
		Bubble Shooter		120		135		178	144.3333	

		Game no.3	Tune 1	Time	Pass/Fail	Tune 2	Time	Pass/Fail		
		Baby Xylophone	Complete	45	P	Complete	39	P	42	
		Game	**Score**			**Time**			**Avg. Time**	**ASQ**
		Game no.1	Attempt 1	Time	Attempt 2	Time	Attempt 3	time		
		Color Switch		3		2		2	2.333333	
Deuteranopia	12	Game no.2	Attempt 1	Time	Attempt 2	Time	Attempt 3	time		4.33
		Bubble Shooter		86		78		65	76.33333	
		Game no.3	Tune 1	Time	Pass/Fail	Tune 2	Time	Pass/Fail		
		Baby Xylophone	Complete	42	P	Complete	36	P	39	
		Game	**Score**			**Time**			**Avg. Time**	**ASQ**
		Game no.1	Attempt 1	Time	Attempt 2	Time	Attempt 3	time		
		Color Switch		7		4		3	4.666667	
Protanopia	13	Game no.2	Attempt 1	Time	Attempt 2	Time	Attempt 3	time		3.33
		Bubble Shooter		142		129		110	127	
		Game no.3	Tune 1	Time	Pass/Fail	Tune 2	Time	Pass/Fail		
		Baby Xylophone	Complete	37	P	Complete	28	P	32.5	
		Game	**Score**			**Time**			**Avg. Time**	**ASQ**
		Game no.1	Attempt 1	Time	Attempt 2	Time	Attempt 3	time		
		Color Switch		7		8		8	7.666667	
Protanopia	14	Game no.2	Attempt 1	Time	Attempt 2	Time	Attempt 3	time		3
		Bubble Shooter		87		67		84	79.33333	
		Game no.3	Tune 1	Time	Pass/Fail	Tune 2	Time	Pass/Fail		
		Baby Xylophone	Complete	31	P	Complete	32	P	31.5	
		Game	**Score**			**Time**			**Avg. Time**	**ASQ**
		Game no.1	Attempt 1	Time	Attempt 2	Time	Attempt 3	time		
Protanopia	15	**Color Switch**		15		14		10	13	5.33
		Game no.2	Attempt 1	Time	Attempt 2	Time	Attempt 3	time		
		Bubble Shooter		199		190		180	189.6667	

		Game no.3	Tune 1	Time	Pass/Fail	Tune 2	Time	Pass/Fail		
		Baby Xylophone	Complete	32	P	Complete	29	P	30.5	
		Game	**Score**			**Time**			**Avg. Time**	**ASQ**
Protanopia	16	Game no.1	Attempt 1	Time	Attempt 2	Time	Attempt 3	time		4.66
		Color Switch		19		22		31	24	
		Game no.2	Attempt 1	Time	Attempt 2	Time	Attempt 3	time		
		Bubble Shooter		82		80		76	79.33333	
		Game no.3	Tune 1	Time	Pass/Fail	Tune 2	Time	Pass/Fail		
		Baby Xylophone	Complete	43	P	Complete	55	P	49	
		Game	**Score**			**Time**			**Avg. Time**	**ASQ**
Protanopia	17	Game no.1	Attempt 1	Time	Attempt 2	Time	Attempt 3	time		2.33
		Color Switch		25		33		38	32	
		Game no.2	Attempt 1	Time	Attempt 2	Time	Attempt 3	time		
		Bubble Shooter		112		125		110	115.6667	
		Game no.3	Tune 1	Time	Pass/Fail	Tune 2	Time	Pass/Fail		
		Baby Xylophone	Complete	58	P	Complete	59	P	58.5	
		Game	**Score**			**Time**			**Avg. Time**	**ASQ**
Protanopia	18	Game no.1	Attempt 1	Time	Attempt 2	Time	Attempt 3	time		3.66
		Color Switch		45		56		66	55.66667	
		Game no.2	Attempt 1	Time	Attempt 2	Time	Attempt 3	time		
		Bubble Shooter		155		135		131	140.3333	
		Game no.3	Tune 1	Time	Pass/Fail	Tune 2	Time	Pass/Fail		
		Baby Xylophone	Complete	39	P	Complete	47	P	43	
		Game	**Score**			**Time**			**Avg. Time**	**ASQ**
Protanopia	19	Game no.1	Attempt 1	Time	Attempt 2	Time	Attempt 3	time		6
		Color Switch		8		7		3	6	
		Game no.2	Attempt 1	Time	Attempt 2	Time	Attempt 3	time		
		Bubble Shooter		125		142		120	129	

		Game no.3	Tune 1	Time	Pass/Fail	Tune 2	Time	Pass/Fail		
		Baby Xylophone	Complete	66	P	Complete	56	P	61	
Protanopia	20	**Game**	**Score**			**Time**			**Avg. Time**	**ASQ**
		Game no.1	Attempt 1	Time	Attempt 2	Time	Attempt 3	time		6
		Color Switch		15		12		11	12.66667	
		Game no.2	Attempt 1	Time	Attempt 2	Time	Attempt 3	time		
		Bubble Shooter		113		110		108	110.3333	
		Game no.3	Tune 1	Time	Pass/Fail	Tune 2	Time	Pass/Fail		
		Baby Xylophone	Complete	35	P	Complete	39	P	37	
Protanopia	21	**Game**	**Score**			**Time**			**Avg. Time**	**ASQ**
		Game no.1	Attempt 1	Time	Attempt 2	Time	Attempt 3	time		5
		Color Switch		21		23		31	25	
		Game no.2	Attempt 1	Time	Attempt 2	Time	Attempt 3	time		
		Bubble Shooter		78		79		73	76.66667	
		Game no.3	Tune 1	Time	Pass/Fail	Tune 2	Time	Pass/Fail		
		Baby Xylophone	Complete	35	P	Complete	41	P	38	
Protanomaly	22	**Game**	**Score**			**Time**			**Avg. Time**	**ASQ**
		Game no.1	Attempt 1	Time	Attempt 2	Time	Attempt 3	time		3
		Color Switch		11		12		10	11	
		Game no.2	Attempt 1	Time	Attempt 2	Time	Attempt 3	time		
		Bubble Shooter		122		145		120	129	
		Game no.3	Tune 1	Time	Pass/Fail	Tune 2	Time	Pass/Fail		
		Baby Xylophone	Complete	66	P	Complete	59	P	62.5	
Protanomaly	23	**Game**	**Score**			**Time**			**Avg. Time**	**ASQ**
		Game no.1	Attempt 1	Time	Attempt 2	Time	Attempt 3	time		2
		Color Switch		22		21		31	24.66667	
		Game no.2	Attempt 1	Time	Attempt 2	Time	Attempt 3	time		
		Bubble Shooter		151		155		163	156.3333	

		Game no.3	Tune 1	Time	Pass/Fail	Tune 2	Time	Pass/Fail		
		Baby Xylophone	Complete	46	P	Complete	51	P	48.5	
Deuteranomaly	24	**Game**	**Score**			**Time**			**Avg. Time**	**ASQ**
		Game no.1	Attempt 1	Time	Attempt 2	Time	Attempt 3	time		3.33
		Color Switch		15		16		14	15	
		Game no.2	Attempt 1	Time	Attempt 2	Time	Attempt 3	time		
		Bubble Shooter		178		193		201	190.6667	
		Game no.3	Tune 1	Time	Pass/Fail	Tune 2	Time	Pass/Fail		
		Baby Xylophone	Complete	69	P	Complete	57	P	63	
Deuteranomaly	25	**Game**	**Score**			**Time**			**Avg. Time**	**ASQ**
		Game no.1	Attempt 1	Time	Attempt 2	Time	Attempt 3	time		5.66
		Color Switch		16		18		20	18	
		Game no.2	Attempt 1	Time	Attempt 2	Time	Attempt 3	time		
		Bubble Shooter		171		176		182	176.3333	
		Game no.3	Tune 1	Time	Pass/Fail	Tune 2	Time	Pass/Fail		
		Baby Xylophone	Complete	57	P	Complete	61	P	59	
Deuteranomaly	26	**Game**	**Score**			**Time**			**Avg. Time**	**ASQ**
		Game no.1	Attempt 1	Time	Attempt 2	Time	Attempt 3	time		2.33
		Color Switch		13		14		14	13.66667	
		Game no.2	Attempt 1	Time	Attempt 2	Time	Attempt 3	time		
		Bubble Shooter		86		88		79	84.33333	
		Game no.3	Tune 1	Time	Pass/Fail	Tune 2	Time	Pass/Fail		
		Baby Xylophone	Complete	55	P	Complete	59	P	57	
Tritanopia	27	**Game**	**Score**			**Time**			**Avg. Time**	**ASQ**
		Game no.1	Attempt 1	Time	Attempt 2	Time	Attempt 3	time		3.33
		Color Switch		23		29		39	30.33333	
		Game no.2	Attempt 1	Time	Attempt 2	Time	Attempt 3	time		
		Bubble Shooter		240		231		210	227	

		Game no.3	Tune 1	Time	Pass/Fail	Tune 2	Time	Pass/Fail		
		Baby Xylophone	Complete	45	P	Complete	49	P	47	
Tritanomaly	28	**Game**	**Score**			**Time**			**Avg. Time**	**ASQ**
		Game no.1	Attempt 1	Time	Attempt 2	Time	Attempt 3	time		3.33
		Color Switch		8		7		3	6	
		Game no.2	Attempt 1	Time	Attempt 2	Time	Attempt 3	time		
		Bubble Shooter		136		133		130	133	
		Game no.3	Tune 1	Time	Pass/Fail	Tune 2	Time	Pass/Fail		
		Baby Xylophone	Complete	44	P	Complete	49	P	46.5	
Tritanomaly	29	**Game**	**Score**			**Time**			**Avg. Time**	**ASQ**
		Game no.1	Attempt 1	Time	Attempt 2	Time	Attempt 3	time		4.66
		Color Switch		9		13		16	12.66667	
		Game no.2	Attempt 1	Time	Attempt 2	Time	Attempt 3	time		
		Bubble Shooter		87		83		80	83.33333	
		Game no.3	Tune 1	Time	Pass/Fail	Tune 2	Time	Pass/Fail		
		Baby Xylophone	Complete	51	P	Complete	53	P	52	
Tritanomaly	30	**Game**	**Score**			**Time**			**Avg. Time**	**ASQ**
		Game no.1	Attempt 1	Time	Attempt 2	Time	Attempt 3	time		2.33
		Color Switch		8		9		11	9.333333	
		Game no.2	Attempt 1	Time	Attempt 2	Time	Attempt 3	time		
		Bubble Shooter		78		75		73	75.33333	
		Game no.3	Tune 1	Time	Pass/Fail	Tune 2	Time	Pass/Fail		
		Baby Xylophone	Complete	31	P	Complete	36	P	33.5	

Adaptive Environment									
Type	**User**	**Experiment**							
Deuteranopia	1	**Game**	**Score**			**Time**			**Avg. Time**	**ASQ**
		Game no.1	Attempt 1	Time	Attempt 2	Time	Attempt 3	time		5.66
		Color Switch		47		40		30	39	
		Game no.2	Attempt 1	Time	Attempt 2	Time	Attempt 3	time		
		Bubble Shooter		220		195		180	198.3333	
		Game no.3	Tune 1	Time	Pass/Fail	Tune 2	Time	Pass/Fail		
		Baby Xylophone	Complete	50	P	Complete	39	P	44.5	
Deuteranopia	2	**Game**	**Score**			**Time**			**Avg. Time**	**ASQ**
		Game no.1	Attempt 1	Time	Attempt 2	Time	Attempt 3	time		4
		Color Switch		23		22		9	18	
		Game no.2	Attempt 1	Time	Attempt 2	Time	Attempt 3	time		
		Bubble Shooter		209		195		183	195.6667	
		Game no.3	Tune 1	Time	Pass/Fail	Tune 2	Time	Pass/Fail		
		Baby Xylophone	Complete	41	P	Complete	33	P	37	
Deuteranopia	3	**Game**	**Score**			**Time**			**Avg. Time**	**ASQ**
		Game no.1	Attempt 1	Time	Attempt 2	Time	Attempt 3	time		5.33
		Color Switch		6		6		4	5.333333	
		Game no.2	Attempt 1	Time	Attempt 2	Time	Attempt 3	time		
		Bubble Shooter		63		63		53	59.66667	
		Game no.3	Tune 1	Time	Pass/Fail	Tune 2	Time	Pass/Fail		
		Baby Xylophone	Complete	35	P	Complete	35	P	35	
Deuteranopia	4	**Game**	**Score**			**Time**			**Avg. Time**	**ASQ**
		Game no.1	Attempt 1	Time	Attempt 2	Time	Attempt 3	time		6.33
		Color Switch		15		10		10	11.66667	
		Game no.2	Attempt 1	Time	Attempt 2	Time	Attempt 3	time		

		Bubble Shooter		111		120		90	107	
		Game no.3	Tune 1	Time	Pass/Fail	Tune 2	Time	Pass/Fail		
		Baby Xylophone	Complete	46	P	Complete	30	P	38	
Deuteranopia	5	**Game**	**Score**			**Time**			**Avg. Time**	**ASQ**
		Game no.1	Attempt 1	Time	Attempt 2	Time	Attempt 3	time		5.66
		Color Switch		8		7		5	6.666667	
		Game no.2	Attempt 1	Time	Attempt 2	Time	Attempt 3	time		
		Bubble Shooter		74		68		82	74.66667	
		Game no.3	Tune 1	Time	Pass/Fail	Tune 2	Time	Pass/Fail		
		Baby Xylophone	Complete	14	P	Complete	14	P	14	
Deuteranopia	6	**Game**	**Score**			**Time**			**Avg. Time**	**ASQ**
		Game no.1	Attempt 1	Time	Attempt 2	Time	Attempt 3	time		5.66
		Color Switch		8		12		15	11.66667	
		Game no.2	Attempt 1	Time	Attempt 2	Time	Attempt 3	time		
		Bubble Shooter		210		230		250	230	
		Game no.3	Tune 1	Time	Pass/Fail	Tune 2	Time	Pass/Fail		
		Baby Xylophone	Complete	50	P	Complete	45	P	47.5	
Deuteranopia	7	**Game**	**Score**			**Time**			**Avg. Time**	**ASQ**
		Game no.1	Attempt 1	Time	Attempt 2	Time	Attempt 3	time		3.33
		Color Switch		18		15		13	15.33333	
		Game no.2	Attempt 1	Time	Attempt 2	Time	Attempt 3	time		
		Bubble Shooter		300		300		300	300	
		Game no.3	Tune 1	Time	Pass/Fail	Tune 2	Time	Pass/Fail		
		Baby Xylophone	Complete	50	P	Complete	48	P	49	
Deuteranopia	8	**Game**	**Score**			**Time**			**Avg. Time**	**ASQ**
		Game no.1	Attempt 1	Time	Attempt 2	Time	Attempt 3	time		6.33
		Color Switch		8		7		7	7.333333	
		Game no.2	Attempt 1	Time	Attempt 2	Time	Attempt 3	time		

		Bubble Shooter		180		175		171	175.3333	
		Game no.3	Tune 1	Time	Pass/Fail	Tune 2	Time	Pass/Fail		
		Baby Xylophone	Complete	33	P	Complete	35	P	34	
Deuteranopia	9	**Game**	**Score**			**Time**			**Avg. Time**	**ASQ**
		Game no.1	Attempt 1	Time	Attempt 2	Time	Attempt 3	time		2.33
		Color Switch		10		11		13	11.33333	
		Game no.2	Attempt 1	Time	Attempt 2	Time	Attempt 3	time		
		Bubble Shooter		255		245		220	240	
		Game no.3	Tune 1	Time	Pass/Fail	Tune 2	Time	Pass/Fail		
		Baby Xylophone	Complete	35	P	Complete	39	P	37	
Deuteranopia	10	**Game**	**Score**			**Time**			**Avg. Time**	**ASQ**
		Game no.1	Attempt 1	Time	Attempt 2	Time	Attempt 3	time		6
		Color Switch		40		45		53	46	
		Game no.2	Attempt 1	Time	Attempt 2	Time	Attempt 3	time		
		Bubble Shooter		69		59		55	61	
		Game no.3	Tune 1	Time	Pass/Fail	Tune 2	Time	Pass/Fail		
		Baby Xylophone	Complete	28	P	Complete	26	P	27	
Deuteranopia	11	**Game**	**Score**			**Time**			**Avg. Time**	**ASQ**
		Game no.1	Attempt 1	Time	Attempt 2	Time	Attempt 3	time		7
		Color Switch		22		25		31	26	
		Game no.2	Attempt 1	Time	Attempt 2	Time	Attempt 3	time		
		Bubble Shooter		132		121		103	118.6667	
		Game no.3	Tune 1	Time	Pass/Fail	Tune 2	Time	Pass/Fail		
		Baby Xylophone	P	39	P	Complete	32	P	35.5	
Deuteranopia	12	**Game**	**Score**			**Time**			**Avg. Time**	**ASQ**
		Game no.1	Attempt 1	Time	Attempt 2	Time	Attempt 3	time		6.33
		Color Switch		8		9		11	9.333333	
		Game no.2	Attempt 1	Time	Attempt 2	Time	Attempt 3	time		

		Bubble Shooter		64		54		52	56.66667	
		Game no.3	Tune 1	Time	Pass/Fail	Tune 2	Time	Pass/Fail		
		Baby Xylophone	Complete	35	P	Complete	29	P	32	
Protanopia	13	**Game**	**Score**			**Time**			**Avg. Time**	**ASQ**
		Game no.1	Attempt 1	Time	Attempt 2	Time	Attempt 3	time		
		Color Switch		5		5		2	4	
		Game no.2	Attempt 1	Time	Attempt 2	Time	Attempt 3	time		3.33
		Bubble Shooter		120		124		110	118	
		Game no.3	Tune 1	Time	Pass/Fail	Tune 2	Time	Pass/Fail		
		Baby Xylophone	Complete	20	P	Complete	34	P	27	
Protanopia	14	**Game**	**Score**			**Time**			**Avg. Time**	**ASQ**
		Game no.1	Attempt 1	Time	Attempt 2	Time	Attempt 3	time		
		Color Switch		8		5		9	7.333333	
		Game no.2	Attempt 1	Time	Attempt 2	Time	Attempt 3	time		6.66
		Bubble Shooter		84		67		63	71.33333	
		Game no.3	Tune 1	Time	Pass/Fail	Tune 2	Time	Pass/Fail		
		Baby Xylophone	Complete	30	P	Complete	30	P	30	
Protanopia	15	**Game**	**Score**			**Time**			**Avg. Time**	**ASQ**
		Game no.1	Attempt 1	Time	Attempt 2	Time	Attempt 3	time		
		Color Switch		23		20		7	16.66667	
		Game no.2	Attempt 1	Time	Attempt 2	Time	Attempt 3	time		6.33
		Bubble Shooter		113		107		110	110	
		Game no.3	Tune 1	Time	Pass/Fail	Tune 2	Time	Pass/Fail		
		Baby Xylophone	Complete	26	P	Complete	24	P	25	
Protanopia	16	**Game**	**Score**			**Time**			**Avg. Time**	**ASQ**
		Game no.1	Attempt 1	Time	Attempt 2	Time	Attempt 3	time		
		Color Switch		22		35		39	32	5.33
		Game no.2	Attempt 1	Time	Attempt 2	Time	Attempt 3	time		

		Bubble Shooter		75		71		63	69.66667	
		Game no.3	Tune 1	Time	Pass/Fail	Tune 2	Time	Pass/Fail		
		Baby Xylophone	Complete	39	P	Complete	45	P	42	
Protanopia	17	**Game**	**Score**			**Time**			**Avg. Time**	**ASQ**
		Game no.1	Attempt 1	Time	Attempt 2	Time	Attempt 3	time		4.33
		Color Switch		35		48		59	47.33333	
		Game no.2	Attempt 1	Time	Attempt 2	Time	Attempt 3	time		
		Bubble Shooter		125		108		101	111.3333	
		Game no.3	Tune 1	Time	Pass/Fail		Time	Pass/Fail		
		Baby Xylophone	Complete	52	P	Complete	49	P	50.5	
Protanopia	18	**Game**	**Score**			**Time**			**Avg. Time**	**ASQ**
		Game no.1	Attempt 1	Time	Attempt 2	Time	Attempt 3	time		5.66
		Color Switch		66		69		72	69	
		Game no.2	Attempt 1	Time	Attempt 2	Time	Attempt 3	time		
		Bubble Shooter		125		109		98	110.6667	
		Game no.3	Tune 1	Time	Pass/Fail	Tune 2	Time	Pass/Fail		
		Baby Xylophone	Complete	35	P	Complete	39	P	37	
Protanopia	19	**Game**	**Score**			**Time**			**Avg. Time**	**ASQ**
		Game no.1	Attempt 1	Time	Attempt 2	Time	Attempt 3	time		3
		Color Switch		9		5		3	5.666667	
		Game no.2	Attempt 1	Time	Attempt 2	Time	Attempt 3	time		
		Bubble Shooter		135		149		159	147.6667	
		Game no.3	Tune 1		Pass/Fail	Tune 2	Time	Pass/Fail		
		Baby Xylophone	Complete	69	P	Complete	59	P	64	
Protanopia	20	**Game**	**Score**			**Time**			**Avg. Time**	**ASQ**
		Game no.1	Attempt 1	Time	Attempt 2	Time	Attempt 3	time		4
		Color Switch		4		4		3	3.666667	
		Game no.2	Attempt 1	Time	Attempt 2	Time	Attempt 3	time		

		Bubble Shooter		135		142		149	142	
		Game no.3	Tune 1	Time	Pass/Fail	Tune 2	Time	Pass/Fail		
		Baby Xylophone	Complete	49	P	Complete	48	P	48.5	
Protanopia	21	**Game**	**Score**			**Time**			**Avg. Time**	**ASQ**
		Game no.1	Attempt 1	Time	Attempt 2	Time	Attempt 3	time		5
		Color Switch		12		18		11	13.66667	
		Game no.2	Attempt 1	Time	Attempt 2	Time	Attempt 3	time		
		Bubble Shooter		88		93		101	94	
		Game no.3	Tune 1	Time	Pass/Fail	Tune 2	Time	Pass/Fail		
		Baby Xylophone	Complete	34	P	Complete	43	P	38.5	
Protanomaly	22	**Game**	**Score**			**Time**			**Avg. Time**	**ASQ**
		Game no.1	Attempt 1	Time	Attempt 2	Time	Attempt 3	time		6.33
		Color Switch		15		18		25	19.33333	
		Game no.2	Attempt 1	Time	Attempt 2	Time	Attempt 3	time		
		Bubble Shooter		112		110		105	109	
		Game no.3	Tune 1	Time	Pass/Fail	Tune 2	Time	Pass/Fail		
		Baby Xylophone	Complete	51	P	Complete	48	P	49.5	
Protanomaly	23	**Game**	**Score**			**Time**			**Avg. Time**	**ASQ**
		Game no.1	Attempt 1	Time	Attempt 2	Time	Attempt 3	time		7
		Color Switch		35		32		38	35	
		Game no.2	Attempt 1	Time	Attempt 2	Time	Attempt 3	time		
		Bubble Shooter		145		143		138	142	
		Game no.3	Tune 1	Time	Pass/Fail	Tune 2	Time	Pass/Fail		
		Baby Xylophone	Complete	40	P	Complete	46	P	43	
Deuteranomaly	24	**Game**	**Score**			**Time**			**Avg. Time**	**ASQ**
		Game no.1	Attempt 1	Time	Attempt 2	Time	Attempt 3	time		5.33
		Color Switch		31		36		35	34	
		Game no.2	Attempt 1	Time	Attempt 2	Time	Attempt 3	time		

		Bubble Shooter		155		149		136	146.6667	
		Game no.3	Tune 1	Time	Pass/Fail	Tune 2	Time	Pass/Fail		
		Baby Xylophone	Complete	49	P	Complete	41	P	45	
		Game	**Score**			**Time**			**Avg. Time**	**ASQ**
		Game no.1	Attempt 1	Time	Attempt 2	Time	Attempt 3	time		
		Color Switch		19		23		31	24.33333	
Deuteranomaly	25	Game no.2	Attempt 1	Time	Attempt 2	Time	Attempt 3	time		3
		Bubble Shooter		178		182		183	181	
		Game no.3	Tune 1	Time	Pass/Fail	Tune 2	Time	Pass/Fail		
		Baby Xylophone	Complete	49	P	Complete	46	P	47.5	
		Game	**Score**			**Time**			**Avg. Time**	**ASQ**
		Game no.1	Attempt 1	Time	Attempt 2	Time	Attempt 3	time		
		Color Switch		19		25		29	24.33333	
Deuteranomaly	26	Game no.2	Attempt 1	Time	Attempt 2	Time	Attempt 3	time		4.33
		Bubble Shooter		79		75		74	76	
		Game no.3	Tune 1	Time	Pass/Fail	Tune 2	Time	Pass/Fail		
		Baby Xylophone	Complete	46	P	Complete	48	P	47	
		Game	**Score**			**Time**			**Avg. Time**	**ASQ**
		Game no.1	Attempt 1	Time	Attempt 2	Time	Attempt 3	time		
		Color Switch		26		31		37	31.33333	
Tritanopia	27	Game no.2	Attempt 1	Time	Attempt 2	Time	Attempt 3	time		6
		Bubble Shooter		225		209		197	210.3333	
		Game no.3	Tune 1	Time	Pass/Fail	Tune 2	Time	Pass/Fail		
		Baby Xylophone	Complete	38	P	Complete	39	P	38.5	
		Game	**Score**			**Time**			**Avg. Time**	**ASQ**
		Game no.1	Attempt 1	Time	Attempt 2	Time	Attempt 3	time		
Tritanomaly	28	**Color Switch**		8		7		7	7.333333	6.66
		Game no.2	Attempt 1	Time	Attempt 2	Time	Attempt 3	time		

		Bubble Shooter		137		29		20	62	
		Game no.3	Tune 1	Time	Pass/Fail	Tune 2	Time	Pass/Fail		
		Baby Xylophone	Complete	39	P	Complete	33	P	36	
Tritanomaly	29	**Game**	**Score**			**Time**			**Avg. Time**	**ASQ**
		Game no.1	Attempt 1	Time	Attempt 2	Time	Attempt 3	time		3
		Color Switch		11		12		11	11.33333	
		Game no.2	Attempt 1	Time	Attempt 2	Time	Attempt 3	time		
		Bubble Shooter		101		93		89	94.33333	
		Game no.3	Tune 1	Time	Pass/Fail	Tune 2	Time	Pass/Fail		
		Baby Xylophone	Complete	49	P	Complete	46	P	47.5	
Tritanomaly	30	**Game**	**Score**			**Time**			**Avg. Time**	**ASQ**
		Game no.1	Attempt 1	Time	Attempt 2	Time	Attempt 3	time		6.66
		Color Switch		14		19		26	19.66667	
		Game no.2	Attempt 1	Time	Attempt 2	Time	Attempt 3	time		
		Bubble Shooter		69		66		59	64.66667	
		Game no.3	Tune 1	Time	Pass/Fail	Tune 2	Time	Pass/Fail		
		Baby Xylophone	Complete	24	P	Complete	29	P	26.5	

Summarized Data for Colour-blind Users

Type	User	Non-Adaptive Environment				Adaptive Environment			
		Attempt	Overall time	Completed Task /min	ASQ	Attempt	Overall time	Completed Task /min	ASQ
Protanopia	1	1	164.16667	36.54822261	3.33	1	149	40.26845638	3.33
Protanopia	2	1	118.499997	50.63291267	3	1	108.666663	55.21472579	6.66
Protanopia	3	0	0	0	5.33	1	151.66667	39.56043869	6.33
Protanopia	4	1	152.33333	39.3873094	4.66	1	143.66667	41.7633401	5.33
Protanopia	5	1	206.1667	29.10266304	2.33	1	209.16663	28.68526399	4.33
	5	4	641.166697	155.6711077	18.65	5	762.166633	205.4922249	25.98
Deuteranopia	1	1	254.8333	23.5448036	4	1	281.8333	21.28918052	5.66
Deuteranopia	2	0	0	0	6.33	1	250.6667	23.93616703	4
Deuteranopia	3	1	72.5	82.75862069	4	0	0	0	5.33
Deuteranopia	4	0	0	0	3.33	1	156.66667	38.29787153	6.33
Deuteranopia	5	1	109.166663	54.96183391	4	1	95.333337	62.93706052	5.66
	5	3	436.499963	161.2652582	21.66	4	784.500007	146.4602796	26.98
Tritanopia	1	1	304.33333	19.71522475	3.33	1	280.16663	21.41582672	6
Tritanopia	2	0	0	0	3.4	1	216.66667	27.69230727	5.66
Tritanopia	3	1	117.666663	50.99150301	4.2	0	0	0	6.33
Tritanopia	4	0	0	0	3.5	1	180.1667	33.30249153	7
Tritanopia	5	1	196	30.6122449	6	1	217.333367	27.60735769	3
	5	3	617.999993	101.3189727	20.43	4	894.333367	110.0179832	27.99

Summarized Data of Colour Vision Deficient (CVD) Users

Type	User	Non-Adaptive Environment				Adaptive Environment			
		Attempt	Overall time	Completed Task /min	ASQ	Attempt	Overall time	Completed Task /min	ASQ
Protanomaly	1	1	229.49997	26.14379	2	1	220	27.27273	7
Protanomaly	2	1	159.99997	37.50001	6	1	194.1667	30.90129	4
Protanomaly	3	0	0	0	5	1	146.1667	41.04903	5
Protanomaly	4	1	246.999967	24.2915	4.3	1	216.6666	27.69231	6.33
Protanomaly	5	1	268.6667	22.3325	3.33	1	226.6667	26.47058	5.33
	5	4	515.833367	110.2678	20.63	5	409.3333	153.3859	27.66
Deuteranomaly	1	1	253.3333	23.68421	5.66	1	252.8333	23.73105	3
Deuteranomaly	2	1	155	38.70968	2.33	0	147.3333	0	4.33
Deuteranomaly	3	1	315.3333	19.02749	5	1	289.1667	20.74928	5.66
Deuteranomaly	4	0	0	0	4.33	1	364.3333	16.46844	3.33
Deuteranomaly	5	1	185.5	32.34501	3.33	1	105.3333	56.96203	6.66
	5	4	1736.833397	113.7664	20.65	4	1603.833	117.9108	22.98
Tritanomaly	2	1	148	40.54054	4.66	1	153.1667	39.17302	3
Tritanomaly	3	0	118.166663	0	2.33	1	110.8333	54.13534	6.66
Tritanomaly	5	1	269.33333	22.27723	5.3	1	288.3333	20.80925	2.33
Tritanomaly	6	0	139.66667	0	2	1	134	44.77612	6
Tritanomaly	7	1	233.83333	25.6593	3.33	1	156.6667	38.29787	6.33
	5	3	1769.499919	88.47707	17.62	5	1574.667	197.1916	24.32

Appendix-E

Ontology Rendered Vocabulary

V card 1	V card 2	V card 3	V card 4	V card 5, PIM	FOAF	Soupa	CoDaMOS	Cobra
https://www.w3.org/TR/2013/WD-vcard-rdf-20130502/	https://www.w3.org/TR/vcard-rdf/	https://www.w3.org/2006/vcard/ns	https://tools.ietf.org/html/rfc6350	http://www.ibiblio.org/hhalpin/homep-age/notes/vcardtable.html	http://www.ibiblio.org/hhalpin/homep-age/notes/vcardtable.html	http://cobra.umbc.edu/ont/soupa-ont.tar.gz	https://distrinet.cs.kuleuven.be/projects/CoDAMoS/ontology/	http://daml.umbc.edu/ontologies/cobra/0.4/
Acquaintance	Home	Female	Kind	Full name	foaf:fullName	Action	Activity	Parent Directory
Address	Work	Male	Individual	Name	Foaf:Name	Agent	Enviroment	academia
Addressing	Female	none	Organisation	family name	foaf:givenname	bdi	Enviromental Condition	action
Agent	Male	other	Group	given name	foaf:name	Device	Hardware	adjustlighting
Calendar link	Unknown	indviual	hasNickname	additional name	foaf:title	Digital Doc	Location	agent
Calendar request	Smart (mobile)	Location	hasStreetAddress	honorific prefix	foaf:nick	Document	Modality	bookroom
Category	Fax	Org	hasLocality	honorific suffix	foaf:homePage	Event	Mood	broker-admin
Smart	Pager	Smart	hasRegion	nick name	foaf:img	Geo_measurement	Platform	broker-comm
Child	Text (sms)	fax	hasCountryName	url	foaf:logo	Img-Capture	Profile	calendarclock
Code	TextPhone	paper	hasPostalCode	email	foaf:birthday	Knowledge	Role	context
Colleague	Video	text	hasTelephone	fax	foaf:title	Location	Service	contextbroker
Communication	Voice	text phone	hasEmail	tel	foaf:Organization	Meeting	Service Ground-ing	demo-session
Contact	Acquaintance	video		adr		Person	Service Model	device
Coresident	Agent1	voice		post office box		Policy	Service Profile	document
Coworker	Child	Acquaintance		extended address		Rcc	Software	fipa-agent
Crush	Colleague	Agent		locality		Schedule	Task	foaf-basic
Date	Contact	child		region		Space	Time	hc-model
Email	Coresident	Colleague		postal code		Time	User	image-doc
Emergency	Coworker	Contact		Country name		Light Control		loadpresentation
Explanatory	Crush	Coresident		label				location
Fax	Date	coworker		geo				meeting

Female	Emergency	Crush		latitude				participatemeet-ing
Formatted name		date		longitude				personal-device
Friend		emergency		tz				photograph
Gender		friend		photo				place
Geo		kin		logo				powerpoint
Geographical		me		sound				rcc-basic
Group		met		birthday				role
Home		muse		title				space-basic
Identification		neighbor		role				talk
Individual		parent		org				time-basic
Key		sibling		org name				umbc
Kin		spouse		org unit				umbc-ecs
Language		sweetheart		category				umbc-ite
Location		home		note				ebiquity-geo
Logo		work		class				ebiquity-meetings
Male				key				ebiquity-Actions
Me				mailer				
Messaging				uid				

Met				rev				
Muse				role				
Name				sort string				
Neighbor								
Nickname								
None								
Note								
Org								
Organisational								
Organizational Unit								
Name								
Other								
Pager								
Parent								
Phone								
Photo								
Related								
Relation Type								
Role								
Security								
Sibling								
Sound								
Spouse								
Sweetheart								
Telephone								
Text								
Text phone								
Time zone								
Title								
Type								
Unknown								
URL								
vCard Kind								
vCard Kind								
Video								
Voice								

Work								

Appendix-F

Context and interface HashMap

Context HashMap	Interface HashMap

//Usecase 1 Context hashmap
HashMap<String, String> ontology_map_Usecase1 = new HashMap<String, String>();
ontology_map_Usecase1.put("Username","child");
ontology_map_Usecase1.put("location","roomWindow");
ontology_map_Usecase1.put("activity","VideoRecording");
ontology_map_Usecase1.put("time","night");
	// interface map of Usecase 1
	HashMap<String, String> interface_map_UseCase1 =new HashMap<String, String>();
	interface_map_UseCase1.put("brightness","medium");
	interface_map_UseCase1.put("wifi","on");
	interface_map_UseCase1.put("camera","on");
	interface_map_UseCase1.put("flashlight","on");
	interface_map_UseCase1.put("background","Image1");

//Usecase 2 Context hashmap
HashMap<String, String> ontology_map_Usecase2 = new HashMap<String, String>();
ontology_map_Usecase2.put("Username","illiteratePerson");
ontology_map_Usecase2.put("location","TVLoung");
ontology_map_Usecase2.put("activity","listeningNews");
ontology_map_Usecase2.put("time","night");
	// interface map of Usecase 2
	HashMap<String, String> interface_map_UseCase2 = new HashMap<String, String>();
	interface_map_UseCase2.put("wifi","on");
	interface_map_UseCase2.put("Ring volume","0");
	interface_map_UseCase2.put("brightness","medium");
	interface_map_UseCase2.put("mobile data","On");
	interface_map_UseCase2.put("viberation","On");

//Usecase 3 Context hashmap
HashMap<String, String> ontology_map_Usecase3 = new HashMap<String, String>();
ontology_map_Usecase3.put("Username",”officeWorker");
ontology_map_Usecase3.put("location","office");
ontology_map_Usecase3.put("activity","videoConferencing");
ontology_map_Usecase3.put("time","noon");
	//interface map of Usecase 3
	HashMap<String, String> interface_map_Usecase3 = new HashMap<String, String>();
	interface_map_UseCase3.put("bluethooth","On");
	interface_map_UseCase3.put("wifi","on");
	interface_map_UseCase3.put("messaging status","off");
	interface_map_UseCase3.put("call status","block");
	interface_map_UseCase3.put("flashlight","off");

	interface_map_UseCase3.put("volume","10"); interface_map_UseCase3.put("brightness","low");

//Usecase 4 Context hashmap
HashMap<String, String> ontology_map_Usecase4 = new HashMap<String, String>();
ontology_map_Usecase4.put("Username","student");
ontology_map_Usecase4.put("location","classRoom");
ontology_map_Usecase4.put("activity","downloading lecture slides");
ontology_map_Usecase4.put("time","morning");
	//interface map of Usecase 4
	HashMap<String, String> interface_map_UseCase4 =new HashMap<String, String>();
	interface_map_UseCase4.put("wifi","on");
	interface_map_UseCase4.put("mobile data","off");
	interface_map_UseCase4.put("volume","5");
	interface_map_UseCase4.put("messaging status","auto");
	interface_map_UseCase4.put("call status","block");
	interface_map_UseCase4.put("bluethooth","Off");

//Usecase 5 Context hashmap
HashMap<String, String> ontology_map_Usecase5 = new HashMap<String, String>();
ontology_map_Usecase5.put("Username","elderly person");
ontology_map_Usecase5.put("location","drawing room");
ontology_map_Usecase5.put("activity","using social network");
ontology_map_Usecase5.put("time","night");
	//interface map of Usecase 5
	HashMap<String, String> interface_map_UseCase5 = new HashMap<String, String>();
	interface_map_UseCase5.put("fontsize","14");
	interface_map_UseCase5.put("wifi","on");
	interface_map_UseCase5.put("volume","10");
	interface_map_UseCase5.put("viberation","on");
	interface_map_UseCase5.put("brightness","medium");

//Usecase 6 Context hashmap
HashMap<String, String> ontology_map_Usecase6 = new HashMap<String, String>();
ontology_map_Usecase6.put("Username","driver");
ontology_map_Usecase6.put("location","roadside");
ontology_map_Usecase6.put("activity","searching for ATM");
ontology_map_Usecase6.put("time","night");
	// interface map of Usecase 6
	HashMap<String, String> interface_map_UseCase6 = new HashMap<String, String>();
	interface_map_UseCase6.put("wifi","on");
	interface_map_UseCase6.put("mobile data","on");
	interface_map_UseCase6.put("volume","10");
	interface_map_UseCase6.put("brightness","high");
	interface_map_UseCase4.put("messaging status","auto");
	interface_map_UseCase3.put("call status","on");