UBIQUITOUS COORDINATED AND MULTIPLE VIEWS

by

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To my family and friends, for their support.

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ABSTRACT

This thesis explores the concept of Ubiquitous Coordinated and Multiple Views (UCMV), or the linking of related static and/or digital views that are distributed in a work environment, we introduce a prototype system that uses the medium of augmented reality (AR) on handheld devices as a means of drawing correlations across paper documents and retrieving related digital content. The thesis focuses on identifying the techniques suitable for selecting items or regions from a document or view. We consider three selection techniques: *Device Pointing*, *Touch on Screen* and *Finger Pointing*. With the *Device Pointing* technique, the mobile device is itself used as a pointer to make a selection by tapping directly on the document. The *Touch on Screen* technique uses the mobile device's screen to make selections. Finally, the user points their finger at a desired document region to make a selection in the *Finger Pointing* technique. We present early design work and preliminary prototype evaluations leading to a set of expected strengths and weaknesses for each of the three techniques. We hypothesized that no one technique would be ideal for the full range of selection operations expected. A formal study was then conducted in order to provide evidence for our hypothesis, grounded in an airplane mechanic scenario. Results show that *Device Pointing* was the fastest and most preferred technique for discrete part selection while the *Touch on Screen* technique was the fastest and most preferred for region selection on large documents. We discuss implications for future UCMV designs, and consider limitations of our study.

LIST OF ABBREVIATIONS USED

CMV	Coordinated and Multiple Views
UCMV	Ubiquitous Coordinated and Multiple Views
AR	Augmented Reality
ANOVA	Analysis of Variance
REB	Research Ethics Board

ACKNOWLEDGEMENTS

CHAPTER 1 INTRODUCTION

Coordinated and Multiple Views (CMV) are an interface pattern wherein one dataset, document or model is shared across many presentations or views. Whenever the model changes, for instance, due to user input or sensor input, the changes are propagated to any and every view (Roberts, 2007). Coordinated and Multiple Views (CMV) consists of several distinct but tightly coupled representations of a data set. This assists researchers to discover structure in data through relating views. Many studies have been conducted involving CMV in the domains of desktop computing and exploratory visualization (Shachtman, 2007).
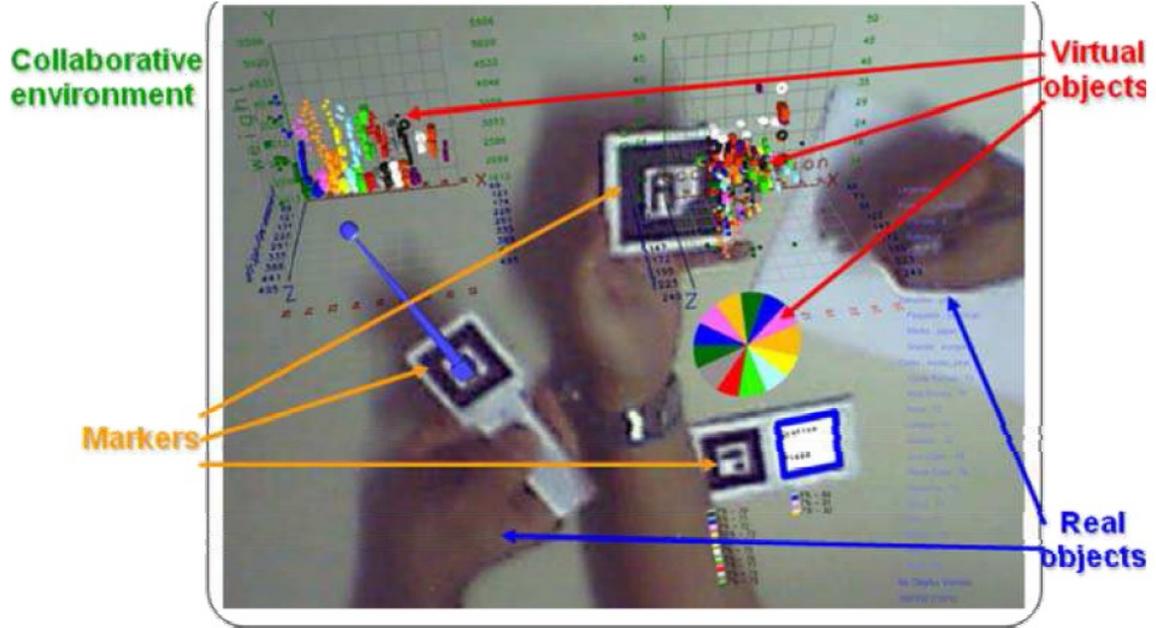
Figure 1: Example of Coordinated and Multiple Views (Meiguins & Meiguins, 2009)

Figure 1 shows an example of Coordinated and Multiple Views using augmented reality. The augmented interface superimposes 3D scatter plots and other virtual objects related to the underlying data. The augmented environment is built with the interaction of real devices and markers (Meiguins & Meiguins, 2009).

1.1 Ubiquitous Coordinated and Multiple Views (UCMV)

UCMV (Ubiquitous CMV) can be defined as a variation of traditional CMV adapted for pervasive interaction ("off-the-desktop") scenarios. UCMV provides the features of just-in-time data, personal and device mobility, and integration with activities and artifacts in the real world. Ubiquity means it is possible to link data views that are distributed across space, and in different media. Consider an airplane mechanic scenario where the mechanic is using two paper documents: one document cataloguing the parts of an airplane, and another document displaying a full schematic drawing of the airplane. We can create a UCMV application using a mobile device in the following way. When a particular part is selected from the first document (using the mobile device to perform the selection), a virtual indication of that part's location might be shown on the schematic via an augmented reality overlay. Prior work evaluated a single technique for item selection on a document (physically pointing at items using an edge of the mobile device) (Reilly, Inkpen & Watters, 2009) (Reilly, Welsman-Dinelle, Bate & Inkpen, 2005) (Reilly, Rodgers, Argue, Nunes & Inkpen, 2005). This thesis considers three distinct selection techniques: *Device Pointing, Touch on Screen and Finger Pointing*.

1.1.1 Motivation for the UCMV Prototype

Documents set are used by the mechanics to perform various kinds of tasks to have meaningful information. Tasks like search a particular part on the engineering document, highlight a part on the document or circle the region on the document to list the parts present in that region are performed by the mechanics. Other task like matching of the parts on the document set can also be performed by the mechanics. These tasks help the mechanics to have information about the engineering parts which can be used to perform essential operations. Mechanics usually follow the manual approach for linking the related documents. Since our project was Boeing company sponsored project, we considered airplane mechanics document set in our prototype to visualize information across the paper documents digitally through a mobile device rather than manually. UCMV prototype selects a part from a document using a mobile device and that part is located as a virtual object on the other document using the medium of augmented reality. UCMV prototype uses the mobile device as a tool for linking the documents digitally to

visualize information across the paper documents. This prototype can help mechanics to perform various tasks using a mobile device on the document set.

1.1.2 Brief Description of the Prototype

An augmented reality prototype was developed for visualizing relationships between two or more paper documents, using Unity 3D software[1]. The prototype offers three selection techniques, enabling the user to select part of one paper document and then see related information overlaid atop another paper document. Paper documents were chosen because we want to see how the information present on the paper documents can be linked to each other digitally through a mobile device. For example consider engineering documents which contains information relevant to each other and can be linked with the help of mobile device instead of doing it manually. This workflow is inspired by the Coordinated and Multiple Views (CMV) approach in information visualization. We used multiple paper documents to demonstrate the phenomenon of Ubiquitous Coordinated and Multiple Views (UCMV).

The three selection techniques are:

- The *Device Pointing* technique: To select a target, the user touches the target with a corner of the mobile device.

- The *Touch on Screen* technique: To select a target, the user views the target through the mobile device's camera and touches the image of the target on-screen.

- The *Finger Pointing* technique: To select a target, the user views the target through the device's camera and covers part of the target with a finger.

1.2 Research Objectives

First we conducted an initial design exploration of the UCMV concept, and then ran a controlled study with 18 participants. We outline the research objectives of both studies here.

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[1] http://unity3d.com/

1.2.1   Design Exploration Research Objectives

1. To refine the research questions of the formal study by identifying potential strengths and weaknesses of the item selection techniques that would be under study.
2. To collect design feedback on the three selection techniques to be assessed in the controlled study. The objective was to refine the prototype prior to the final study.
3. To establish and refine the materials and tasks used in the formal study.
4. To explore the plausibility of UCMV applications across a range of contexts.

1.2.2   Formal Study Research Objectives

1. To evaluate which of the three selection techniques was most suitable, and most preferred by the participants under different kinds of tasks.
2. To build an understanding of how the selection techniques might be used together to support higher level activities involving a range of inter-document correlation actions.

1.3   Contribution

The main contribution of this thesis is an analysis of how to link information across multiple media (in our case, multiple paper documents) using a mobile device. We identify three selection techniques that can be used to relate the documents digitally and provide a characterization of each technique's strengths and weaknesses.

While the research focuses on a specific applied scenario (linking engineering diagrams and parts catalogues in aerospace), many of the results should translate readily into other domains. For example consider a medical scenario where we want to relate the X-Ray documents of a person.

Other students from the Faculty of Computer Science, Dalhousie University also contributed to this thesis. Jihal Patel worked on the initial implementation of the UCMV prototype and consultation for the implementation of this prototype was provided by Joseph Howse. Xiaoyu (Casey) Yu did the video coding of the data of the participants which was collected in the controlled study of the UCMV.

1.3.1 Summary of Results

Design exploration study helped to refine the research questions and tasks for the formal study.

The formal study provided a more in-depth understanding of the relationship between selection technique, task, and document set. Specifically:

- Selecting using the mobile device touch screen was most effective when selecting regions, and when differentiating items placed very close to each other.

- Selecting using the mobile device as a pointer was most effective when selecting discrete items from a catalogue and selecting a part which is very close to another part.

- The bimanual technique (touching the object of interest using the hand not holding the mobile device) was generally not effective and was preferred least overall by participants.

1.4   Overview of the Thesis

The remainder of this thesis is organized as follows.

Chapter 2, Background and Related Work, briefly reviews the Coordinated and Multiple Views literature and explains how UCMV is inspired from CMV. It also describes the concept of Paper Based Augmented Reality using the mobile device camera. The motive of this chapter is to provide the reader with a strong understanding of CMV and UCMV and to situate the contribution of this thesis in relation to prior work.

Chapter 3, Prototype Implementation, presents in detail the implementation of the three UCMV selection techniques i.e. Device Pointer, Finger Pointer and Touch on Screen. It also describes the API (Application Programmer Interface) and software used in the study.

Chapter 4, Design Exploration, presents the pilot study and the focus group that was conducted to explore the UCMV concept and better understand the design requirements of the prototype that was used in the controlled study. This chapter reflects on how the information and feedback obtained was used to refine the research questions, materials and tasks of the final study.

Chapter 5, Formal Study, presents the final study design. This chapter also describes issues encountered when implementing and executing the study, and details about how data was captured during the study.

Chapter 6, Analysis, presents the results of the formal study. After a detailed presentation of specific results, the results are considered in relation to the research goals of this thesis.

Chapter 7, Discussion and Conclusion, provides conclusions and discusses the limitations of this research. The last part of this chapter includes a number of key research and design issues that can be explored in future work.

CHAPTER 2 BACKGROUND AND RELATED WORK

Visualization was defined by McCormick, DeFanti, and Brown as "the study of mechanisms in computers and in humans which allow them in concert to perceive, use, and communicate visual information" (McCormick, DeFanti & Brown, 1987). Users can understand their data better if they can view it through different representations and interact with the presented information (Roberts, 2007). According to Wang Baldonado et al., a multiple view system is the one which is capable of producing two or more distinct views of a single conceptual entity under investigation (Wang Baldonado, Woodruff, & Kuchinsky, 2000). The views can interact either simultaneously or sequentially. The changes encountered in a model are propagated to all the corresponding views (Roberts, 2007). Roberts has identified three modes of generating or modifying multiple views, namely replace, replicate and overlay. In the replace mode, the old views are replaced sequentially by new views. The replicate mode involves presenting related views simultaneously in new window. The new view merges with old views in the overlay mode. According to Roberts, the principle mode of CMV systems is the replicate mode. Our UCMV prototype which is of replicate type shows the relationship between multiple documents through a mobile device. A particular item selected on one document is manifested as a virtual object on top of another document.

2.1   Previous Work on Coordinated and Multiple Views

Thus, CMV interfaces are highly relevant to collaborative editing (Schmalstieg, Fuhrmann, Szalavari, Encarnacao, Gervautz & Purgathofer, 2002), command and control (Mackay, Fayard, Frobert & Médini, 1998) (McGee, Wesson & Horman, 2002), decision analysis (Andrienko & Andrienko, 2003), clinical practice (Hartl, Arth & Schmaltstieg, 2011), forensics (Poelman, Akman, Lukosch & Jonker, 2012), and other contexts that require complex data and inputs to be dynamically filtered, especially for multiple users having different roles.

Coordinated and Multiple Views is a technology used in various domains like visual analytics, file browser system etc. and it is an active research area these days. According to Scherr, CMV consists of isolated views that share a relationship between them (Scherr, 2003). The relationship between these views can be understood through coordination

between them. Coordination between views helps to perform tasks such as information seeking and visualizing large and complex data sets. Poorly designed CMV systems may degrade task performance and can also lead to large complex models of data sets (Pattison & Philips, 2001). CMV is known to improve user performance by reducing the need to manually coordinate views. It also helps to increase awareness of how different perspectives are related. CMV aids in exploratory visualization by enabling users to explore their data from multiple perspectives (Meiguins & Meiguins, 2009). CMV research is also increasingly moving towards the use of CMV as a tool for exploratory visualization (Roberts, 2007). CMV techniques have been applied in broad range of domains. As early as 1986, Shneiderman et al. attempted to increase the efficiency of a programmer by presenting a program browsing tool. In this system, the contents of the windows appeared and scrolled automatically, contrary to most of the other windowing systems of the time, where the user had to perform tedious manipulations and context switching tasks (Shniederman, 1997). Research conducted by the US military suggests that when users are given huge datasets, comprehension and awareness of data is increased when different views of the data are presented to the users (Shachtman, 2007). CMV has also been used by Brodbeck and Girardin to analyze geo-referenced high dimensional data set (Brodbeck & Girardin, 2003).

CMV interfaces may operate through various media. Traditionally, transparent overlays and projectors allow for documents in hardcopy to be dynamically filtered and edited, while indexing schemes facilitate cross-document lookup. CMV survived and thrived in the personal computing revolution, to become commonplace in desktop apps. Windows or tabs may present one document (or related documents) with different filters and editing tools, while hypertext provides the standard means of cross-document lookup. Networking provides the means to open up such applications to collaborative use and to diverse sources of user-generated and third-party documents. With mobile computers, an increasingly popular use of networked CMV is "crowd-sourcing", whereby various users generate and review data about their locales (Lane, Miluzzo, Hong Lu, Peebles, Choudhury & Campbell, 2010).

2.2　Augmented Reality

Augmented Reality is the phenomenon of superimposing a layer of virtual content over physical objects or environments. This effect can be viewed through a head-mounted display, through a mobile device screen, or indirectly on a secondary screen. In Figure 2 we can see that an augmented environment is produced by integrating virtual elements with the underlying data. The figure shows an example of *paper-based augmented reality* by Hull et al. (Hull, Erol, Graham, Qifa, Kishi, Moraleda & Van Olst, 2007). When the text on the paper is viewed through the device camera, related information is linked in the form of a menu (the translucent blue box). In this work, paper documents are scanned and indexed using the "text patch" algorithm to create paper-based augmented reality documents. Rectangular patches of text on the documents are identified as "hot spots". Index information is linked to hot spots in a database. When the user captures the portion of a page with the device camera, the text patch algorithm is used to return the index of the page, the desired screen coordinates of the blue box and a list of hot spots on the page and on nearby pages (Hull et al., 2007).
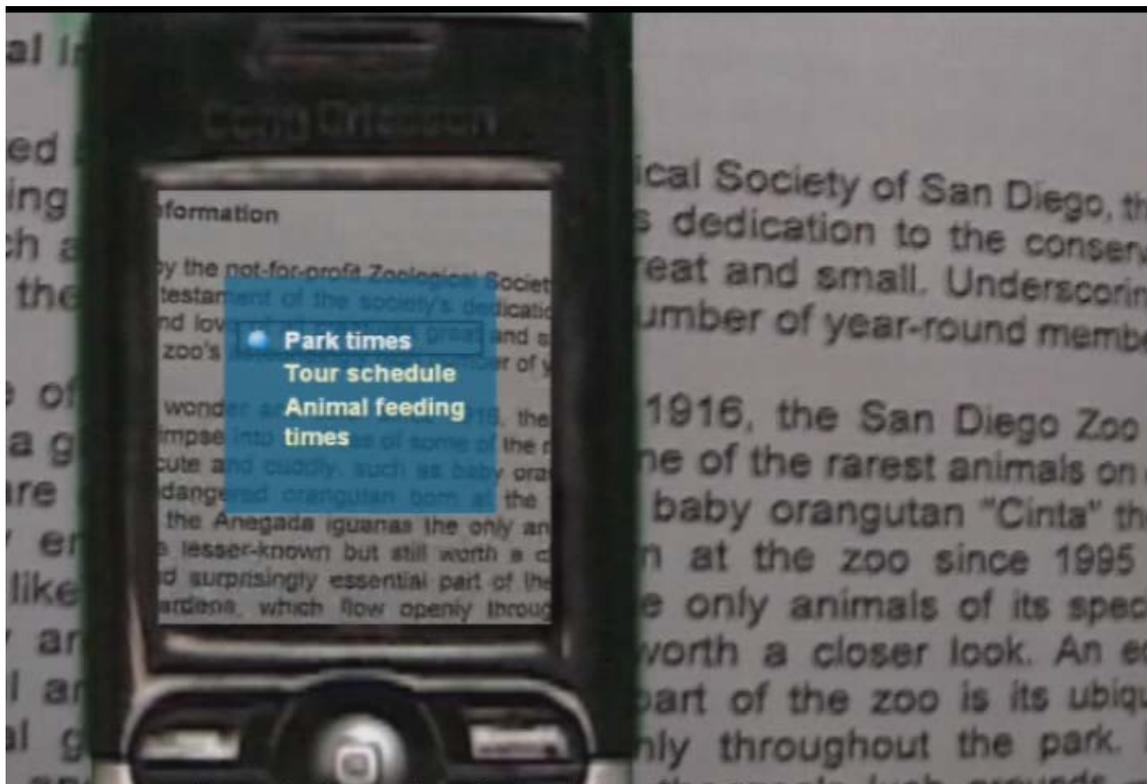
Figure 2: Example of paper based augmented reality (Hull et al., 2007)

2.3   UCMV as a Variation of CMV

Ubiquitous computing is defined as a method that "enhances computer use by making many computers available throughout the physical environment, while having them effectively invisible to the user" (Weiser & Brown, 1996) (Rogers, 2006). Ubiquitous computing may give rise to another set of CMV media and use cases. Coordinated and Multiple Views can be adapted to create a new kind of interface we call Ubiquitous Coordinated and Multiple Views. The term Ubiquitous in UCMV refers to the ability to define and query relationships between analog and digital media distributed in a work context or other environment. In the work presented in this thesis, UCMV are achieved via augmented reality (AR), which is the use of automated object tracking to create the illusion that virtual content exists in real space, in real time (Milgrim, Takemura, Utsumi & Kishino, 1994) (Azuma, 1997). Augmented reality places 2D or 3D digital images over image targets or relative to markers in the physical environment. Applications include, guided manufacturing (Caudell & Mizell, 1992), navigation (Reitmayr & Schmalstieg, 2004), museum tours (Schmalstieg & Wagner, 2005), advertising, and children's items such as picture books (Billinghurst, Kato & Poupyrev, 2001). By requiring only a camera and a recognizable object, AR brings current-generation consumer technology (e.g., smartphones) (Joe Byrd., 2010) (Poslad, 2009) closer to the vision of ubiquity: objects everywhere are relevant to computing, though in AR the objects are mostly not themselves computers.

The concept of UCMV involves linking data present across multiple paper and digital media, in the form of different views and patterns presented on a mobile device. The mobile device is also used as the primary interaction device. UCMV can be applied to visualize data in different forms and across different views. UCMV could include digital views of the underlying data set on large displays and could involve views that aren't laidout carefully on a single tabletop. For example, if we are viewing a particular dataset on a mobile device, a UCMV application would allow us to see the relationship of this data to physical documents or to content on large screens, either simultaneously or as part of an activity sequence. UCMV can also provide scatter plots, pie charts etc. of the underlying data on the large displays or other digital media when the data is selected with the help of the mobile device. For example, selecting a set of stocks in a paper newspaper

using a mobile device might bring up comparative historical data on a nearby display. Brushing and linking are interaction techniques of CMV which are used to reflect changes in the data across the different views. These are the techniques used to perform visual exploration and analysis of large, structured data sets. *Brushing* is a technique which allows the user to move around the data display to highlight or select groups of data points. *Linking* visually indicates which parts of one data display correspond to that of another. Our UCMV prototype highlights the location of parts on airplane schematic diagrams and other aircraft images using a virtual pointer in a corresponding manner. The part is selected from the catalog document using the mobile device (brushing), and the pointer(s) are viewed by holding the device over the related diagrams (linking). Brushing and Linking interaction techniques are relevant to the UCMV prototype because the selection techniques which are used in this prototype select a part from one document and the selected part is represented as a virtual object on the other document, in fact these selection techniques visually indicate parts of one document on the another document.

UCMV can be advantageous when dealing with the combination of hardcopy/softcopy documents. Various complementary characteristics of these documents should be considered when dealing with large and critical data sets. Military command (McGee, Cohen, Wesson & Horman, 2002) and aircraft control (Mackay et al, 1998) provide prime examples, in which operators and decision-makers require the hardcopies failsafe and multi-sensory properties, along with the softcopies' potential for instantaneous transfer and automated filtering.

2.4 Research Gap Analysis

Studies in ubiquitous computing (Weiser & Brown, 1996) and AR (Caudell & Mizell, 1992) (Mizell, 2001) (Ballagas, Borchers, Rohs & Sheridan R., 2006) recommend peripheral and transitory use of the computer. This pioneering work suggests that persistent use of personal computers and personal cameras is failure-prone and cumbersome for people who do multitasking as they have to move around and use their hands to do different things. User studies have also been conducted by (Ruziko, Leichtenstern, Callaghan, Holleis, Schmidt & Chin, 2001) to evaluate three mobile

interaction techniques: scanning, touching and pointing to identify which technique is useful and suitable under a particular scenario and situation for a given context.

The existing studies have not explored the interaction techniques that can be used for building a UCMV interface that can be used peripherally by people doing hands-on work. Therefore, we have explored the computer's use in an outlying role.

The focus of our study is to use UCMV for coordination of multiple hardcopies. In our study, a handheld computer acts a mediator among documents. It is used to select regions or items of interest on documents, and to provide an AR overlay that highlights relationships between selected items and regions on the same document or on other documents. While this technique could also work with digital documents (on a large display, for example), we focus on the hardcopy case in this thesis. In addition, while it is possible to use the mobile device itself to define annotations or modify inter-document relationships (which are then queried via the mobile device) (Reilly, 2006), we do not explore that in this thesis.

The work in this thesis aims to implement and refine a prototype based on UCMV in which a mobile device serves as a tool for understanding relationships between multiple paper documents (for example, a parts catalogue and a mechanical schematic). Items selected from one document can be viewed on another document. By focusing on the selection task, and considering multiple selection techniques, we aim to build a better understanding of how UCMV can support workflows where the computer interface is used peripherally.

2.4.1 Figure showing the mock up design of UCMV

Figure 3 shows the UCMV prototype system in which a mobile device is used to relate the information between the multiple paper documents on the table.

Figure 3: Mock up design of UCMV by Caitlin Bauman.

CHAPTER 3 UCMV PROTOTYPE IMPLEMENTATION

In this chapter the UCMV prototype implementation is described in detail. Jihal Patel worked on the initial implementation of the UCMV prototype and consultation for the implementation was provided by Joseph Howse. The main motivation for the development of this prototype is to determine how the concept of UCMV can be applied to a document set in which the mobile device serves as a tool for relating the information present across the multiple paper documents. Since it was a Boeing company sponsored project, so we chose airplane mechanics document set for the development of the UCMV prototype. Through this prototype airplane mechanics can relate the engineering documents through a mobile device instead of doing it manually. For example if an airplane part is selected from a parts catalogue using a mobile device then that selected part can be located on the airplane schematic by holding the mobile device over the schematic as a lens, through which the selected part will become highlighted. The prototype offers several selection techniques, each enabling the user to select details from one paper document and then see related information overlaid atop one or more related documents. This workflow is inspired by the Coordinated and Multiple Views (CMV) "brushing and linking" interaction paradigm, where "brushing" is used to select detail from one view, and relevant detail becomes highlighted in the other, "linked" views.

3.1   Three Types of Selection Techniques

The three types of selection techniques implemented in the prototype are described in the table 1. Three selection techniques used in the UCMV are *Device Pointing, Finger Pointing and Touch on Screen.*

Selection Technique	Description
Device Pointing	It involves using the mobile device as a pointer on the document to select a particular element or region from it.

Selection Technique	Description
Finger Pointing	It involves viewing the document through the device's camera and pointing to the element (or circling a region) on the paper using a finger on the free hand.
Touch on Screen	It involves viewing the document through the device's camera and selecting an element or region via the touch screen interface.

Table 1: Description of Selection Techniques

Detailed description of all the three selection techniques with figures is described in the next section of this chapter.

3.2   Detailed Description of the Selection Techniques

The prototype realizing the three selection techniques described above was implemented using the Unity game engine (http://unity3d.com/) and the Vuforia image tracking plug-in (http://www.qualcomm.com/solutions/augmented-reality). The prototype was built for standalone (offline) use on an iPhone 4S, with no auxiliary hardware requirements.

Vuforia's image tracking functionality requires that the appearance of the targets be defined at compile time. Vuforia can track freeform images. However, for best results, each target should contain many local contrast features that cover a high proportion of its area and do not form any repeating patterns. When the mobile device is placed on the top of the image target, device camera recognizes the target and the selection operation can be made. If the device camera is moved quickly and a target gets out of focus, if the target is not presented in high contrast, or if lighting fluctuates dramatically, then the device camera may not recognize the targets and the selection operation cannot occur.

3.2.1   Finger Pointing Technique

The *Finger Pointing* technique involves viewing the target through the device's camera and pointing to the target on paper using the free hand. Vuforia provides functionality for "virtual buttons" that correspond to the Finger Pointer technique: when the marker image is occluded, an event is fired.

Virtual buttons are like hotspots on the image target which when touched by the user triggers an event. Virtual buttons can be added to the scene through virtual button prefabs and can be assigned a specific name. We can translate and scale the size of the virtual button to match the desired location/size on the image. Target Events can be associated with these virtual buttons by implementing IVirtualButtonEventHandler. This event handler has two methods "OnButton Pressed and OnButton released[2].

Virtual buttons are placed on the image targets. Whenever an object is encountered between the image target and the AR camera (such as a finger), an event is triggered and the part is selected from that document.

Figure 4: Example of Virtual Buttons on Image targets
(http://www.qualcomm.com/solutions/augmented-reality)

In the figure 4 the green colored regions highlight the extents of four virtual buttons, which can be scaled/translated to match the desired location on the image targets.

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[2] http://www.qualcomm.com/

3.2.1.1 Finger Pointing Technique for Single Item Selection

This technique is used to select an individual part from the document by pointing the finger on the document.

Figure 5: Demonstration of Finger Pointing technique to select a part
(http://www.qualcomm.com/solutions/augmented-reality)

In Figure 5 we can see a document with three virtual buttons labeled A, B and C on three different square boxes. Using the Finger Pointing technique, when a finger is encountered between a label and the mobile device, that particular virtual button is selected.

3.2.1.2 Finger Pointing Technique for Selecting a Region:

This technique is used to select a region on the document. For example, on the airplane schematic virtual buttons are placed around the cockpit region and tail region of the plane. When these buttons are pressed their names are stored in an array. The intention of the array was to capture, in sequence, the buttons traversed by the user's finger as they circled a region. This data would then be used to determine the region bounded by the selected buttons in the array. Rather than analyze the entire array, for the purposes of our evaluation we implemented a version that required that specific predetermined regions were associated with particular virtual buttons. After the region selection operations, we simply check to ensure that the array size is at least three and that the first and last virtual buttons are the same, and are mapped to a region. We used this as an indication that the

associated region has been selected. The limitation of this approach was that the size of the virtual buttons should be adjusted accordingly with respect to the size of the document. If the size of virtual buttons is too big or small then it might lead to problems in selecting the region on the document. If the button size is too small then it is not sometimes recognized by the finger and if the size is too big then it is pressed several times within a fraction of a second.

3.2.2   Touch on Screen Technique

The *Touch on Screen* technique involves viewing the target through the device's camera and selecting using the touch screen. The Touch on Screen selection technique is another standard usage of the Vuforia plugin: when touch coordinates are captured by Unity, they are ray casted into 3D space and tested for collision with a marker's coordinates. The class Raycasthit is used to implement this technique.

3.2.2.1 Touch on Screen Technique for a Single Part Selection.

Figure 6: Demonstration of Touch on Screen technique to select a part

As shown in Figure 6, the user can select the three targets (A, B, C) by touching the target on the screen of the mobile device. When the user selects a particular target, touch

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coordinates are captured by Unity, they are ray cast into 3D space and tested for collision with the marker's coordinates and then user can view the selected target on the other document. There was an implementation issue associated with this technique. Since this technique uses image targets/markers on the documents, there were some problems encountered due to the quality of the documents for tracking purposes. Several of the images and regions in the document set we used for our studies were not optimal for tracking (for example, they did not have many unique high-contrast features). As a result, some study participants found it difficult to select document elements when the mobile device was held further away from the document. To overcome this problem, participants had to move their mobile device quite close to the image targets (less than 20 cm from the image target) on the documents to make the appropriate selection.

3.2.2.2 Touch on Screen Technique for Region Selection

This technique is used to select a region on the document by Touch on Screen technique. This is implemented using the concept of virtual buttons along with the respective colliders in addition to the Raycasthit class as described earlier. Colliders are the built in components of the Unity Software which are used for collision detection in the form of boxes. Virtual buttons with respective colliders are placed around the region of the document. When the user touches the region, touch coordinates are captured by Unity, they are ray cast into 3D space and tested for collision with the respective colliders in the scene. The name of the colliders are saved in the single dimensional array, if the first and last value in the array are same then a pop up box indicates that region is selected on the document. As with the Finger Pointing technique, this algorithm was a shortcut, made possible due to the limited number of regions we needed to support in the study. A general purpose implementation would need to consider all elements in the array to determine the region selected.

3.2.3 Device Pointing Technique

In the *Device Pointing* technique, selection operations are made by tapping a corner of the mobile device on the document. During this interaction, the device's camera does not face the document. However, in a controlled environment such as a lab or a kiosk, it is feasible to use the iPhone's camera to track other markers that have fixed positions relative to the

document; thus, the relative position of the iPhone's corner can be inferred. In this technique distance and angle are measured from the document to the marker on the side wall and with respect to particular angle and distance combination selection is made from the document.

3.2.3.1 Device Pointing Technique for a Single Part Selection

Figure 7: Demonstration of Device Pointing technique to select a part

When an iPhone is tapped against a particular part on the document, it records the distance and angle between the document and the side wall marker. If the distance and angle are within the upper and lower boundary limit of a particular selection, the part is selected from the document, which is indicated by sound.

3.2.3.2 Device Pointing Technique for Region Selection

Regions of a document are selected by dragging the mobile device around the region. During prototype development we encountered major implementation difficulties. As the mobile device measures the angle and distance from the side wall marker to the document, it was difficult to capture and store in the data structure the initial (distance, angle) when region selection was started and final (distance, angle) when region selection

was completed. To overcome this, swiping the mobile device across the region was used to select the region.

CHAPTER 4 DESIGN EXPLORATION FOR UCMV

There were two goals of the design exploration phase. The first was to explore in general the concept of Ubiquitous Coordinated and Multiple Views (UCMV), using the medium of Augmented Reality (AR) on mobile devices. The second was to refine the prototype in preparation for the final study and also to understand the strengths and weaknesses of each selection technique. In particular, we wanted to explore the utility of each selection technique with respect to document size and placement relative to the user. Milestones of this work included the development of a first software prototype, mock-ups of proposed use cases, a pilot study exploring selection techniques, and a focus group session used to explore different techniques and scenarios where UCMV could be used.

4.1 Pilot Study Design

For the pilot study, we used two documents: a 24"-wide schematic of an airplane (Figure 8) and an A4-sized mock-up of a parts catalogue (Figure 9, 10, 11). The version of the prototype used in the design exploration permitted single item selection only (region selection was not yet implemented).
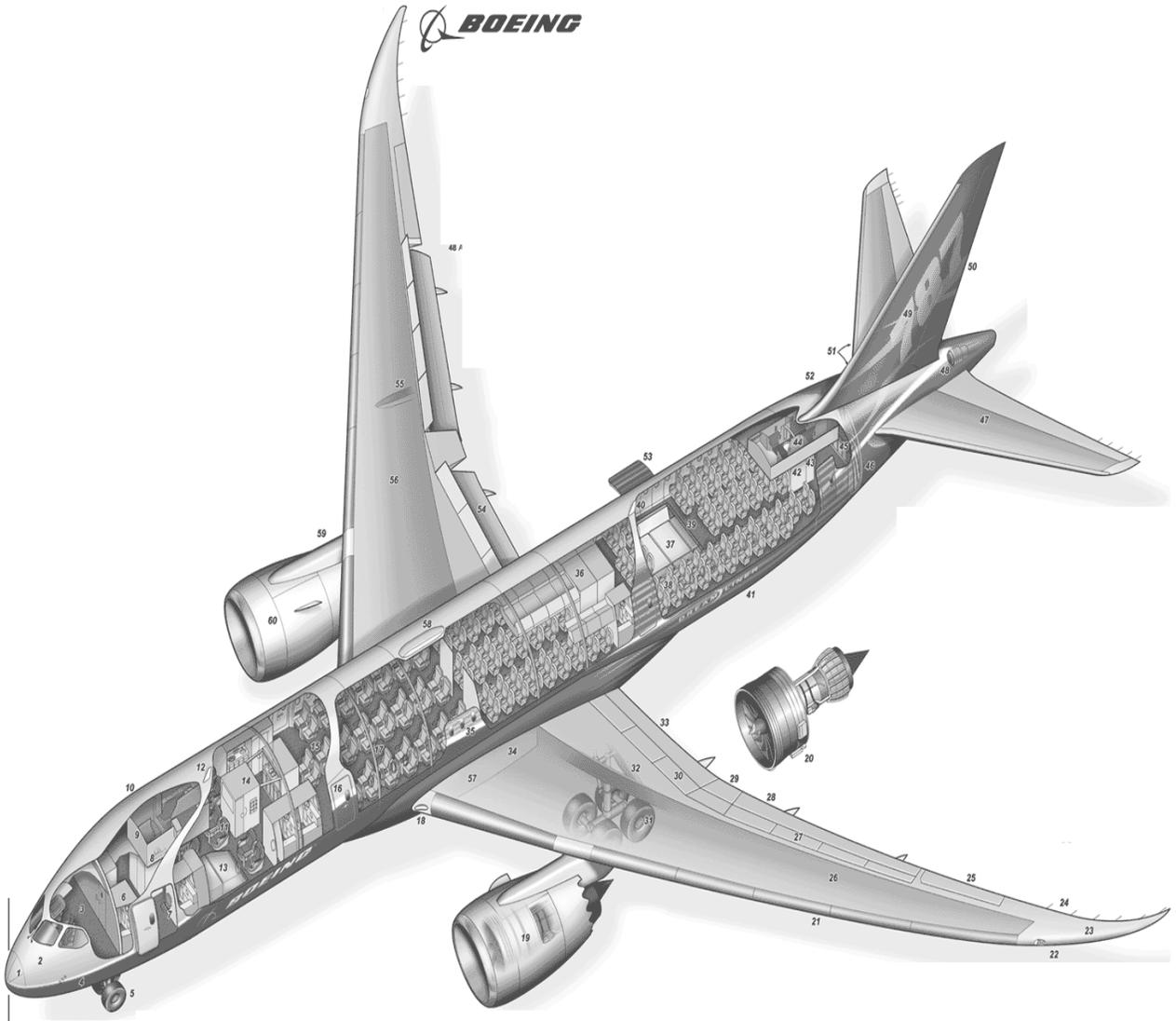
Figure 8: Large Schematic of Airplane

Cockpit

Rudder Peddal
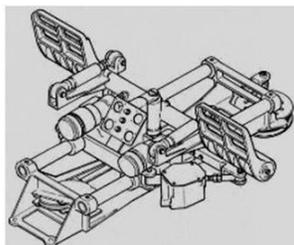
Product Code: 1001
Price: XXXXXX
Weight: XXXXX

Rudder Peddal:

Using the rudder pedals, the rudder is activated and while on ground, the nose wheel, as long as the NWS switch (missile step switch on the SSC)) is activated. When the nose wheel steering is activated, the NWS indexer light on the right indexer at the HUD will glow. By pressing the tips of the pedals on ground, the corresponding wheel-brake is applied. The pedal adjust handle allows the desired pedal positioning.

Side Stick Controller
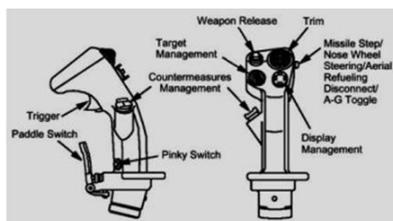
Product Code: 1002
Price: XXXXXX
Weight: XXXXX

Side Stick Controller:

A **side-stick** or **sidestick controller** is an aircraft control column (or joystick) that is located on the side console of the pilot, usually on the righthand side, or outboard on a two-seat flightdeck. Typically this is found in aircraft that are equipped with fly-by-wire control systems. The throttle controls are typically located to the left of the pilot (or centrally on a two-seat flightdeck). Only one hand may thus be used for the stick, and both-hands operation is neither possible nor required.

Figure 9: Page 1 of Catalog Document

Cockpit

Throttle Quadrant
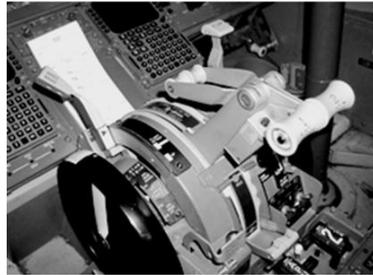
Product Code: 1003
Price: XXXXXX
Weight: XXXXX

Throttle Quadrant:

A throttle quadrant, as the name indicates, is a set of one or more levers that are most often used to simulate throttles or other similar controls in a real vehicle, particularly an aircraft. Throttle quadrants are most popular in conjunction with joysticks or yokes used in flight simulation.

FMS

Product Code: 1004
Price: XXXXXX
Weight: XXXXX

FMS:

A **flight management system** (FMS) is a fundamental part of a modern airliner's avionics. An FMS is a specialized computer system that automates a wide variety of in-flight tasks, reducing the workload on the flight crew to the point that modern aircraft no longer carry flight engineers or navigators. A primary function is in-flight management of the flight plan. Using various sensors (such as GPS and INS often backed up by radionavigation) to determine the aircraft's position, the FMS can guide the aircraft along the flight plan. From the cockpit, the FMS is normally controlled through a Control Display Unit (CDU) which incorporates a small screen and keyboard or touchscreen. The FMS sends the flight plan for display on the EFIS, Navigation Display (ND) or Multifunction Display (MFD).

Figure 10: Page 2 of Catalog Document

Engine

Combustion Liner
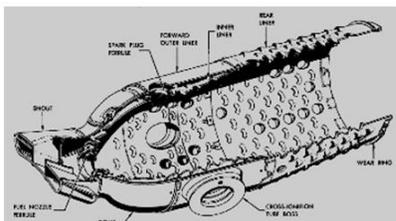
Product Code: 1005
Price: XXXXXX
Weight: XXXXX

Combustion Liner:

The perforated steel liner that fits into the combustion chamber of a gas turbine engine. Fuel is sprayed into this liner. Both combustion air and cooling air flow through the combustion liner.

Turbine Section
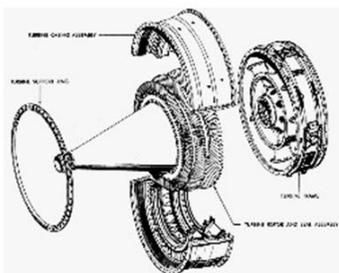
Product Code: 1006
Price: XXXXXX
Weight: XXXXX

Turbine Section:

A **turbine** is a rotary mechanical device that extracts energy from a fluid flow and converts it into useful work. The simplest turbines have one moving part, a rotor assembly, which is a shaft or drum with blades attached. Moving fluid acts on the blades, or the blades react to the flow, so that they move and impart rotational energy to the rotor. Early turbine examples are windmills and water wheels.

Figure 11: Page 3 of Catalog Document

Three selection techniques were used. We refer to them as "Device Pointing technique", "Touch on Screen technique" and "Finger Pointer technique" as described earlier.

4.1.2 Study Details

Four participants completed the pilot study. They were recruited from the Graphics and Visualization Lab at Dalhousie University. The pilot study was conducted with one participant at a time. It started with a demonstration of the three selection techniques so that the participant became familiar with them and could complete the tasks. Next, the participant was asked to carry out three different tasks:

Task 1: The participant was asked to select a part from the catalogue using all three selection techniques and then locate the position of that part in the airplane schematic. The purpose of this task was to determine how participants used the three selection techniques to select a particular part from one document and view it on another document. This helped us to refine the implementation of the three selection techniques for our controlled study.

Task 2: The participant was required to select a particular region on the airplane schematic using whichever selection technique the individual deemed most appropriate. After selecting, the user was asked to move the device over the catalogue document that depicted the parts that were present in the selected region. Since the implementation of the selection techniques was not done for this task when the pilot study was being conducted so the participants were just asked to assume that the implementation is done to complete this task. This task allowed us to explore user preference for the selection operations, and to consider the scenario of selecting a region from a large diagram.

Task 3: The user was asked to select a particular part from one document and then select a part from another document to check whether both the parts were similar or not. Again, the user was asked to do the selection using the selection technique he/she deemed most appropriate for the task. This task was an example of conducting multiple selection interactions in sequence, across more than one document.

The participant was asked to "think aloud" during all tasks. After the participant completed all the tasks, he/she was asked to fill out a questionnaire containing several Likert scale questions about the interfaces. Included in these questions were the following: whether the interface was easy to use; whether the participant was previously familiar with any of the selection techniques; and whether the participant was more focused on the document than on the device while completing the tasks. Also, the participant was asked to explain their choice of selection techniques for the second and third tasks.

Participants were also invited to return for a second session (at a later date), which was conducted as a focus group.

4.1.3 Results: Pilot Study

Pilot study was done with 4 participants, so these 4 participants indicated the following preferences and experiences in the context of each task:

Task 1: The first task was to select a part from catalog document using each selection technique and locate it on large schematic airplane. The participants found all three techniques easy to use. Also, they found that in using these selection techniques, they were able to relate the information in both documents quite comfortably. Of the four participants, one was undecided whether he was focusing more on the documents or on the device, and rest of the participants were more focused on the document than on the device. All the 4 participants said that Touch on Screen selection technique was most familiar technique to use and the other two selection techniques were new to them.

Task 2: Of the four participants, three preferred the Touch on Screen selection technique for performing the task and one participant preferred the Device Pointing technique. Participants said that with the Touch on Screen technique it was easy to circle the region on the screen than to move the finger and the mobile device together in tandem while using Finger Pointing selection technique. They said that Touch on Screen technique was familiar and easy to use. With the Device Pointing selection technique participants said that it was awkward to circle the region on the document with the mobile device.

Task 3: Three of the four participants preferred the Device Pointing technique, and one preferred the Touch on Screen selection technique. Participants said that for selecting a particular part from the document Device Pointing technique was fast and easy to use as they simply have to tap the mobile device against the part which they want to select.

The pilot study had too few participants for statistically significant findings but it can still serve its intended purpose of guiding us to a revised study design. Given the consensus that the tasks were easy, we determined that a more challenging set of tasks, matching a clear, real-world purpose, would elicit stronger preferences and experiences. Also, we see that the device pointer technique is favored often enough to suggest that this novel technique is worthy of further exploration. Overall, on reviewing the results of the pilot study, we felt that the data would not be rich enough, even with a larger sample, to satisfactorily explain why users choose one selection technique over another.

4.2   Focus Group: Design

After the pilot study, the participants were invited for the focus group discussion. In the end, only two participants came for the focus group. This focus group was approved by the Dalhousie's Social Science and Humanities Research Ethics Board and the approval is in Appendix A.

The focus group started with a brief recap of the technology (i.e. how the prototype worked). After that, the participants were told about the results of the pilot study and we asked them to comment or elaborate on these results. We then asked the participants whether they cross-referenced documents or edited multiple drafts (either softcopies or hardcopies) in their day-to-day life, and what their experiences are in working with these documents. Participants were also presented with other mockup scenarios: one involving draft forms, another involving sketches, and a third involving medical images to show them how the concept of UCMV can be applied to different scenarios with different types of documents.

4.2.1   Focus Group Results

Reviewing the results of the pilot study, the participants reaffirmed their previous answers about their preferences. One participant preferred the Touch on Screen selection technique, which he considered the most "natural" because of its similarity to standard iOS app interfaces. The other participant preferred the Device Pointing technique and considered it more "natural". While discussing the selection techniques, he wrote down two notes: *"Should be a natural world interaction" and "People are already trained to maneuver using physical devices, such as mice. (Physical objects)"*.

One of the participants in the focus group had a different interpretation of "natural"-ness than we had foreseen. Both participants said that the layout of the paper documents would be very crucial in choosing the selection technique for a given task. Participants also said that the Touch on Screen and Device Pointing selection technique would be good if the target is within the distance of arm's reach.

The participants wanted to discuss the robustness and portability of each technique. Participants observed that the accuracy of the Touch on Screen selection technique depends on the screen size of the mobile device. Participants preferred the Touch on Screen technique than the other two selection techniques as it was familiar and easy to use.

4.3 Outcomes of the Design Exploration describing the details of the controlled study for the UCMV

4.3.1 Strengths and weaknesses of each selection technique.

Selection Technique	Strengths	Weaknesses
Device Pointing	Good for selecting nearby parts and regions. Good for selecting a part which is close to another part.	Not well suited to select distant targets.
Touch on Screen	Good for selecting near as well as distant targets or regions.	Not well suited for selecting a part which is close to another part
Finger Pointing	Good for selecting a part which are at the distance of arm's reach	Not well suited for selecting regions. Not well suited for selecting a part which is very close to another part.

Table 2: Strengths and weaknesses of each Selection technique

4.3.1.1 Description of the table identifying the strengths and weaknesses of each selection technique.

Device Pointing Technique: We assumed that Device Pointing technique was suitable for selecting the nearby targets and for selecting a part which is very close to other part as the users have to simply tap the mobile device on the document to perform selection without any physical movement, but due to an implementation problem for this selection technique described in chapter 3 for selecting regions, we were not able to implement it efficiently for selecting regions on the document. This selection technique was assumed to be not appropriate to select the distance targets because the participants have to do physical movement to make the selection from the document using the mobile device.

Touch on Screen Technique: Touch on Screen technique was assumed to be the most suitable selection technique for selecting near as well as distant targets and regions on the document as one can just tilt the device to make the selection but due to an implementation issue for selecting a part at a varying distance on the catalogue document described in chapter 3, we were not able to accomplish our objective as we wanted. This selection technique was assumed to be not good for selecting two parts close to each other because the finger size of some participants might be large enough and incorrect selections can be made from the documents.

Finger Pointing Technique: This selection technique was assumed to be well suited for a single part selection from the document which are at the distance of arm's reach as the participants have to simply point to that part using the finger to select it from the document. When the finger is obstructed between the device camera and the part, that part is selected from the document. This technique was assumed to be not good for selecting two parts close to each other because when pointing the finger to a particular part may result in incorrect part selection and also selecting regions on the document as it would be difficult to move the finger and mobile device camera in tandem together.

The design exploration phase helped to refine the task set that we used in the controlled study. Since the task set that we first used was not challenging, a richer set of tasks tied to meaningful information-seeking activities was used in the formal study. Through the

design exploration we identified that a particular selection technique is suited for a particular kind of task so a task set consisting of 4 tasks was identified in which 2 tasks were best suited to a particular selection technique and the other two tasks more likely to be completed by that selection technique.

Through the focus group discussion with the participants in the design exploration of the UCMV the researcher identified what type and layout of document sets should be used in the controlled study. Two document sets (Airplane Mechanic scenario and Grocery Store scenario) were finalized to be used in the controlled study. We were unable to get high contrast image targets of grocery store so only one document set of airplane mechanic documents were used in the formal study.

No digital data was captured during the pilot study such as time taken to complete the task, angle and distance of the device with respect to the document. It was felt that this data could give us a more detailed understanding of selection behavior with the three techniques, so we captured this data in software logs for the formal study. Also 4-5 minute interviews were conducted after the study with each participant.

CHAPTER 5 CONTROLLED STUDY FOR UCMV

The outcomes of the pilot study helped us to refine the research questions, tasks and materials for the controlled study. After the design exploration phase, a controlled study was performed with 18 participants to evaluate the UCMV prototype. A set of meaningful tasks (Appendix G) was prepared which consists of 4 types of tasks. This study was approved by the Dalhousie's Social Science and Humanities Research Ethics Board and the approval is in Appendix E

5.1 Research Objectives

1. To determine which of the three selection techniques is most suitable and most preferred by the participants, under a variety of tasks.

2. To build an understanding of how the techniques might be used together to support higher level activities involving a range of inter-document correlation actions.

5.2 Study Design

The study employed a within-subjects design with 1 factor (selection technique). 18 participants were recruited for the study. An email was sent to all the students and faculty of the Faculty of Computer Science at Dalhousie University. Students who were interested were recruited for the study. 14 participants recruited for the study were from the computer science department and 4 participants were from the engineering department. No demographic information of the participants was collected, but all participants were in the range of 18-25 years of age. 12 out of the 18 participants were male and 6 were female. There was no specific reason for the recruitment of these participants as no experience was required with the use of smart phone mobile devices. Participants conducted tasks using each of three selection techniques (Device Pointing, Touch on Screen, Finger Pointing), for a document set. The document set used in the study was built on an aerospace scenario that is relevant to our industry sponsor **(Figure 8, 9, 10 and 11).** The three selection techniques were called Device Pointing technique, Touch on Screen technique, and Finger Pointing technique as described earlier. We counterbalanced the selection technique order using a partial Latin Square (3 orderings with 6 participants each).

The interfaces, tasks and paper documents used reflected the preliminary findings of the design exploration phase (Pilot Study). In particular we identified task types, for each of the three selection techniques that we believed to be best accommodated by that selection technique. Touch on Screen technique was assumed to be best suited to select distance targets and large regions on the documents because we could just tilt the device to make the selection. Device Pointing technique was assumed to be best suited to select nearby parts or regions and to select a part which is very close to another part because the participants simply have to tap the mobile device on the document to make the selection. Finger Pointing technique was assumed to be best suited to select a single part at a varying distance on the document as the participants have to point to a particular part by their finger to make the selection. We also found that selecting regions would not be well served by finger pointing because it would be awkward to move the device and the pointing finger in tandem.

Task set (1 task set with 4 task types) were created. That is, under each interface condition participants conducted two tasks that were best-suited to the selection technique being used, plus two tasks that were more easily completed by that selection technique described in the table below. The order of the tasks in the task set was randomized for each interface condition to counterbalance the learning effect. The task set that was used is described below:

5.2.1 Task Set used to evaluate the UCMV

This section describes the task set that was used to evaluate the UCMV prototype. It consists of 4 different types of task described in table 2.

Task No.	Description of the Tasks

1.	You want to retrieve engineering data about specific regions of the aircraft, listed below. For each, circle the region and verify that it has been selected (a pop up box will indicate this).
	
	     a. Upper wing
	
	     b. Cockpit

Task No.	Description of the Tasks

2.	You wish to identify the location of specific parts on the aircraft. For each of the parts listed below:
	
	  a. select the part from the catalogue
	
	  b. locate the part on the cockpit or engine diagram
	
	  c. identify the region of the aircraft where it is situated

3.	You wish to locate specific cockpit parts in the catalogue. For each of the parts listed below:
	
	  a. Locate and select the part on the cockpit diagram
	
	  b. Locate the part image and description in the catalogue and answer the question listed with the part, below.
	
	Parts: *Side Stick Controller (Question: what kind of control system does an aircraft with a side stick controller typically have?) , Flight Management System (Question: What is the product code for the FMS in the catalogue*

4.	You want to attach a voice memo about the engine turbine to all relevant documents. To do this, you will select the relevant document regions in sequence, as follows:
	
	  a. Engine pop-out on airplane schematic (listed as part #20)
	
	  b. Turbine section of engine diagram
	
	  c. "Turbine section" item in catalogue

Table 3: Task set used to evaluate UCMV

We chose this task set to evaluate which selection technique is preferred by the participant for each task type. Each task described in the table 3 consists of sub tasks which evaluate the strengths and weaknesses of each selection technique as described in table 2 of the previous chapter.

The table 4 in the next section of this chapter lists the tasks described in table 3 that would illustrate the strengths and weaknesses of each selection technique. There were tasks which were left out of scope of this study, For example a group task might highlight how finger pointer and device pointer give a visual indication of selection to your collaborator, but we did not included this group task because the study was focused on individual interaction.

5.2.2   Table consisting of the tasks which would illustrate the strengths and weaknesses of each selection technique

Tasks	Assumptions at the beginning of the study
Task 1 a. Cockpit Region (Near Region) b. Upper Wing Region (Far region)	 Well suited for Device Pointing and Touch on Screen technique Not well suited for Finger Pointing technique Well suited for Touch on Screen technique Not well suited for Device Pointing and Finger Pointing technique
Task 2 a. Rudder Pedal (Near Part) b. Throttle Quadrant (Intermediate Part) c. Combustion Liner (Far Part)	 Well suited for Finger Pointing and Device Pointing selection technique as well as Touch on Screen technique Well suited for Finger Pointing and Touch on Screen selection technique Not well suited for Device Pointing technique Well suited for Touch on Screen and Finger Pointing selection technique Not well suited for Device Pointing technique

Tasks	Assumptions at the beginning of the study
Task 3 a. Side Stick Controller and Flight Management System (Two Parts close to each other)	Well suited for Device Pointing selection technique Not well suited for Finger Pointing and Touch on Screen technique
Task 4	Well suited for Device Pointing and Touch on Screen technique. Not well suited for Finger Pointing technique

Table 4: Indicating the suitability of the selection technique for a particular task

5.2.2.1 Description of the table consisting of the tasks which would illustrate the strengths and weaknesses of each selection technique

Task 1:

Device Pointing technique was assumed to be good for selecting cockpit region (nearby region) as the participants simply have to tap the mobile device on the document to make the selection from the document but this selection technique would not be good for selecting upper wing region (far region) as the participants may have to do physical movement to make the selection from the document. There was an implementation issue with this selection technique for region selection as described earlier.

Touch on Screen selection technique would be good for selecting both cockpit (nearby region) and upper wing (far region) as one can just tilt the device to make the selection from the document.

Finger Pointing selection technique would not be good for selecting both cockpit (nearby region) and upper wing (far region) as it is difficult to move the finger and the mobile device in tandem together to select the region from the document

Task 2:

Device Pointing technique was assumed to be good only for selecting Rudder Pedal (near part) as one can simply tap the device on the document to make the selection but this selection technique was assumed to be not good for selecting the Throttle Quadrant (intermediate part) and Combustion Liner (farthest part) as participants may have to do the physical movement to select the distant part from the document.

Touch on screen technique was assumed to be good for selecting all the three parts which were at a varying distance from the document as one can simply tilt the mobile device to make the selection from the document. There was an implementation issue with this selection technique for this task as explained in the previous chapter.

Finger Pointing technique was assumed to be well suited for all the three parts on the document as the participants simply have to point to a particular part to make the selection from the document.

Task 3

Device Pointing technique was assumed to be best suited for this kind of task where two parts are very close to each other as the participant simply have to tap the mobile device on the document to make the selection.

Touch on Screen technique was assumed to be not well suited for this task as the size of the finger of some participants might be large enough with respect to the screen size which can make the wrong part selection on the screen of the mobile device.

Finger Pointing technique was also assumed to be not well suited for this task as participant may point to the wrong part on the document.

Task 4

Device Pointing Technique was assumed to be well suited for this task as the participants simply have to tap the mobile device on the document set to make the multiple selections from the documents.

Touch on Screen Technique was also assumed to be well suited for this task as one can just tilt the device to make the multiple selections on the screen device from the document set.

Finger Pointing technique was assumed to be not good for this task as it would be difficult for the participants to move the mobile device and the finger in tandem together over the documents to make the selection from the document.

5.2.3 Location of the Research

The study was conducted in the HCI Lab, located in the Computer Science section of the Mona Campbell Building (4th floor).
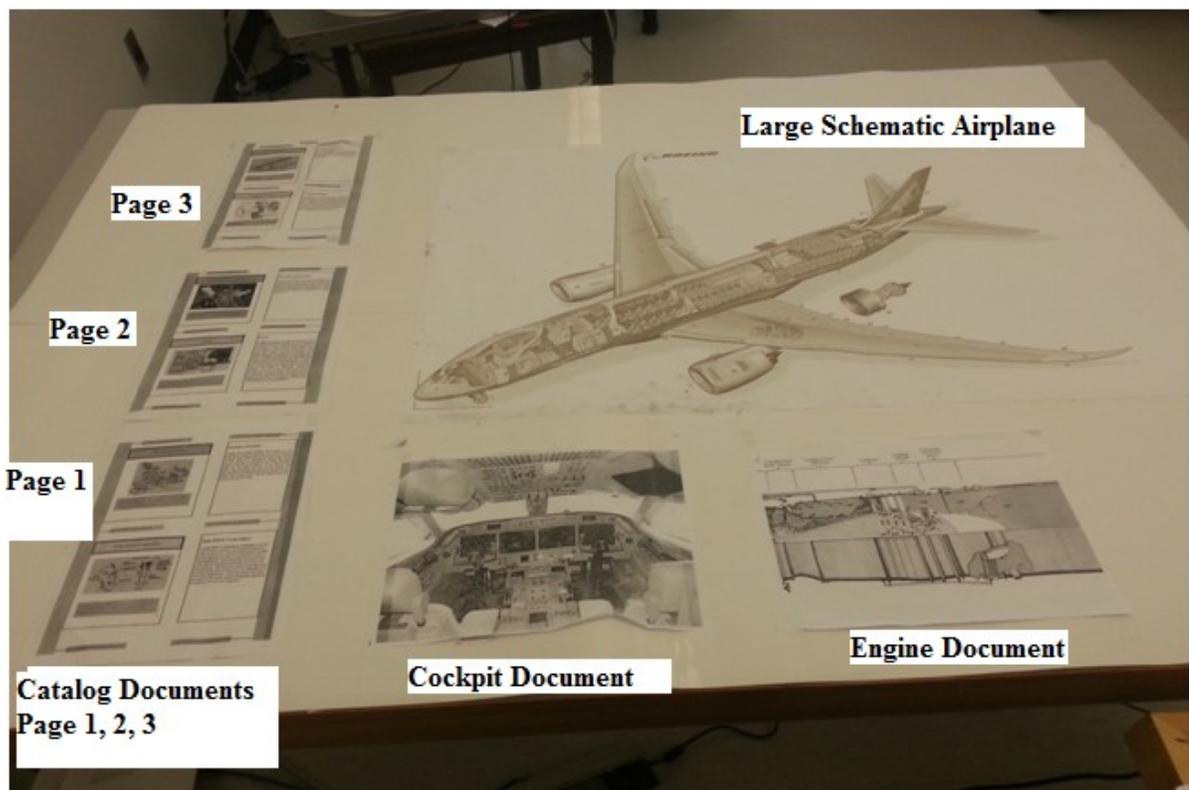
Figure 12: Layout of the documents used in the UCMV study

5.2.4 Study Details

The researcher met with the participants in the Mona Campbell building. The study took about 90 minutes with each participant. The researcher discussed the study and answered

any questions prior to starting the study, and got informed consent **(Appendix B)**. Participants then performed each study condition (selection technique), completing a task set with a selection technique and then filling out the post condition questionnaires **(Appendix C).** The first four questions in the post condition questionnaire were filled by the participant after the each study condition (selection technique) and the last question in the questionnaire in which they have to rate the selection techniques for a particular task was filled by the participant after each task performed by them. After the three conditions were completed, the participant then answered the interview questions. At the end of the study we performed a very short interview where the only two questions we asked were which selection technique they preferred for a particular kind of task and the reason for the preference of that selection technique.

Participants were given a document set **(Figure 8, 9, 10 and 11).** At the beginning of each selection technique condition the facilitator demonstrated the technique and then asked the participant to repeat the demonstrated operation themselves, before attempting the task set for that technique.

After this training (lasting approximately 2 minutes per selection technique), participants were provided with the first task to complete in that condition. The prototype interface was set up to perform that task, and paper materials related to the task were placed before the participant. Each task was completed in turn in this way, until all four tasks in a task set were complete. The facilitator took notes of participant behaviour when completing the tasks. A post-condition questionnaire was also completed by the participants as described above. Participants were also interviewed for 4-5 minutes at the end of the study to note interesting behaviours that they encountered when completing the tasks.

5.2.5   Data collected from the study

When performing tasks with all the three selection techniques, interactions were logged by the software. Specifically, the software captured the time taken from the start of the task to the time the selection operation was made, the angle of the mobile device with respect to the underlying document at the time of selection, and the hit distance from the mobile device to the document at the time of selection. This data was recorded on a

spreadsheet for each of the participants. Box plots for each of the tasks completed using the three selection techniques were constructed and analysed, as discussed in Chapter 6 (Data Analysis). Statistical Package for the Social Sciences (SPSS) software was used to analyze the data recorded in the spread-sheet. One way Anova and Posthoc test known as "Tukeys" were used to do the analysis of the data. All interactions were captured using a motion capture camera (Kinect), and videotaped. The Kinect motion tracking data was not used in analysis. Video coding was done for all participants. Video coding was done to determine how the participants were using the mobile device to perform different kinds of tasks using each of the selection technique for example moving the mobile device very close to the document or close to their eyes or how the participants were using their finger with respect to the device camera while performing tasks using Finger pointing selection technique. This data was used to see how participants used the mobile device to locate the individual parts or circle the regions on the documents. It also helped us to determine any exceptional behaviour of the participants to complete any of the tasks. Participants also completed post-condition questionnaires with two sections. The first section asked the participants to assess their comprehension about the relationships between documents used during the tasks. The second section asked the participants to rate the interface used for each of the tasks completed in the condition (**Appendix C**). At the end of the experiment, the facilitator conducted an interview with the participants in order to elicit explanation and reflection about interesting behaviours that were noted during the experiment.

CHAPTER 6 DATA ANALYSIS

We categorized the results of the formal study according to the research questions that we wanted to answer. Data such as software log data, questionnaire data, interviews and video coded data were recorded and analyzed. Xiaoyu (Casey) Yu did the video coding of the data of the participants who participated in the controlled study of the UCMV.

6.1 Research Question 1:

To determine which of the three selection techniques is most suitable and preferred by the participants, under a variety of tasks.

6.1.1 Task 1:

You wish to identify the location of specific parts on the aircraft. For each of the parts listed below:

a. select the part from the catalogue
b. locate the part on the cockpit or engine diagram
c. identify the region of the aircraft where it is situated

Parts: ***Rudder Peddal , Throttle Quadrant, Combustion Liner***

The purpose of this task was to determine which selection technique is preferred by the participants to make a particular part selection which are at varying distances from the participant. The three parts were placed on the document vertically. Rudder Pedal was the nearest part, Throttle Quadrant was the intermediate part and Combustion Liner was the farthest part on the document.

From the table 2 described in the design exploration of the UCMV, we expected that both Touch on Screen and Finger Pointing technique would be good for all the three parts mentioned above and Device Pointing would be good only for the nearest part (Rudder Pedal) but from the results for this task we found that Device Pointing was the most suitable and preferred selection technique for all the three parts. There were implementation issues with the Touch on Screen selection technique. No participants preferred the Touch on the Screen technique for this task. This is in direct contrast from our expectation, which was that the touch technique would be advantageous particularly

when selecting items further away from the participant (as they would not need to reach to select the target). We attribute this result in part to an implementation issue. Since the Touch on Screen technique captures the coordinates of the image target and then these coordinated are ray casted into the 3D space for collision against the marker coordinates. The implementation of this technique was not able to recognize marker coordinates because the quality of image targets that were used was not of very good quality so when participants were trying to select a part from the catalogue they were not able to select it easily. To overcome these problem participants were asked to move the mobile device very close to the catalogue document so that the target could be easily captured. So this was the reason that this selection technique was taking more time to complete this task as compared to other techniques.

With the Finger Pointing technique, participants were experiencing some difficulty when adjusting their finger position relative to the camera position in this task. Participants were not able to adjust the position of their finger on a particular part with respect to the mobile device camera.

6.1.1.1 Software log Data Analysis

Data such as time taken to complete the task, hit distance from the mobile device to the image target and hit angle of the mobile device with respect to the image target when the selection was made on the document for each selection technique and task was logged in the software in the form of text files and was analyzed using the IBM SPSS software.

Time taken to complete the task: It is the time taken by the participant (in seconds) to complete the task when the interface for the selection technique is started till the part is located on the large schematic diagram.

The Box plot (Figure 13) shows the time taken by the participants for each of the selection techniques to complete this task for the "**Rudder Pedal**" part. This part was located on the large schematic diagram after selecting it from the catalog document by the participant.
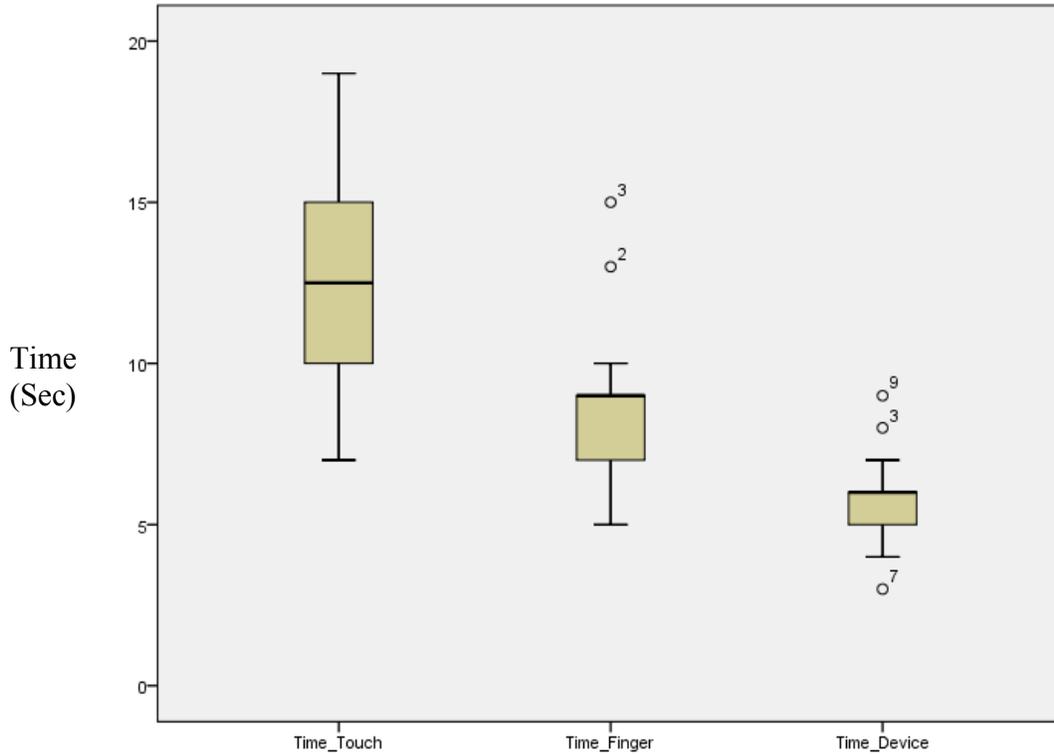
Figure 13: Box Plot for time taken to complete the task for Rudder Pedal part

Table 5 shows the mean and standard deviation of the time taken for the Rudder Pedal part in seconds for each of the selection technique.

	Time_Touch	Time_Finger	Time_Device
Mean	12.5556	8.6111	5.6667
No. of Participants	18	18	18
Std. Deviation	3.05291	2.45282	1.49509

Table 5: Mean and Standard deviation of the time taken for Rudder Pedal part in seconds for each of the selection technique.

There was a statistically significant difference between selection techniques as determined by one-way ANOVA (F (2, 51) = 36.716, p = .002). A Tukey post-hoc test revealed that the time to complete the task was statistically significantly lower for the Device Pointing Technique as compared to the Finger Pointing technique and Touch on Screen Technique.

Box plot (Figure 14) show the time taken by the participants for each of the selection techniques to complete this task for the "**Throttle Quadrant**" part. This part was located between the nearest and farthest part.

Time (Sec)
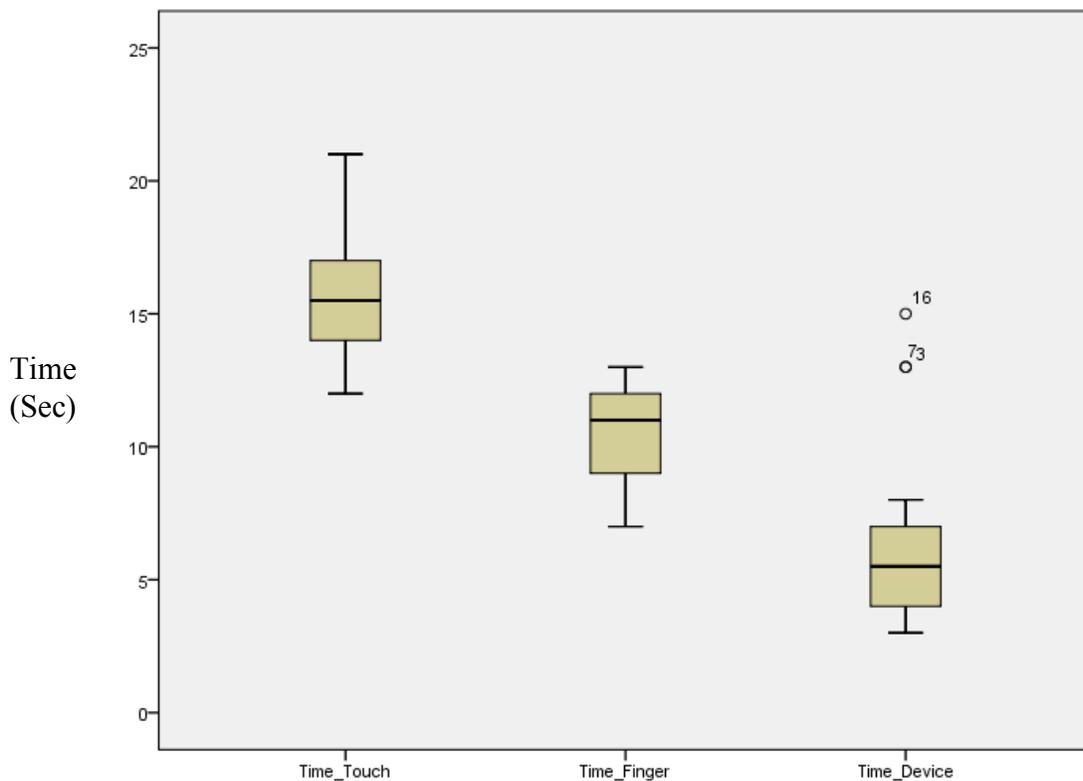
Figure 14: Box Plot for time taken to complete the task for Throttle Quadrant

Table 6 shows the mean and standard deviation of the time taken for the Throttle Quadrant part in seconds for each of the selection technique.

	Time_Touch	Time_Finger	Time_Device
Mean	15.6111	10.6111	5.6667
No. of Participants	18	18	18
Std. Deviation	2.25281	1.81947	1.49509

Table 6: Mean and Standard deviation of the time taken for Throttle Quadrant in seconds for each of the selection technique

There was a statistically significant difference between groups as determined by one-way ANOVA (F (2, 51) = 29.993, p = .001). A Tukey post-hoc test revealed that the time to complete the problem was statistically significantly lower for Device Pointing technique as compared to the Finger Pointing technique and Touch on Screen technique.

Box plot (Figure 15) show the time taken by the participants for each of the selection techniques to complete this task for the "**Combustion Liner**" part.
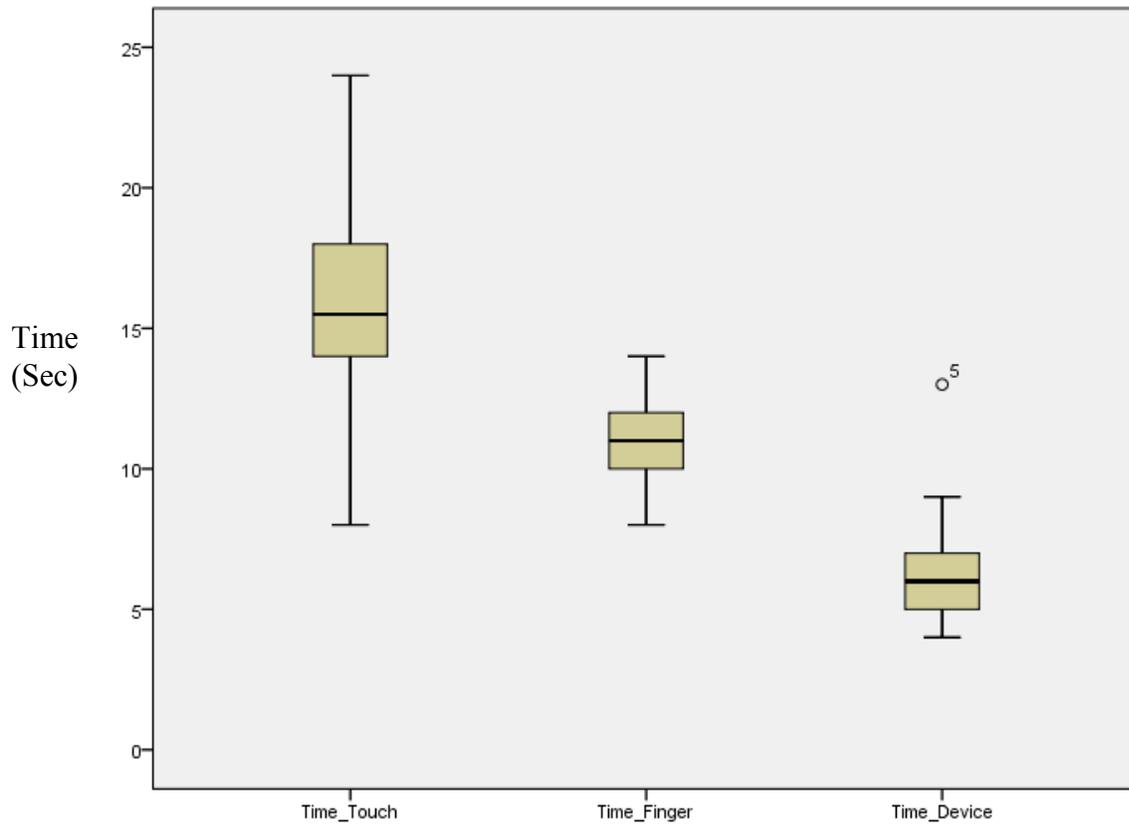
Figure 15: Box Plot for time taken to complete the task for Combustion Liner

Table 7 shows the mean and standard deviation of the time taken for the combustion liner part in seconds for each of the selection technique.

	Time_Touch	Time_Finger	Time_Device
Mean	15.6667	11.0000	6.3889
No. of Participants	18	18	18
Std. Deviation	3.71008	1.78227	2.17307

Table 7: Mean and Standard deviation of the time taken for Combustion Liner in seconds for each of the selection technique

There was a statistically significant difference between groups as determined by one-way ANOVA (F (2, 51) =52.502, p = .002). A Tukey post-hoc test revealed that the time to complete the problem was statistically significantly lower for the Device pointing technique as compared to the Finger pointing technique and Touch on Screen technique.

Hit Distance: It is the distance between the ray start point from the mobile device and the hit point on the image target. It was logged in software and analyzed for the Finger Pointing technique and Touch on Screen technique using the SPSS software. Since the Device Pointing technique relied on a different mechanism for selection (markers on the side wall), we do not include that technique in this analysis.

Box plot (Figure 16) show the hit distance for **Rudder Pedal** part which was the closest part on the document.
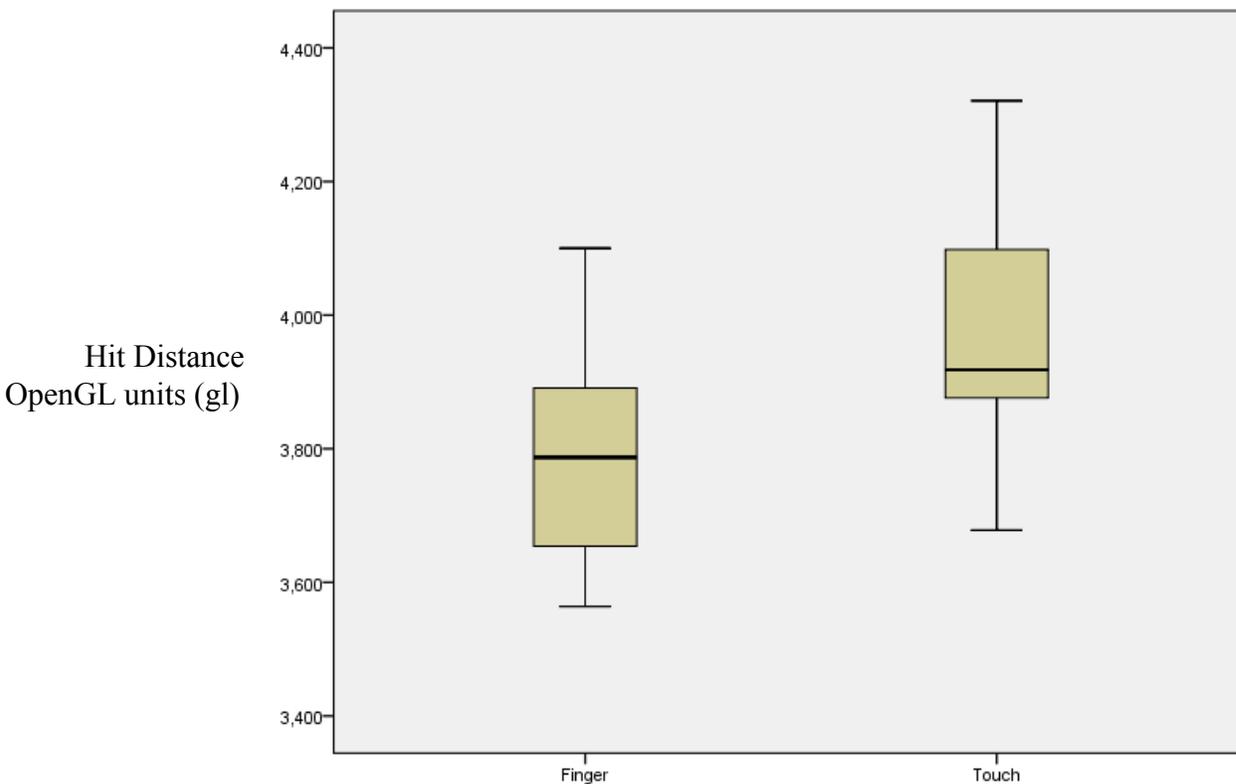
Figure 16: Box Plot for hit distance for Rudder Pedal part

Table 8 shows the mean and standard deviation of the hit distance in OpenGL units (gl) for the Rudder Pedal part for Touch on Screen and Finger Pointing technique.

	Hit_Distance_Finger	Hit_Distance_Touch
Mean	3786.5000	3984.3889
No of Participants	18	18
Std. Deviation	142.88302	182.40876

Table 8: Mean and Standard deviation of the hit distance for Rudder Pedal in OpenGL units (gl) for Touch on Screen and Finger Pointing technique.

There was no statistically significant difference between groups as determined by one-way ANOVA (F (16, 1) =5.942, p = .313).

Box plot (Figure 17) show the hit distance for **Throttle Quadrant** part which was the middle part on the document.

Figure 17: Box Plot for hit distance for Throttle Quadrant part

Table 9 shows the mean and standard deviation of the hit distance in OpenGL units (gl) for the Throttle Quadrant part for Touch on Screen and Finger Pointing technique.

	Hit_Distance_Finger	Hit_Distance_Touch
Mean	3674.8333	3535.8333
No. of Participants	18	18
Std. Deviation	249.96876	326.28231

Table 9: Mean and Standard deviation of the hit distance for Throttle Quadrant in OpenGL units (gl) for Touch on Screen and Finger Pointing technique.

There was no statistically significant difference between groups as determined by one-way ANOVA ($F_{(15, 2)} = .980$, $p = .980$).

Box plot (Figure 18) show the hit distance for **Combustion Liner** part which was the farthest part on the document.

Hit Distance OpenGL units (gl)
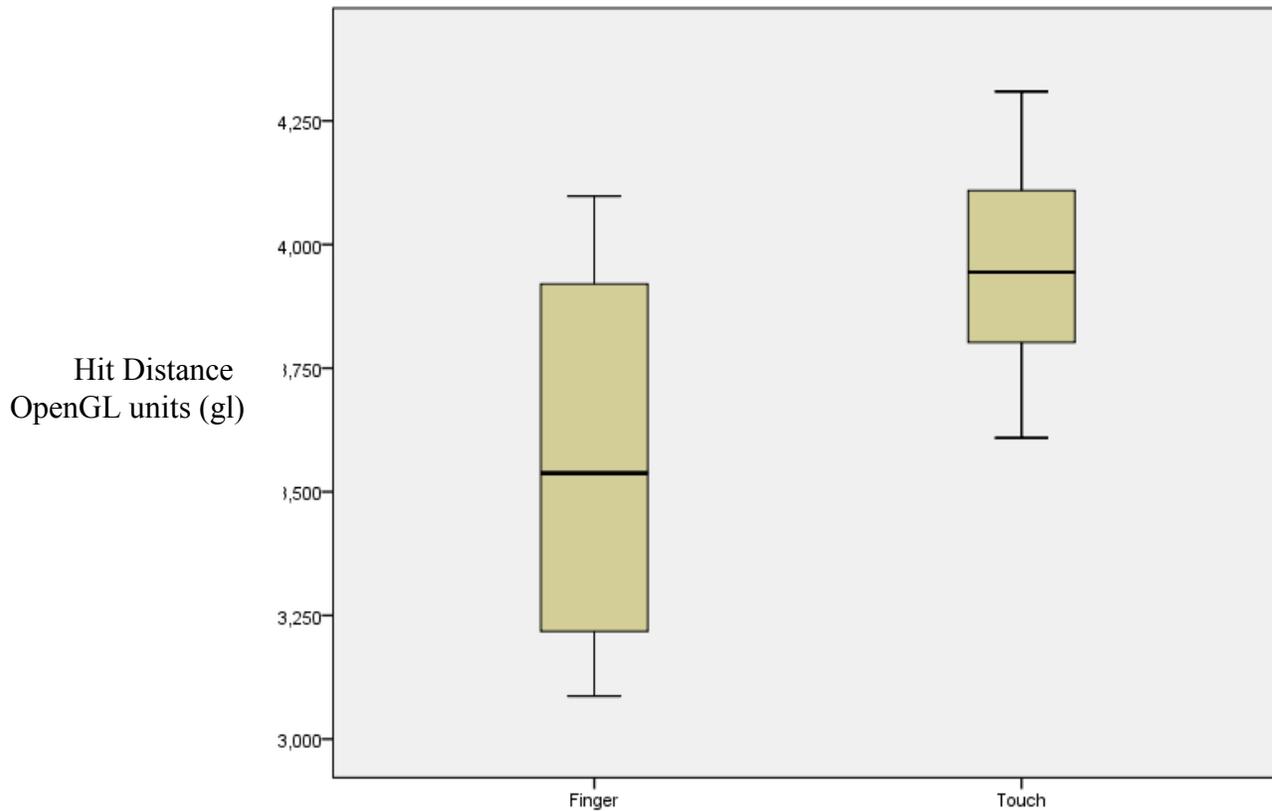
Figure 18: Box Plot for hit distance for Combustion Liner part

Table 10 shows the mean and standard deviation of the hit distance in OpenGL units (gl) for the Combustion Liner part for Touch on Screen and Finger Pointing technique.

	Hit_Distance_Finger	Hit_Distance_Touch
Mean	3987.2976	3654.2354
No. of Participants	18	18
Std. Deviation	349.96876	228.28231

Table 10: Mean and Standard deviation of the hit distance for Combustion Liner in OpenGL units (gl) for Touch on Screen and Finger Pointing technique.

There was no statistically significant difference between groups as determined by one-way ANOVA ($F_{(16, 1)}$ =3.320, p = .409).

Hit Angle: It is the angle between the mobile device and the image target when the selection was made from the document. It was logged in software and analyzed for the Finger Pointing technique and Touch on Screen technique using the SPSS software

Box plot (Figure 19) show the hit angle for **Rudder Pedal** part which was the closest part on the document
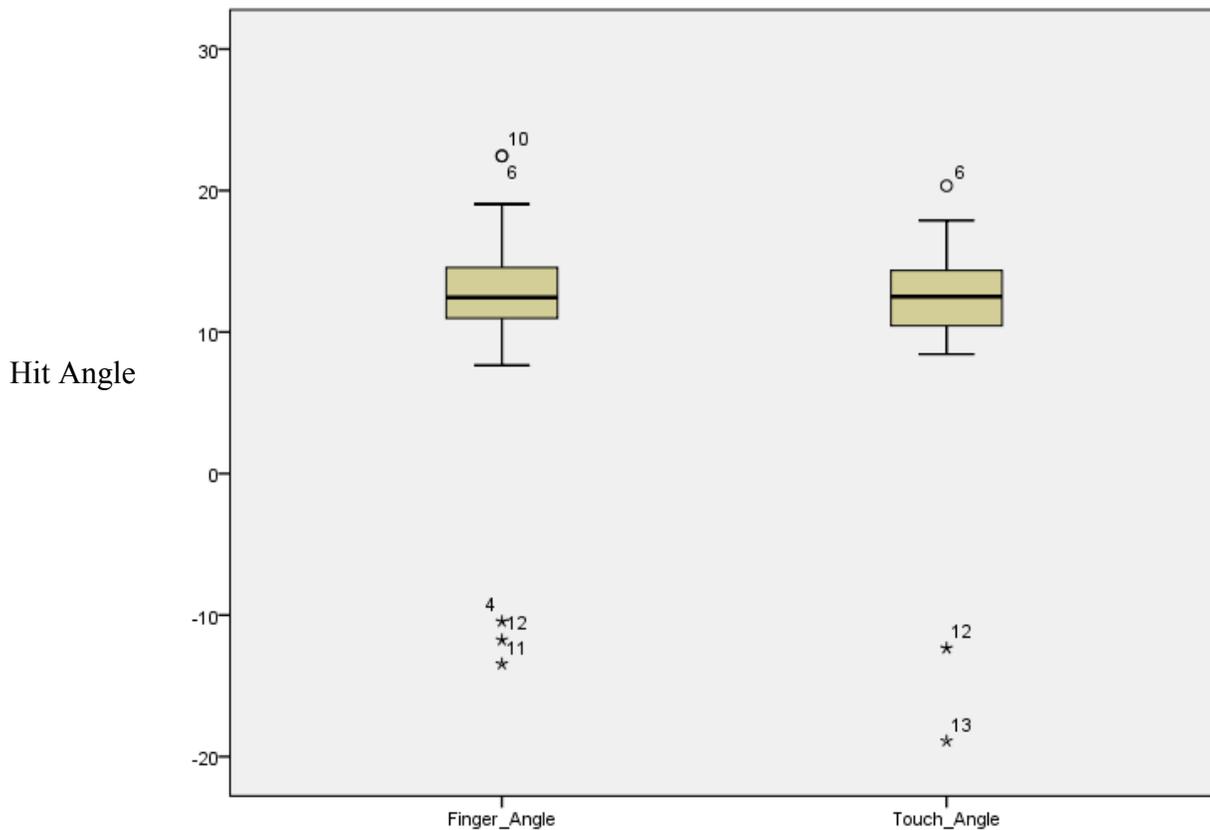
Figure 19: Box Plot for hit angle for Rudder Pedal part

Table 11 shows the mean and standard deviation of the hit angle for the Ruder Pedal part for Touch on Screen and Finger Pointing technique.

	Touch_HitAngle	Finger_HitAngle
Mean	10.1611	11.7522
No. of Participants	18	18
Std. Deviation	9.85671	11.83892

Table 11: Mean and Standard deviation of the hit angle for Rudder Pedal in degrees for Touch on Screen and Finger Pointing technique.

There was no statistically significant difference between groups as determined by one-way ANOVA (F (17, 0) = 0.406, p =0.894).

Box plot (Figure 20) show the hit angle for **Throttle Quadrant** part which was the middle part on the document
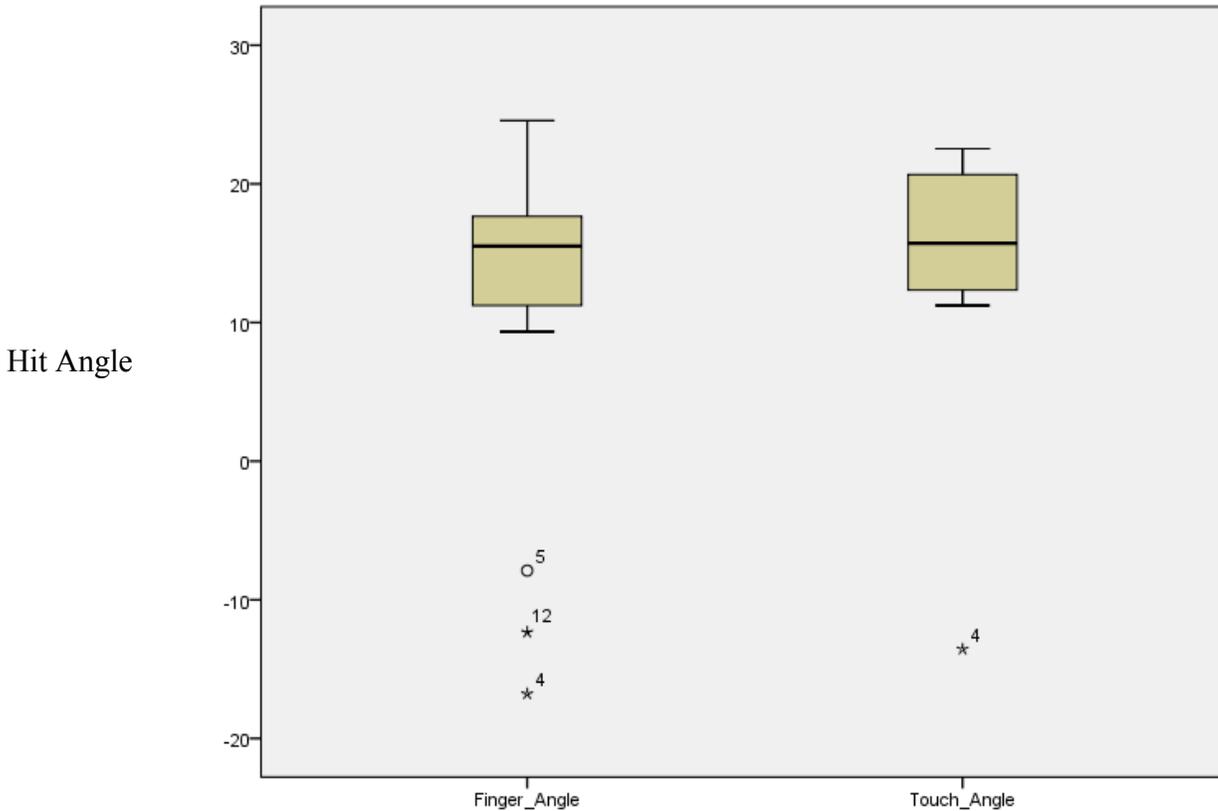

Figure 20: Box Plot for hit angle for Throttle Quadrant part

Table 12 shows the mean and standard deviation of the hit angle for the Throttle Quadrant part for Touch on Screen and Finger Pointing technique.

	Touch_HitAngle	Finger_HitAngle
Mean	14.7872	11.7522
No. of Participants	18	18
Std. Deviation	8.13152	11.83892

Table 12: Mean and Standard deviation of the hit angle for Throttle Quadrant in degrees for Touch on Screen and Finger Pointing technique.

There was no statistically significant difference between groups as determined by one-way ANOVA (F (13, 4) = 1.513, p = .370).

Box plot (Figure 21) show the hit angle for Combustion Liner part which was the farthest part on the document
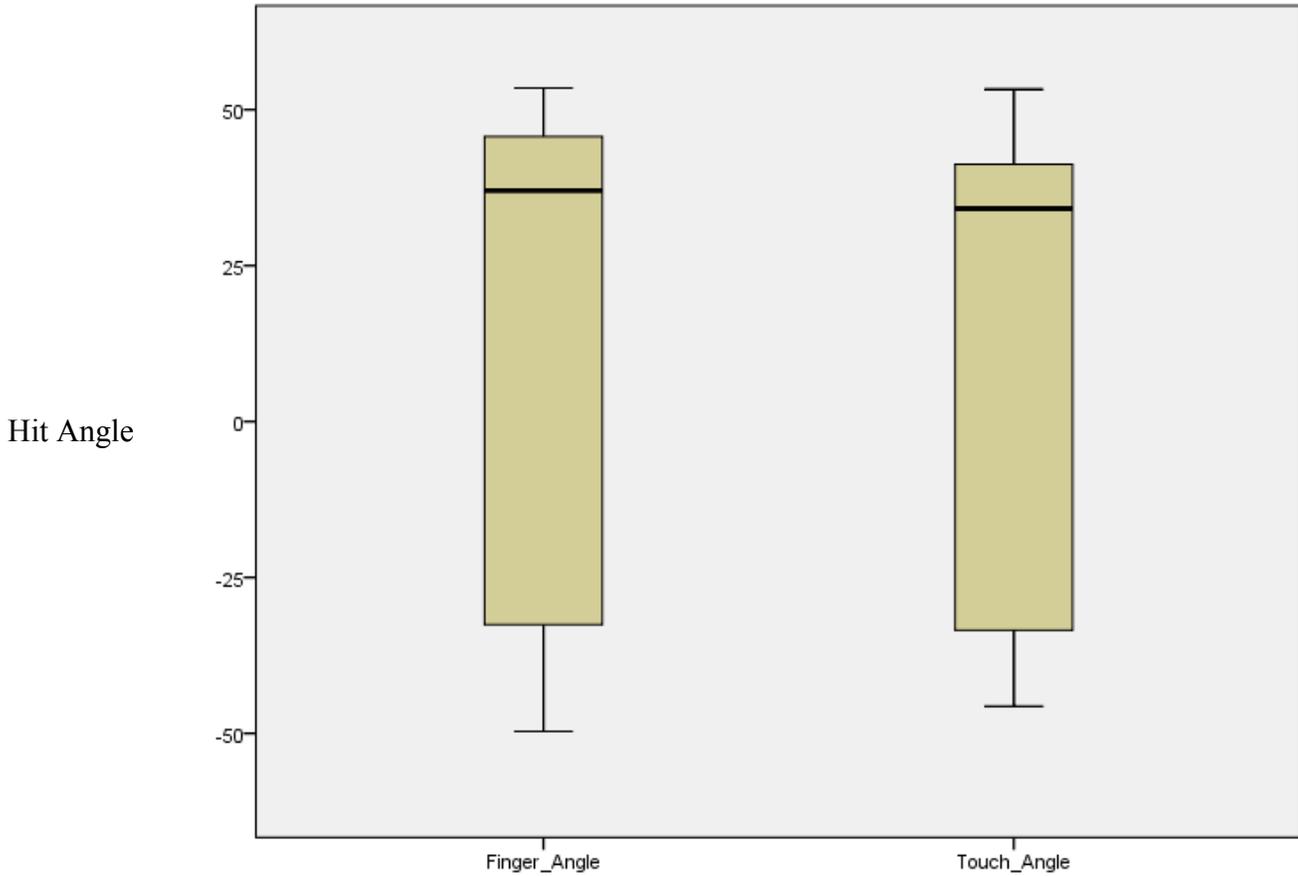
Figure 21: Box Plot for hit angle for Combustion Liner part

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Table 13 shows the mean and standard deviation of the hit angle for the Combustion Liner part for Touch on Screen and Finger Pointing technique.

	Touch_HitAngle	Finger_HitAngle
Mean	14.0594	15.6511
No. of Participants	18	18
Std. Deviation	39.02028	41.17552

Table 13: Mean and Standard deviation of the hit angle for Combustion Liner in degrees for Touch on Screen and Finger Pointing technique.

There was no statistically significant difference between groups as determined by one-way ANOVA ($F(16, 1) = 203.207$, $p = 0.06$).

Participants also completed questionnaires (Appendix F) describing the suitability of each selection technique for each task. Ordinal data was recorded in the questionnaires and was analyzed.

Figure 22 below depicts the suitability of the three selection techniques by the 18 participants for this task and we conclude that the Device Pointing Technique was the most suited selection technique followed by the Finger Pointing Technique for this task.

No. of Participants

Selection Technique
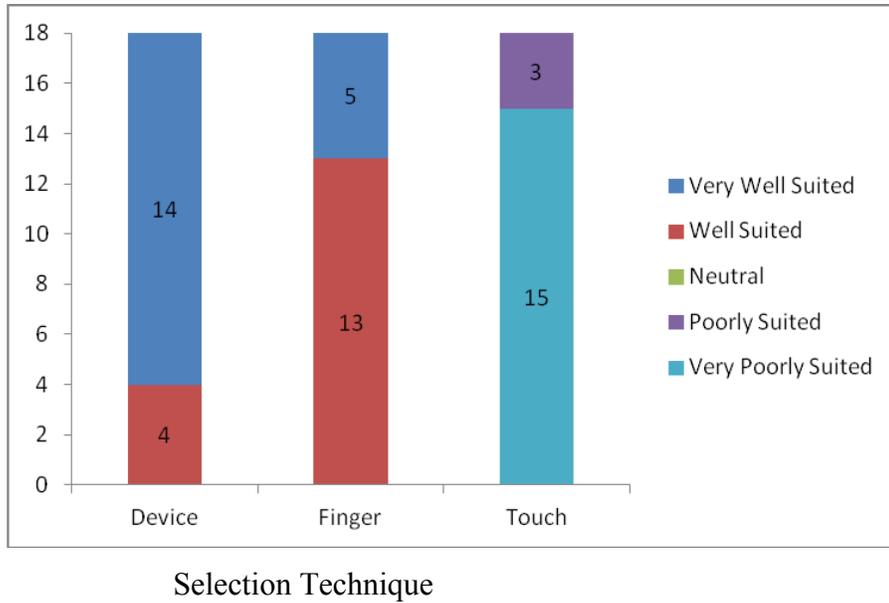
Figure 22: Suitability of the selection technique by the participants for task 1

The Friedman test, which evaluated differences in preference of the selection techniques by the participants for this task among the three selection techniques, is significant (2, N = 18) = 33.500, p < .01

Video Coding Analysis for this task:

Videos of the participants performing tasks using each selection technique were recorded and analyzed. The purpose of the video coding of the data was to determine how the participants used the mobile device to perform the tasks using each of the selection techniques and also to observe any exceptional behavior of the participants with the selection techniques while performing the tasks. Some interesting interactions that were found for this task were:

A. Finger Pointing Technique: Five participants took the device camera very close to the target selection (i.e., very close to their finger), thereby blocking the image target and selection was difficult to perform. Three participants hold the mobile device close to their eyes to make the selection from the document and were having difficulty in performing the selection. Through the video coded data we also found that most of the participant's attention was more focused on the document than on the mobile device using this selection technique. We assumed that the Finger Pointing technique would

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be good for this task to select a single part at a variable distance on the document but from the video coded data analysis we observed that participants were having difficulty to perform this task using the Finger Pointing selection technique as most of the participants were having difficulty to align their finger with respect to the device camera.

B. Touch on Screen Technique: Since there was an implementation issue with this technique, 12 participants were moving the mobile device sometimes closer to the image target/part and sometimes away from the image target/part to select a particular part from the catalogue. From the video coding analysis we observed that most of the participants were moving the mobile device close to the image target/part to make the selection from the document. At the beginning of this task participants were instructed to move the mobile device very close to the image target to make the selection as there was an implementation issue with this selection technique for selecting parts that are at a far distance from the mobile device. We assumed that Touch on Screen would be a good technique for this task but participants were not able to select a part easily using this selection technique, instead they had to move the mobile device closer to the target for its selection.

C. Device Pointing Technique: From the video coded data we observed that participants were comfortable in making selections from the document using this selection technique. Four participants stretched their arm noticeably to make the selection of the part "Combustion Liner" which was the farthest part on the catalogue document, while the remaining participants did not seem to have discomfort reaching the far target. We assumed that Device Pointing would be a suitable technique to select a discrete part from the documents and also from the video data analysis we found that participants were easily making the selections from the documents using this selection technique.

Interview Data Analysis for this task:

Participants were interviewed by the researcher for 3-4 minutes after completing the study. In the interview they were asked for the preference of the selection technique for each kind of task and the reason for choosing that selection technique.

Participant's responses for this task were similar as they preferred Device Pointing technique for this task. Participants said that they simply have to tap the mobile device on the document to make the selection and also it was easy to use as compared to other two selection techniques. One participant stated that "I found Device Pointing interface most unique and interesting to use. I think it is a great method of linking the documents"-P7. There was another participant who stated that "Device Pointing technique was easy and fast to make the selection from the document"-P3.

Since Touch on Screen and Finger Pointing technique were assumed to be most suitable for a part selection at a varying distance from the user but from the responses of the participants Device Pointing technique was found to be the most preferred and suitable selection technique for this task.

6.1.1.2 Synthesis of the results of this task

From the analysis of the results of this task, we found that the Device Pointing selection technique was the most suitable and preferred technique for this kind of task. We assumed that the Touch on Screen and Finger Pointing selection technique would be well suited for all the three parts which were at a varying distance on the document as described above and the Device Pointing technique would be good only for selecting the nearby part (Rudder Pedal). From the analysis of the results of the software log data, video coded data, interview data and questionnaire data, Device Pointing technique was found to be the best selection technique for all the three parts. There were implementation issues with the Touch on Screen selection technique as described earlier in this chapter.

From the software log data we found that the Device Pointing selection technique took the least time to complete the task for all the three parts (see Figures 13, 14, 15). The average time for Device Pointing for Task 1 a was 5.667 seconds , for Task 1b it was 5.66 seconds, for Task 1 c was 6.3889 seconds. The Touch on Screen selection technique took comparatively more time than the other two selection techniques (see Figures 13, 14, 15). The average time for Touch on Screen for Task 1 a was 12.555 seconds, for Task 1 b was 15.611 seconds, for Task 1 c was 15.667 seconds.

From the video coded data we observed that participants were having difficulty in part selection using the Touch on Screen and Finger Pointing selection techniques which were, using Finger Pointing technique participants were not able to adjust their finger position with respect to the device camera. There was an implementation issue with the Touch on screen technique so participants were moving the mobile device very close to the image target for selection. These may be the reasons that these two selection techniques took more time to complete the task as compared to the Device Pointing selection technique. The interview responses of the participants also indicated that the Device Pointing selection technique was the most suitable and preferred technique for this kind of task. One of the participant said that "Device Pointing technique was the most natural and easiest way of selecting parts from the document" –P16.

From the questionnaire data where the participants were asked to rate the selection technique for this task, most of the participants rated the Device pointing selection technique as the most well suited technique for this task which was also reflected from the interview responses of the participants. Also, for the other questions in the questionnaire, we found that participants found the Device Pointing selection easy to use and they able to connect information from one document to another easily using this selection technique.

From all the data sources that we collected and analyzed, we found that the Device Pointing selection technique was the most suitable and preferred technique for this kind of task where the participants have to perform the discrete selection from the document.

6.1.2 Task 2:

You wish to locate specific cockpit parts in the catalogue. For each of the parts listed below:

    a. Locate and select the part on the cockpit diagram.

    b. Locate the part image and description in the catalogue and answer the question listed with the part, below.

Parts: *Side Stick Controller (Question: what kind of control system does an aircraft with a side stick controller typically have?), Flight Management System. (Question: What is the product code for the FMS in the catalogue?)*

The purpose of this task was to consider the scenario where there are two or more specific parts very close to each other, potentially making the selection operation more difficult to accomplish. Using the Figure 23, participants were asked to select the side stick controller and flight management system simultaneously and then view these selected parts on the catalogue.
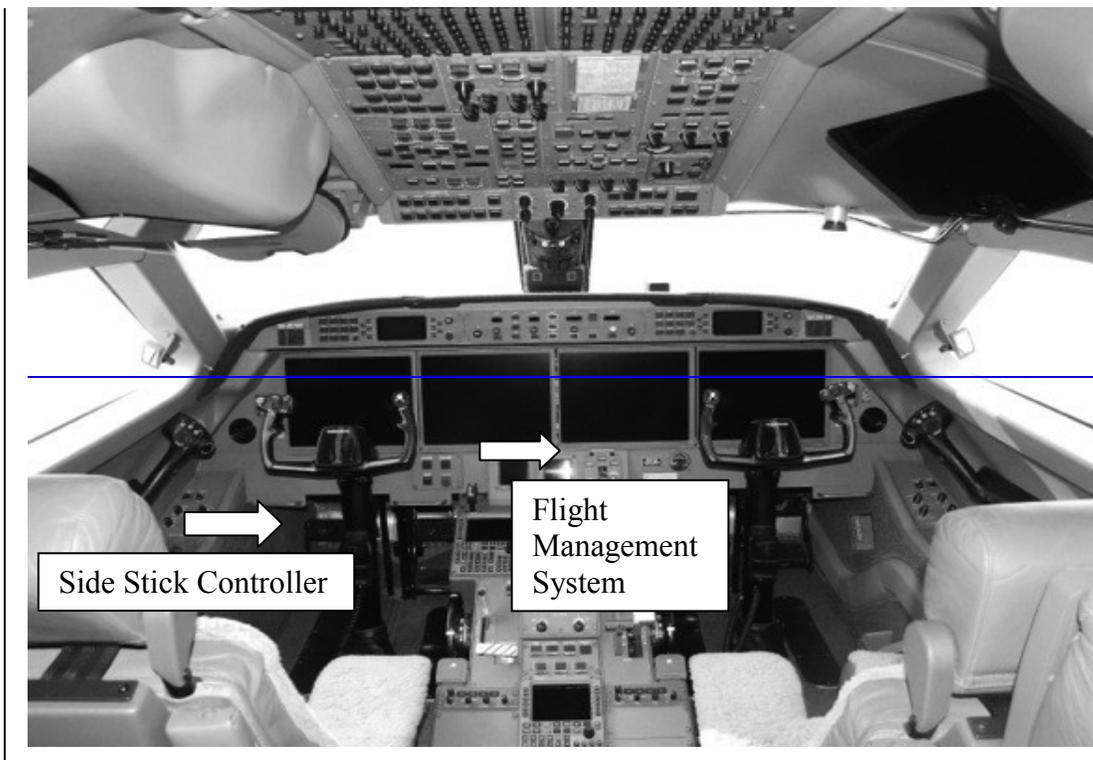
Figure 23: Cockpit diagram of airplane

From the table 2 described in the design exploration of the UCMV, we expected that Device Pointing would be the only suitable selection technique for this kind of task but from the results we found that both Touch on Screen and Device Pointing technique were the most suitable and preferred selection technique for this task.

The Finger pointing technique was a failure in this case. In the case of the Finger Pointing technique virtual buttons are placed on a particular part on the image target, so when the finger is encountered between the virtual button and mobile camera that particular part is

selected. Whenever the participant was trying to point to a specific part that was asked for in the task list, the wrong part was selected in 7 cases. As the two parts were close to each other, when these participants were trying to select the part by moving the finger towards the part the wrong part was selected.

6.1.2.1 Software log Data Analysis

Data such as time taken, hit distance and hit angle as described in previous section were analyzed in the SPSS. Box plots for all these three parameters are described below.

Time taken to complete the task:

Box plots (Figure 24) show the time taken by the participants for each of the selection techniques to complete this task for the "**Side Stick Controller**" part
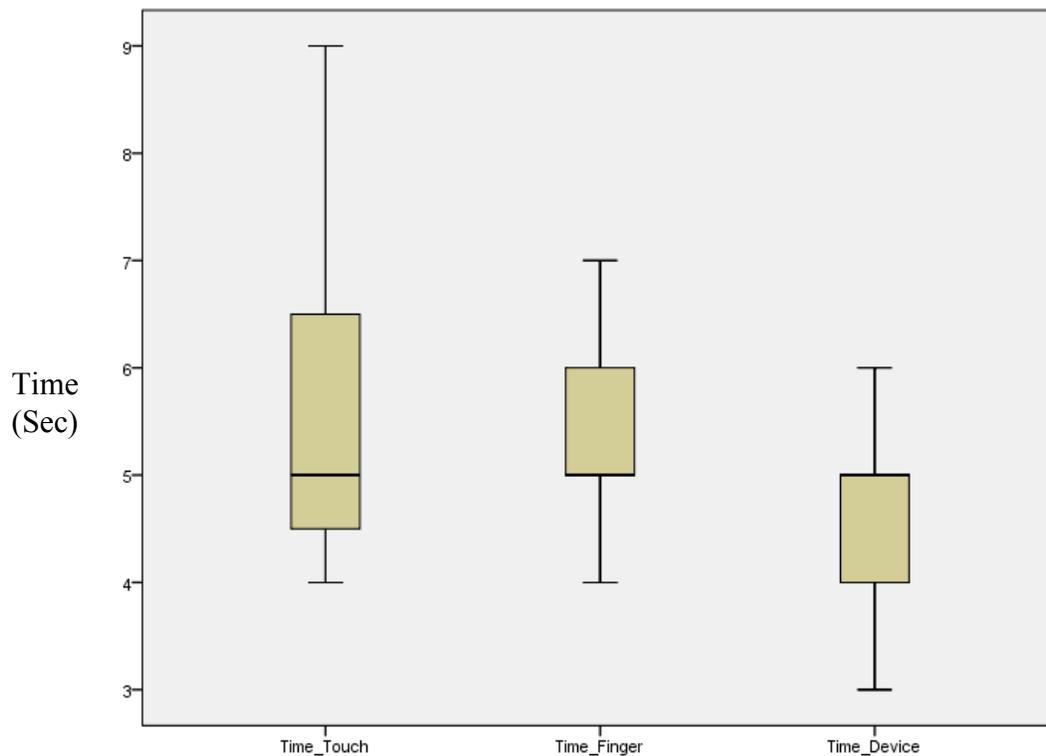
Figure 24: Box Plot for time taken to complete this task for Side Stick Controller part

Table 14 shows the mean and standard deviation of the time taken in seconds for the Side Stick Controller part for each of the selection technique.

	Time_Touch	Time_Finger	Time_Device
Mean	5.6111	5.5000	4.6111
No. of participants	18	12	18
Std. Deviation	1.46082	.90453	1.19503

Table 14: Mean and Standard deviation of time taken for Side Stick Controller in seconds for each of the selection techniques.

There was a statistically significant difference between groups as determined by one-way ANOVA (F (2, 45) =3.352, p = .044). A Tukey post-hoc test revealed that the time to complete the problem was statistically significantly lower for Device pointing technique as compared to the Finger pointing technique and Touch on Screen technique.

Box plot (Figure 25) shows the time taken by the participants for each of the selection techniques to complete this task for the "**Flight Management System**" part.
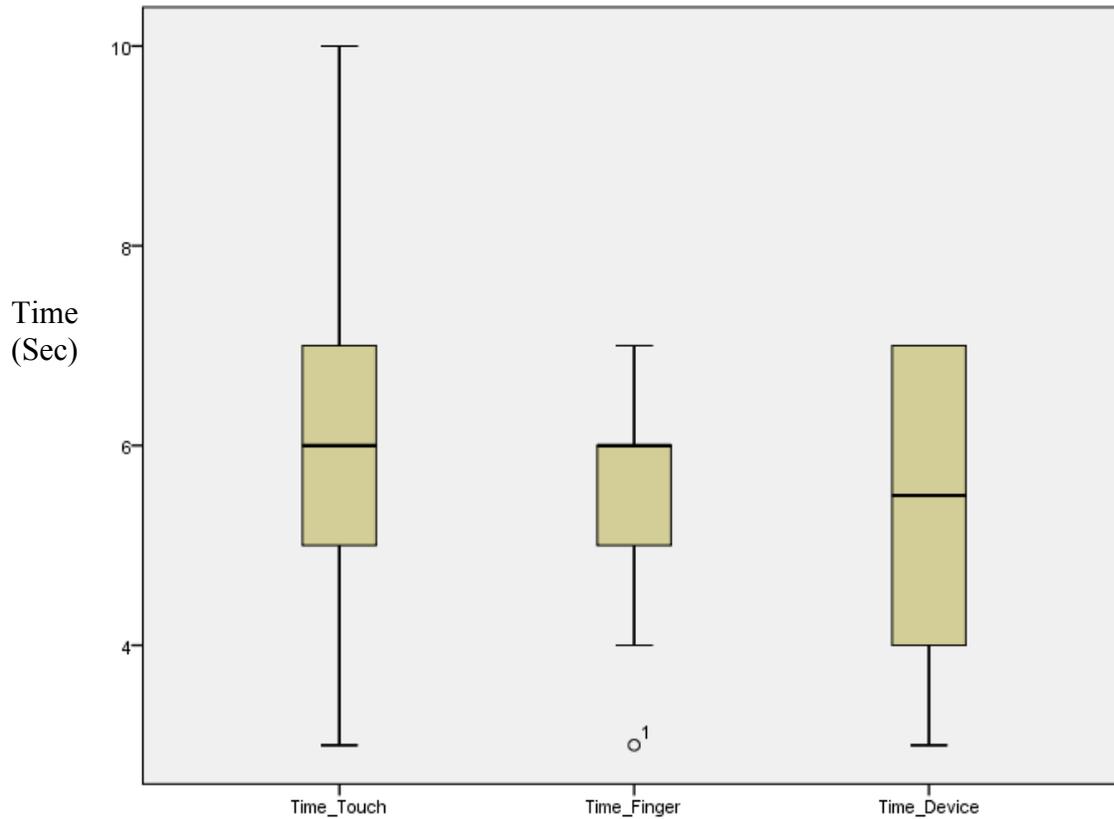
Figure 25: Box Plot for time taken to complete this task for Flight Management System

Table 15 shows the mean and standard deviation of the time taken in seconds for the Flight Management System part for each of the selection technique.

	Time_Touch	Time_Finger	Time_Device
Mean	6.2778	5.5556	5.3889
No. of Participants	18	18	18
Std. Deviation	1.70830	1.14903	1.37793

Table 15: Mean and Standard deviation of time taken for Flight Management System in seconds for each of the selection techniques.

There was no statistically significant difference between groups as determined by one-way ANOVA (F (2, 51) =1.964, p = .151).

Hit Distance:

Box plot (Figure 26) shows the hit distance for the **Side Stick Controller** for Touch on Screen and Finger Pointing technique.
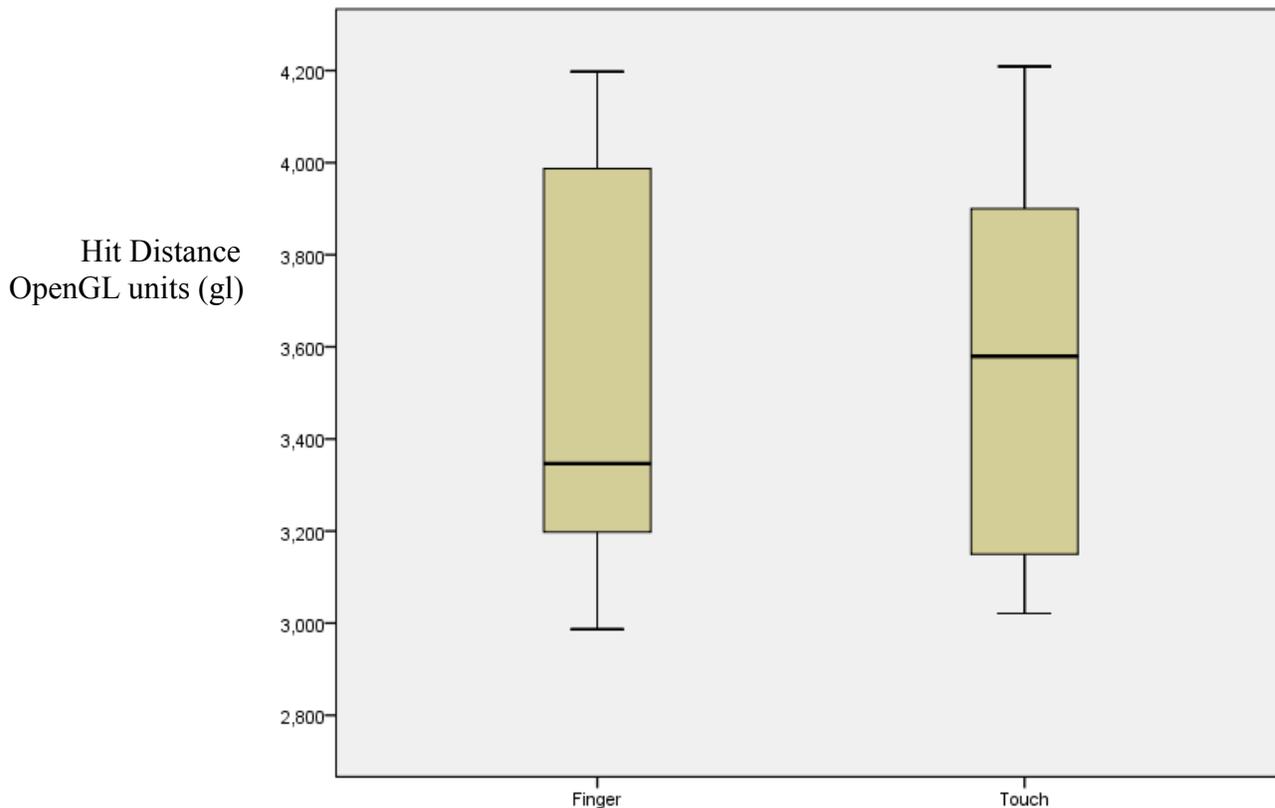
Figure 26: Box Plot for hit distance for Side Stick Controller part

Table 16 shows the mean and standard deviation of the hit distance in OpenGL units (gl) for the Side Stick Controller part for Touch on Screen and Finger Pointing technique.

	Hit_Distance_Finger	Hit_Distance_Touch
Mean	3537.2222	3575.1667
No. of Participants	18	18
Std. Deviation	422.08008	416.72480

Table 16: Mean and Standard deviation of the hit distance for Side Stick Controller in OpenGL units (gl) for Touch on Screen and Finger Pointing technique.

There was no statistically significant difference between groups as determined by one-way ANOVA ($F_{(16, 1)} = 2.091$, $p = 0.501$).

Box plot (Figure 27) shows the hit distance for **Flight Management System** for Touch on Screen and Finger Pointing technique.
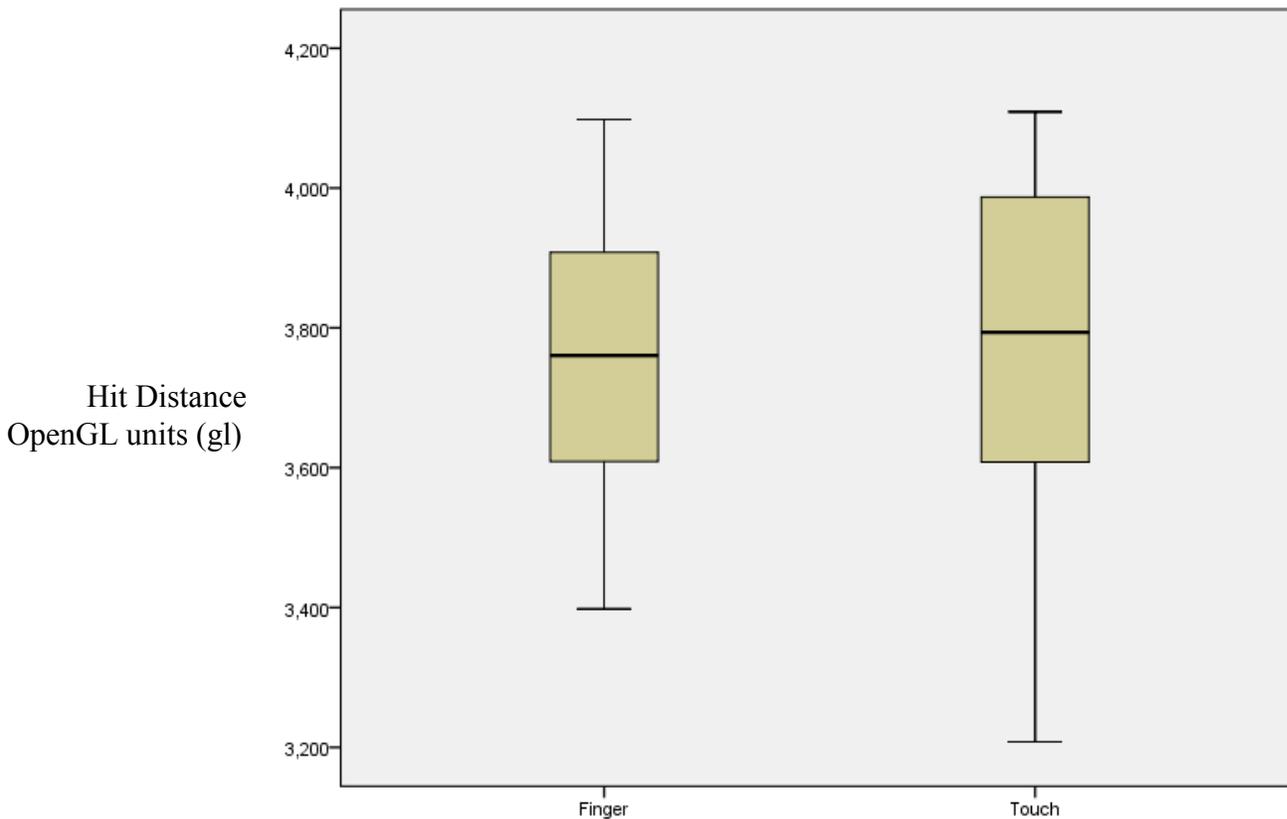
Figure 27: Box Plot for hit distance for Flight Management System

Table 17 shows the mean and standard deviation of the hit distance in OpenGL units (gl) for the Flight Management System for Touch on Screen and Finger Pointing technique.

	Hit_Distance_Finger	Hit_Distance_Touch
Mean	3753.5556	3767.1667
No. of Participants	18	18
Std. Deviation	188.24428	237.66963

Table 17: Mean and Standard deviation of the hit distance for Flight Management System in OpenGL units (gl) for Touch on Screen and Finger Pointing technique.

There was no statistically significant difference between groups as determined by one-way ANOVA ($F (16, 1) = 1.678$, $p = .549$).

Hit Angle:

Box plot (Figure 28) shows the hit angle for the **Side Stick Controller** for Touch on Screen and Finger Pointing technique.
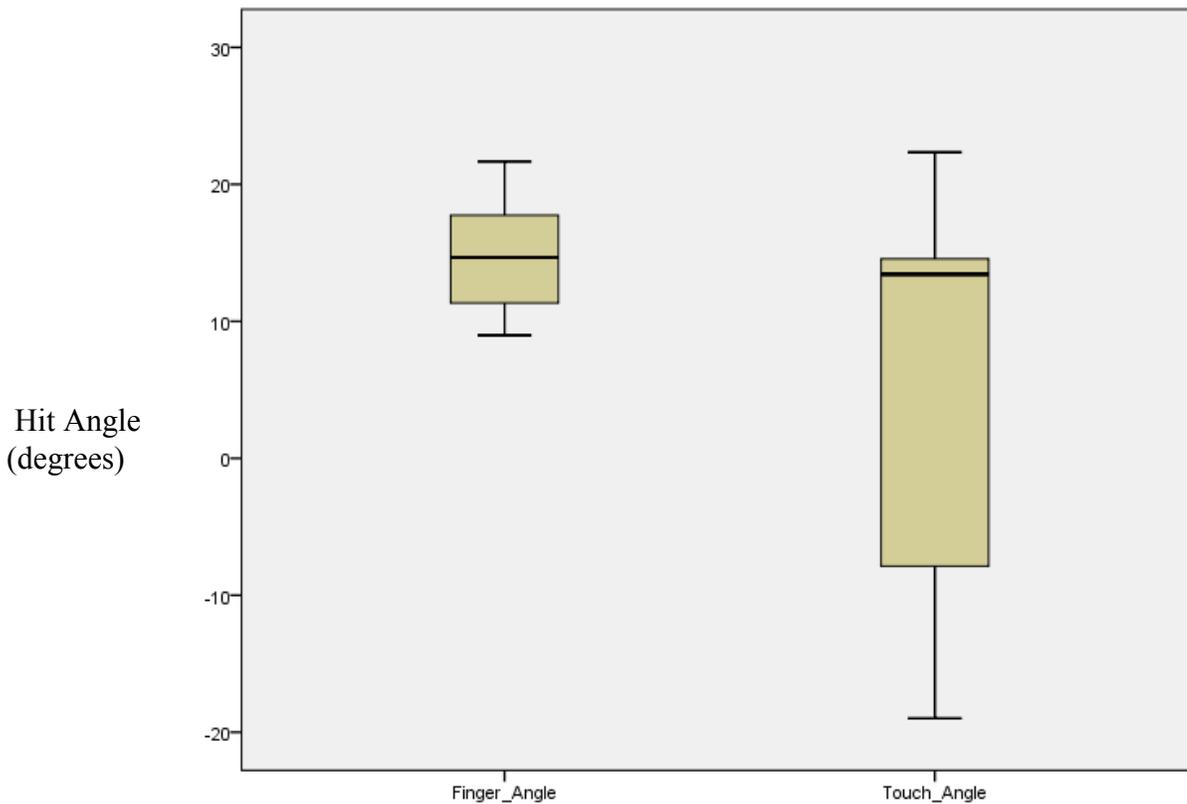
Figure 28: Box Plot for hit angle for Side Stick Controller part

Table 18 shows the mean and standard deviation of the hit angle in degrees for the Side Stick Controller part for Touch on Screen and Finger Pointing technique

	Finger_HitAngle	Touch_HitAngle
Mean	14.6233	7.2094
No. of Participants	18	18
Std. Deviation	3.90436	13.39627

Table 18: Mean and Standard deviation of the hit angle for Side Stick Controller in degrees for Touch on Screen and Finger Pointing technique

There was no statistically significant difference between groups as determined by one-way ANOVA ($F_{(14, 3)} = 0.944$, $p = .603$).

Box plot (Figure 29) shows the hit angle for **Flight Management System** for Touch on Screen and Finger Pointing technique.
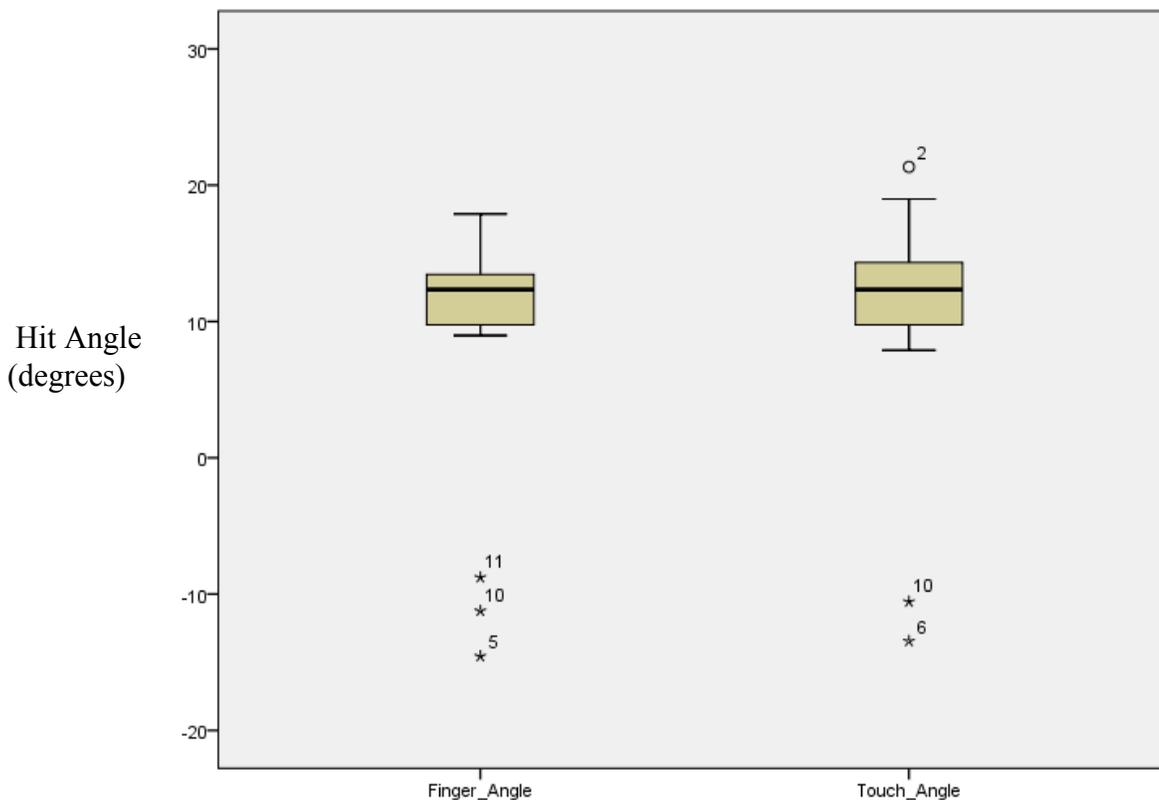
Figure 29: Box Plot for hit angle for Flight Management System part

Table 19 shows the mean and standard deviation of the hit angle in degrees for the Flight Management System part for Touch on Screen and Finger Pointing technique.

	Finger_HitAngle	Touch_HitAngle
Mean	8.8444	10.4861
No. of Participants	18	18
Std. Deviation	9.70444	8.89589
	Finger_HitAngle	

Table 19: Mean and Standard deviation of the hit angle for Flight Management System in degrees for Touch on Screen and Finger Pointing technique.

There was no statistically significant difference between groups as determined by one-way ANOVA (F (15, 2) =0.528, p = .815).

Participant's responses were recorded in the questionnaires to determine the suitability of the selection techniques for this task. For this task Touch on Screen Technique and Device Pointing Technique were preferred equally by the participants as shown in Figure 30.

No. of Participants

Selection Technique
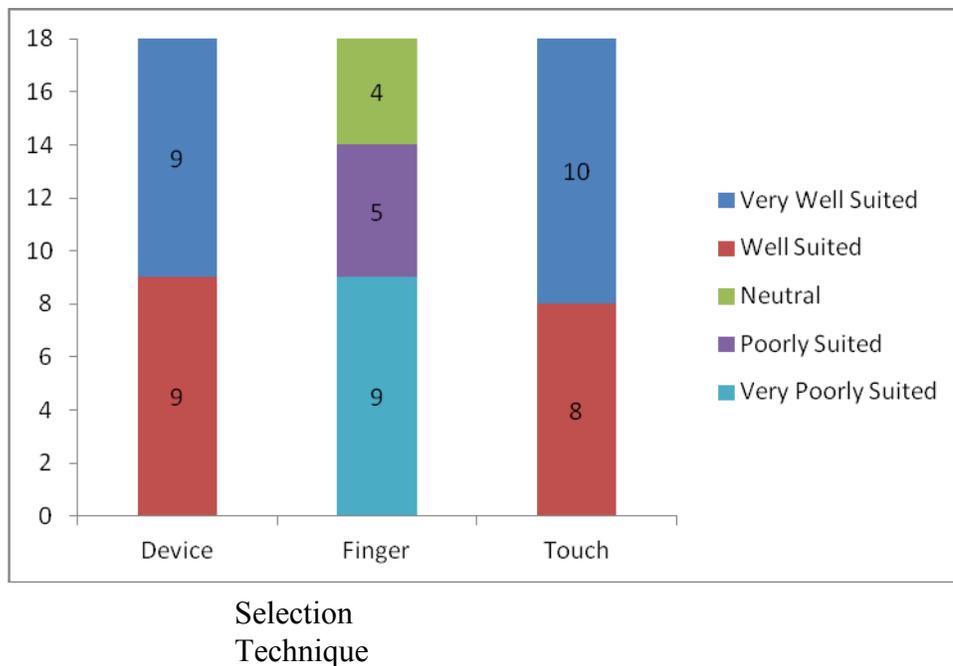
Figure 30: Suitability of the selection technique by the participants for task 2

The Friedman test, which evaluated differences in preference of the selection techniques by the participants for this task among the three selection techniques, is significant (2, N = 18) = 36.000, p < .01

Video Coding Analysis:

As described earlier in this chapter, video data analysis of the participants was performed for each kind of task.

A. Finger Pointing Technique: From the video data analysis we found that seven participants made an incorrect part selection when they were asked to select the Side Stick Controller from the cockpit diagram. Participants were moving their finger above the wrong part and hence were making the wrong selection. Four participants were holding the mobile device very close to their finger and were more focused on the document than on the mobile device. Six participants were holding the mobile device close to their eyes to make the selection from the document and were having problems aligning their finger with respect to the device camera simultaneously. We hypothesized that the Finger Pointing technique would not be a suitable selection technique to perform this kind of task and also from the video coded data we found that participants were making incorrect part selections using this selection technique. Further, this selection technique was not preferred by the participants for this task.

B. Touch on Screen Technique:

From the video data analysis we observed that participants were comfortable in selecting the parts using this selection technique. Participant's attention was more focused on the screen device than on the documents. At the end of the design exploration phase we assumed that this selection technique would not be suitable for this kind of task but from the video data analysis we found that participants were having no difficulty in selecting the parts from the document using this selection technique.

C. Device Pointing Technique:

Video data analysis showed that participants were having no problem in selecting parts from the document for this kind of task where two parts are close to each other. Participants were tapping the corner of the mobile device on the document to make the selection. We assumed that Device Pointing would be suitable for this task and also from the video data analysis we found that this selection was easy to use for the participants for performing this task.

Interview Data Analysis for this task:

As described earlier in this chapter participants were interviewed for 3-4 minutes at the end of the study and were asked for the preference of the selection technique for this task. Participants said that the Device Pointing technique was easy to use and could quickly make the selection from the document. Some participants also liked using the Touch on Screen technique for this task.

Participants didn't prefer the Finger Pointing selection technique for this task because they were finding it difficult to point their finger above the correct part and as a result incorrect part selections were made by the participants.

The Device Pointing technique was assumed to be the most suitable selection technique and the Touch on Screen selection technique was assumed to be not well suited for this kind of task but from the responses of the participants we observe that both Device Pointing techniques as well as Touch on Screen technique were well suited and preferred by the participants for this task.

6.1.2.2 Synthesis of the results of this task

For this kind of task where two parts were close to each other on a document, we assumed that only Device Pointing selection technique would be well suited but from the analysis of the data that we collected, we found that the Device Pointing as well as Touch on Screen selection techniques were the most suitable and preferred selection techniques for this kind of task.

From the software logged data we found that the time taken to complete this task was approximately same for each of the selection techniques (see Figures 24, 25). From the video coded data, we observed that seven participants made the wrong part selection from the document using the Finger Pointing selection technique which can be the reason the participants did not prefer the Finger Pointing selection technique for this kind of task. The video coded data also showed that the participants were having no difficulty in performing this task using the Device Pointing and Touch on Screen selection technique. From the interview responses of the participants, we observed that participants did not prefer the Finger Pointing selection technique for this task as many participants made the wrong part selection from the document which was also observed in the video coded data. One participants stated that " He had a difficult time to superimpose the finger on the document/part with respect to the mobile device in one hand" –P11. Another participant stated that it is difficult to perform the selection using both hands, one hand is holding the mobile device and the other is locating the part on the document- P17.

Also from the interview responses and the questionnaire data where the participants have to rate the selection technique for this task, we observed that the Device Pointing and Touch on Screen selection technique were the most suitable and preferred selection techniques for this task. Also, for the other questions in the questionnaire, we found that there were few participants who did not found Finger Pointing selection technique easy to use to perform different kinds of tasks. We also observed that participants were able to connect information from one document to another document using all the three selection techniques.

6.1.3 Task: 3

You want to retrieve engineering data about specific regions of the aircraft, listed below. Circle For each, circle the region and verify that it has been selected (a pop up box will indicate this).

    a. Upper wing tip
    b. Cockpit

The purpose of this task was to determine which selection technique is the most suitable and preferred by the participants for region selection on airplane schematic. From the table 2 described in the chapter 4 of this thesis identifying the strengths and weaknesses of each selection technique, we expected that Touch on Screen selection technique would be good for selecting distant regions (Upper Wing region) and Device Pointing would be good for selecting near regions (Cockpit region) on airplane schematic. From the results for this task we found that Touch on Screen selection technique was good for selecting both distant as well as near regions on the airplane schematic. However there were implementation issues with the Device Pointing selection technique for region selection on the airplane schematic.

Participants were facing problems selecting region on big schematic with the finger pointing technique as 8 participants observed in the coded video were not able to adjust their finger when they were trying to view the region through the mobile device camera. 4 participants were taking the mobile device very near to the big schematic thereby blocking the whole image target. 3 participants while selecting the region with this technique were not viewing their finger with the device camera and as a result they were facing problems to select the region.

There was implementation issue with the Device Pointing selection technique so to overcome these participants were asked to swipe the mobile device across the region to make the selection from the airplane schematic. With this technique participants were not feeling comfortable swiping the mobile device on the schematic airplane to select the region. It was also taking more time to select the region than the other two techniques. The reason might be due to the implementation issue with this task as described earlier.

6.1.3.1 Software log Data Analysis

Time taken to complete the task:

The Box plot (Figure 31) shows the time taken by the participants for each of the selection techniques to complete this task for the "**Upper Wing**" part.
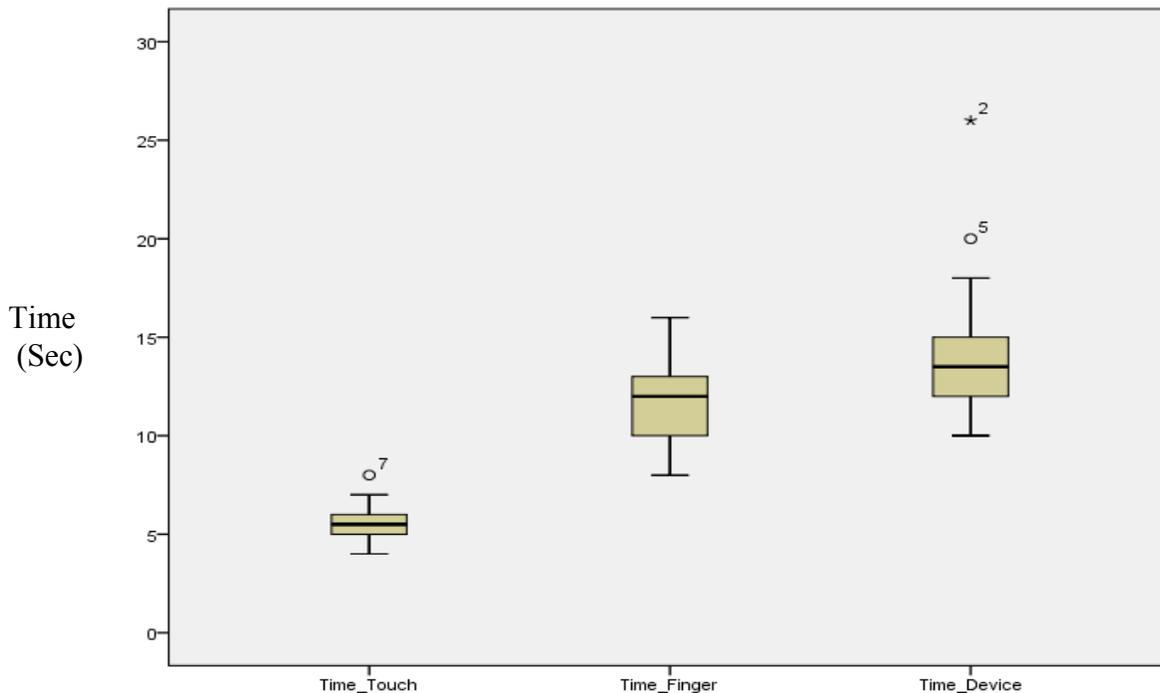
Figure 31: Box Plot for time taken to complete this task for Upper Wing part

Table 20 shows the mean and standard deviation of the time taken in seconds for the Upper Wing part for each of the selection techniques.

	Time_Touch	Time_Finger	Time_Device
Mean	5.5000	11.6667	14.5556
No. of Participants	18	18	18
Std. Deviation	1.04319	2.00000	3.82288

Table 20: Mean and Standard deviation of time taken for Upper Wing part in seconds for each of the selection techniques

There was a statistically significant difference between groups as determined by one-way ANOVA ($F_{(2, 51)}$ =58.641, p = .000). A Tukey post-hoc test revealed that the time to complete the problem was statistically significantly lower for Touch on Screen technique as compared to the Finger pointing technique and Device Pointer technique.

The Box plots (Figure 32) shows the time taken by the participants for each of the selection techniques to complete this task for the "**Cockpit**" region
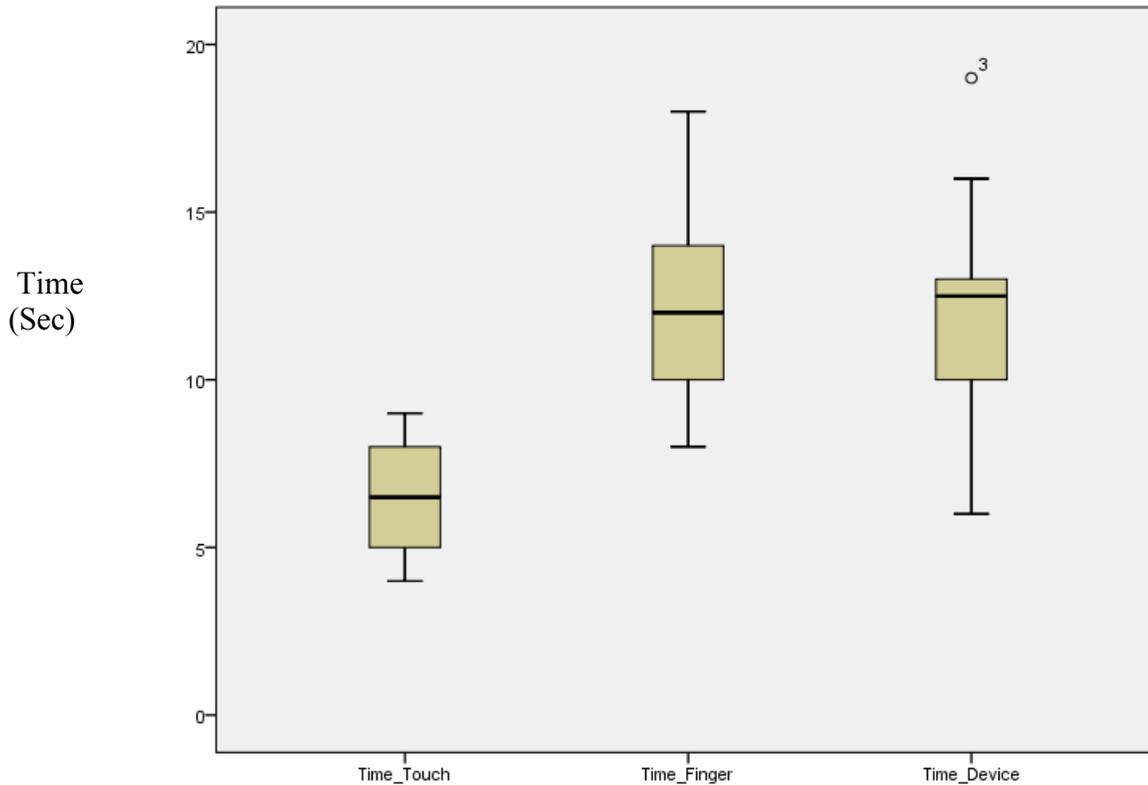
Figure 32: Box Plot for time taken to complete this task for Cockpit region

Table 21 shows the mean and standard deviation of the time taken in seconds for the Cockpit part for each of the selection techniques.

	Time_Touch	Time_Finger	Time_Device
Mean	6.5000	12.0000	12.2222
No. of Participants	18	18	18
Std. Deviation	1.54349	2.65684	2.94170

Table 21: Mean and Standard deviation of the time taken for Cockpit in seconds for each of the selection techniques

There was a statistically significant difference between groups as determined by one-way ANOVA (F (2, 51) =31.357, p = .000). A Tukey post-hoc test revealed that the time to complete the problem was statistically significantly lower for Touch on Screen technique as compared to the Finger pointing technique and Device Pointer technique.

Participant's responses were recorded in the questionnaires to determine the suitability of the selection techniques for this task as described earlier. Figure 33 showed that for this task, Touch on Screen technique was most preferred by the participants for region selection.

No. of Participants

Selection Technique
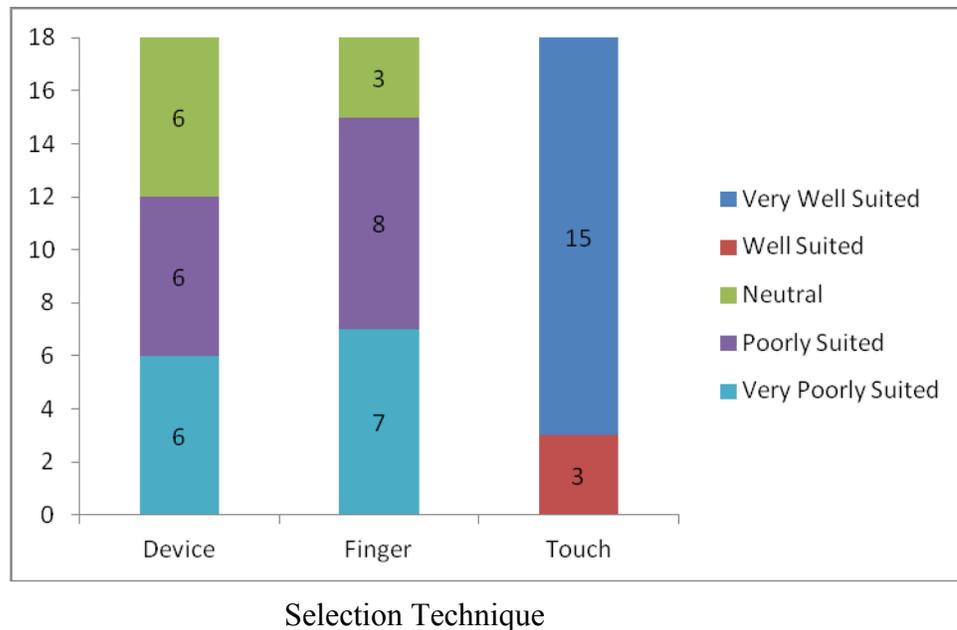
Figure 33: Suitability of the selection technique by the participants for task 3

The Friedman test, which evaluated differences in preference of the selection techniques by the participants for this task among the three selection techniques, is significant (2, N = 18) = 34.069, p < .01

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Video Coding Analysis:

Video data was analyzed for each selection technique performing this task as described earlier in this chapter.

A. Finger Pointing Technique: From the video data analysis we observed that five participants were holding the device very close to their finger (closer to the image target) for region selection, and were trying to re-align the finger with respect to the mobile device camera when viewing through the device camera, but were unsuccessful to select the region on the document. Their attention was more focused on the document than on the mobile device. Four participants placed the mobile device very close to their eyes and then tried to select the region on the big schematic plane but were facing problems in doing that. Participants were not able to move the mobile device camera and their finger in tandem together. Most of the participant's attention was more focused on the underlying document than on the mobile device. From the outcomes of the design exploration phase we assumed that the Finger Pointing technique would not be good for selecting regions on airplane schematic. From the video data analysis we found that participants were having difficulty in selecting regions on airplane schematic using this selection technique.

B. Device Pointing Technique: Since there was an implementation issue with this technique, we observed from the video data analysis that participants had to move the device back and forth across the region on the document to make the region selection. We assumed that this selection technique would be good for selecting nearby regions but from the video data analysis we found that participants were finding it difficult to select regions using this selection technique.

C. Touch on Screen Technique: From the video data analysis we observed that participants' attention was more focused on the mobile screen device than on the document. Two participants took the mobile device very close to the document for region selection thereby blocking the image target and were unsuccessful in selecting region from the document. One participant moved the mobile device closer to their eyes and then tried to select region by touching on the screen of the mobile device.

The remaining participants did not appear to have difficulties using this technique. From the video data analysis we found that this selection technique was suitable for this task, which supported our assumption for this selection technique.

Interview Data Analysis for this task:

15 participants preferred the Touch on Screen technique for this task. Participants stated that region selection was easier using the Touch on Screen technique than the other two selection techniques. Regarding the Finger Pointing technique, one participant stated that "I found it distracting to keep track of the phone, my finger and the drawing and to get them all lined up. It may have been better if I would had held the phone still, and touched the item I wanted to select (on the page) , instead of trying to interpose my finger between the camera and the page"- P12.

We hypothesized that the Device Pointing technique would be suitable for near region selections and Touch on Screen technique for selecting both near and far regions on the airplane schematic but from the participant's responses we observed that Touch on Screen was the most preferred selection technique by the participants for both near and far region selection. There were some implementation issues as described earlier for region selection with the Device Pointing selection technique.

6.1.3.2 Synthesis of the results for this task

We assumed that the Device Pointing selection technique would be good for selecting nearby regions on the document and Touch on Screen would be good for selecting distant regions on the documents but from the analysis of the data that we collected, we found that the Touch on Screen selection technique was found to be the most suited and preferred selection technique for near as well as distant regions on the documents. There was an implementation issue with the Device Pointing technique for this task so participants were asked to swipe across the region to make the selection from the document.

From the software log data we observed that the Device Pointing selection technique took more time than the other two selection techniques to complete this task (see Figures 31,

32). Due to an implementation issue with the Device Pointing selection technique, participants were having difficulty in selecting region on the document which was also observed from the video coded data which was the reason this selection technique took more time as compared to other two selection techniques. From the video coded we also observed that participants were also having difficulty in selecting regions on the documents using the Finger Pointing selection technique as they were not able to move the finger with respect to the device camera in tandem together. In the questionnaire data where the participants have to rate the selection technique for a task, participants didn't prefer these two selection techniques for this task.

 Also from the interview responses of the participants, we found that they were not comfortable in selecting regions on the documents using Finger Pointing and Device Pointing selection techniques. One participant stated that "Region selection using the Finger Pointing technique was really a hard task as one have to move the mobile device and their finger together simultaneously over the document"- P5. Another participant stated that while using the Device Pointing technique it was really awkward to scratch the tip of the mobile device against the document to perform region selection"-P9. We observed from the video coded data that participants were making region selections easily from the documents using Touch on Screen selection technique. Also the interview responses and the questionnaire data indicated that Touch on Screen selection technique was the most suitable and preferred selection technique for the region selection task on the documents. From the questionnaire data we observed that using the three selection techniques participant were more focused on the document than on the mobile device.

6.1.4 Task: 4

You want to attach a voice memo about the engine turbine to all relevant documents. To do this, you will select the relevant document regions in sequence using each selection technique, as follows:

a.   Engine pop-out on airplane schematic (listed as part #20)

b.   Turbine section of engine diagram

c.   "Turbine section" item in catalogue

In this task participants were asked to perform multiple selections on the documents using each selection technique. The purpose of this task was to determine how the participants perform multiple selections following a sequence on the documents. Unfortunately we were not able administer this task correctly because implementation of multiple selection required for this task was not completed in time for the study. Instead, we asked participants to consider how the selection technique might be used in this scenario. Since the task was not completed by participants we do not include it in analysis. This task can be used in future studies of the UCMV to evaluate the different strengths and weaknesses of the selection techniques used.

6.2 Summary of the results for each task.

Table 22 describes the summary of the results for each task. This table describes what the expected result was for each of the task type using each selection technique and the actual results observed in the controlled study based on all the data collection methods. Data was collected in the form of software log data, video coded data, interview data and the questionnaire data. This table described the assumed result for each task type and the found results based on the analysis of the data.

Tasks	Assumed Results	Found Results
Task 1 a) Cockpit Region (Near Region)	Well suited for Device Pointing and Touch on screen technique. Not well suited for Finger Pointing Technique	Touch on Screen technique was found to be the most suitable technique for this task after the analysis of all type of data that was captured. There were implementation issue with the Device Pointing technique and participants didn't prefer the Finger Pointing technique.

b) Upper Wing Region (Far region)	Well suited for Touch on Screen technique Not well suited for Device Pointing and Finger Pointing selection technique	Touch on Screen technique was found to be the most suitable technique for this task after the analysis of all type of data that was captured. There were implementation issue with the Device Pointing technique and participants didn't prefer the Finger Pointing technique.
Task 2 a) Rudder Pedal (Near Part)	Well suited for all of the three selection techniques	Device Pointing technique was found to be the most suitable technique for this task, however there were implementation issues with the Touch on screen selection technique and participants didn't prefer the Finger Pointing technique
b) Throttle Quadrant (Intermediate Part)	Well suited for Finger Pointing and Touch on Screen technique Not well suited for Device Pointing technique	Device Pointing technique was found to be the most suitable technique for this task, however there were implementation issues with the Touch on screen selection technique and participants didn't prefer the Finger Pointing technique
c) Combustion Liner (Far Part)	Well suited for Finger Pointing and Touch on Screen technique Not well suited for Device Pointing technique	Device Pointing technique was found to be the most suitable technique for this task, however there were implementation issues with the Touch on screen selection technique and participants didn't prefer the Finger Pointing technique

Task	Assumed Result	Found Result
Task 3 a) Side Stick Controller and Flight Management System (Two Parts close to each other)	Well suited for Device Pointing technique Not well suited for Finger Pointing and Touch on Screen technique	Touch on screen and the Device Pointing technique were preferred by the participants. Finger Pointing selection was not preferred by the participants.

Table 22: Summary of the results for each task

6.3 Research Question 2:

To build an understanding of how the selection techniques might be used together to support higher level activities involving a range of inter-document correlation actions.

From the data analysis of the three tasks, we observed that Finger Pointing technique was not very well suited for any of three tasks that were used. Participants were having problem to select a part or region from the document as they were not able to adjust their finger with respect to the mobile device camera precisely. The other problem with this technique was, sometimes participants were making wrong selection of the part from the document because their finger was occluded by the other parts present on the same document. From the video coded data we observed that participants were having difficult time to focus on the underlying document with the finger and mobile device simultaneously.

Device Pointing technique could be a good selection technique to select discrete parts from the document which are in the reach of participant's arm. In case of region selection on the documents this technique might not be well suited, since there was an implementation issue with this selection technique for this task so we were not able to evaluate this selection technique for region selection efficiently.

Touch on Screen selection technique can serve as a suitable technique to select regions on the documents. More refined implementation of this selection technique using high

contrast documents set with distinct features can be a useful technique to select individual parts at a varying distance on the documents.

6.4 Questionnaire Data Analysis

Participants also filled the post condition questionnaire for each selection technique in which they were asked to rate how strongly they agree or disagree with the following statements. Participants were asked questions (1-3) in the questionnaire described below after the each study condition (selection technique). The responses are about the selection technique as a whole.

1. The interaction technique was easy to use:

No. of Participants

Selection Technique
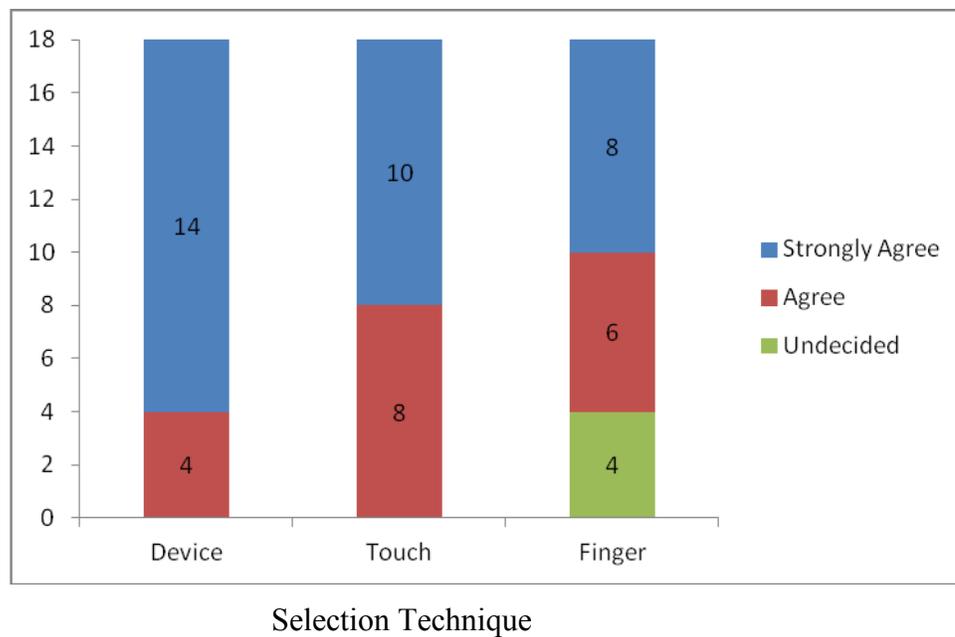
Figure 34: The number of participants who agreed that the selection techniques were easy to use.

Figure (34) shows the rating of the 18 participants for the statement "The interaction technique was easy to use" which was asked in the questionnaire.

Participants found Device Pointing technique and Touch on Screen technique easy to use as comparative to the Finger Pointing technique as participants were having problem in aligning their finger with respect to the device camera for performing the tasks using the Finger Pointing selection technique.

The Friedman test, which evaluated differences in rating by the participants for this statement among the three selection techniques, is significant (2, N = 18) = 14.000, p < .01

2. The interaction technique helped me connect information in one document to information in another
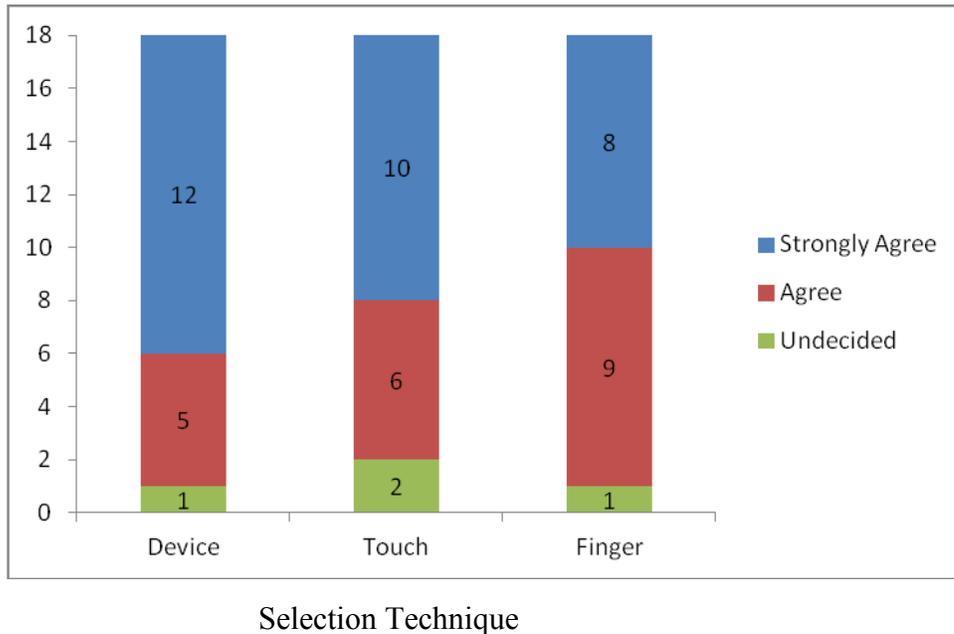
Figure 35: The number of participants who agreed that the interaction technique helped in connecting information from one document to another document.

Figure (35) shows the rating of the 18 participants for the statement "The interaction technique helped me connect information in one document to information in another" which was asked in the questionnaires.

From the figure we can conclude that participants were able to relate information across the documents using each selection technique.

The Friedman test, which evaluated differences in rating by the participants for this statements among the three selection techniques, is not significant (2, N = 18) = 7.000, p > .01

3. My attention was more focused on the document than on the device.
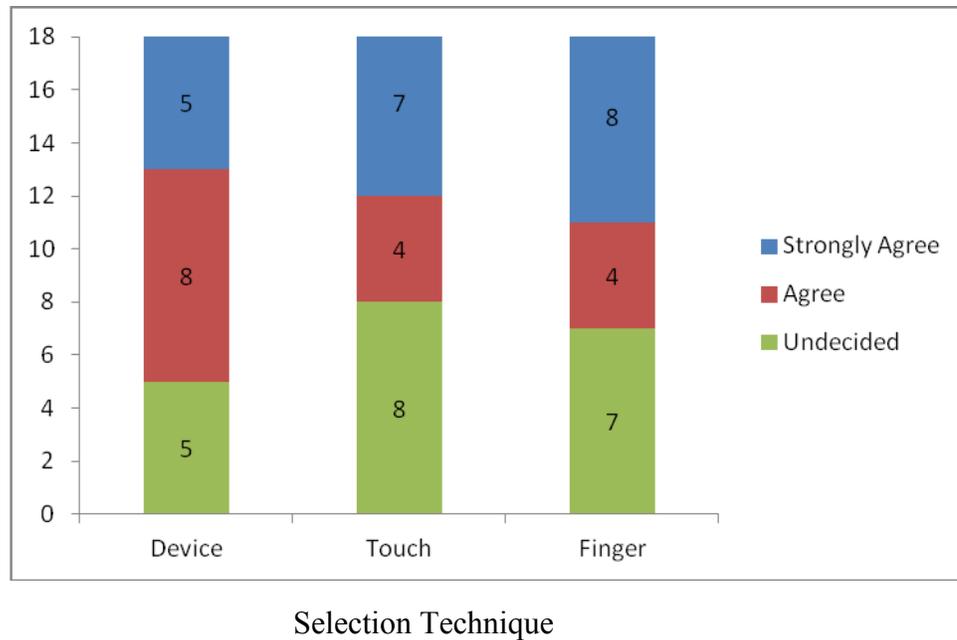
Figure 36: The number of participants who agreed that they paid more attention to the document over the device

Figure (36) shows the rating of the 18 participants for the statement "My attention was more focused on the document than on the device" which was asked in the questionnaires.

From the figure we observed that majority of the participant's attention was more focused on the document than on the mobile device using each of the selection techniques.

The Friedman test, which evaluated differences in rating by the participants for this statements among the three selection techniques, is not significant (2, N = 18) = 1.500, p > .01

6.5 Overall Discussion

UCMV was designed to relate the information across the multiple paper documents with the mobile device through the medium of augmented reality. Three types of selection techniques: Device Pointing, Finger Pointing and Touch on screen were used and evaluated in the UCMV prototype. The strengths and weaknesses of these selection techniques were identified during the design exploration phase of the UCMV and are listed in the table 2 of this thesis. A task set was designed consisting of 4 tasks to evaluate the UCMV prototype as explained in the previous chapter of this thesis.

In the first task participants were asked to select parts from the catalog documents which were at a varying distance from the document as described earlier in this chapter. For this task we assumed that the Touch on Screen and Finger Pointing selection would be well suited for selection of all the three parts on the document and Device Pointing would be good only for selecting nearby part on the document. On the document set, Rudder Pedal was the closest part, Throttle Quadrant was the intermediate part and Combustion Liner was the farthest part on the document. From the analysis of the all types of data that we captured, we found that Device Pointing selection technique was the most suitable and preferred technique for all the three parts on the document. There were implementation issue with the Touch on Screen technique as explained earlier in this chapter. Data such as software log data, interview with the participants at the end of the study, video coded data and questionnaire data were recorded and analyzed. From the software log data we observed that the Device Pointing technique was the fastest selection technique to complete this task for all the three parts on the document. Due to an implementation issue with the Touch on Screen technique as described earlier, it was the slowest technique for this task for all the three parts on the documents. Participants were experiencing difficulty in part selection using the Finger Pointing selection technique as they were not able to align their finger with respect to the device camera so it took more time as compared to the Device Pointing selection technique but it was faster than Touch on Screen technique. There was no significant difference between the hit distances of the three selection techniques for all the three parts, so there was no difference how far the device was held from the document during the part selection. From the analysis of the video coded data as

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described earlier, we observed that participants were facing difficulty in part selection using the Finger Pointing and Touch on Screen technique. As there was an implementation issue with the Touch on Screen for this task, we found from the video coded data that the participants were moving the mobile device very close to the document for selection which was the reason it took more time to complete the task than the other two selection techniques. We also observed from the video coded data that the participants were having difficulty in adjusting their finger with respect to the device camera so it took more time than the Device Pointing technique but it was faster than the Touch on Screen technique. Since the Device Pointing selection technique was the fastest technique, so from the interview responses of the participants we found that this was the most preferred technique by the participants for this task. Participants also rated the selection techniques in the questionnaire for this task and we found that the Device Pointing was the most suitable and preferred technique as it was the fastest technique to complete this task and we also found from the video coded data that participants were having no difficulty to perform this task using the Device Pointing selection technique.

The second task was conducted to determine which selection technique is preferred by the participants when two parts are very close to each other on the document. We assumed that only Device Pointing selection technique would be good for this kind of task but from the analysis of the data that we captured, we found that both Touch on Screen and Device Pointing selection technique were well suited and preferred by the participants. We assumed that the Touch on Screen technique and Finger Pointing technique would not be well suited for this kind of task because with the Touch on Screen technique the size of some participants might be large enough which may lead to wrong selection of part on the screen of the mobile device and with the Finger Pointing selection technique, participants may point to the wrong part on the document. Time taken to complete the task was approximately same for all the selection techniques and there was also no significant difference between the hit distances for all the selection techniques. From the video coded data we observed that participants were having no difficulty in making selection from the documents using the Device pointing and Touch on screen technique and with the Finger Pointing selection technique seven participants made the incorrect part selection from the

document. Due to incorrect part selection made in seven cases using the Finger Pointing selection technique, participants didn't preferred this selection technique when they were interviewed and were asked for the preference of the selection technique for this task. From the questionnaire data we observed that participants preferred Touch on Screen and Device Pointing technique for this task and they didn't prefer Finger Pointing technique as seven incorrect selections were made.

The purpose of the third task was to determine which selection technique is preferred by the participants for region selection on the large documents. We assumed that Device Pointing selection technique would be good for selecting nearby regions and Touch on Screen would be well suited for selecting distant regions. From the analysis of the data that we captured, we found that Touch on Screen was the most suitable and preferred selection technique for nearby region as well as distant region selection on the large documents however there was a major implementation issue with the Device Pointing selection technique for this task. From the software log data we found that Touch on Screen selection technique took the least time to complete this task and since there was an implementation issue with the Device Pointing technique, it was the slowest technique to complete this task. We carefully qualify the results for the Device Pointing technique in this task, as there was a major implementation issue associated with the Device Pointing technique described in chapter 3. The result of this issue was that there was an odd mapping between selection action and result – instead of circling the region of interest, participants needed to "swipe through" (intersect) the region with the device; this may have been confusing for some participants. In addition, participants needed to repeat a swipe gesture several times before the action was recognized. The video coded data showed that the participants were swiping the mobile device across the region several times which was the reason it took more time than the other two selection techniques to complete this task. Video coded data also showed that the participants were having difficulty in selecting regions using the Finger Pointing technique as they were not able to align their finger with respect to the device camera while selecting the region on the document. As participants were having problem in selecting regions using the Device Pointing and Finger Pointing technique, so these selection techniques were not preferred

by the participants when they were asked to rate the selection techniques for this task in the questionnaire. Participants preferred the Touch on Screen selection technique as the most suitable and preferred technique for region selection task. Also from the interview responses of the participants, Touch on Screen selection technique was the most suitable selection technique for this kind of task.

Participants also filled the post condition questionnaire after completing a task set with a selection technique. Participants found Device Pointing and Touch on Screen selection technique easy to use as compared to the Finger Pointing selection technique. For all the tasks in the task set, participants were having difficulty to complete the task using the Finger Pointing selection technique as they were not able to align their finger with respect to the device camera. From the rating of the participants in the questionnaire, most of the participants were able to connect information from one document to another document with all the three selection techniques. The questionnaire data also showed that the most of the participant's attention was more focussed on the document than on the device.

CHAPTER 7 DISCUSSION, FUTURE WORK AND CONCLUSIONS

In this chapter, we discussed the results of the formal study and identify some future research pathways that are required to further improve and evaluate our UCMV prototype. We then present some final conclusions.

7.1 Discussion and Analysis of the Results from the Formal Study

Our UCMV prototype was designed to establish a link between the multiple paper documents digitally through a mobile device. This research project considered three selection techniques: Touch on Screen technique, Device Pointing technique and Finger Pointing technique to perform various activities involving multiple paper documents. Our UCMV prototype was developed using these three selection techniques.

A controlled study of our UCMV was conducted to determine which selection technique is most preferred and suitable for a particular kind of task. In the first task where the participants have to select an individual part at a varying distance from the catalog document and then view it on the cockpit or engine diagram and large schematic airplane simultaneously, Device Pointing selection technique was the most suitable and preferred by the participants than the other two selection techniques. The Device Pointing technique took the least time to complete this task for all the three parts at a varying distance on the document than the other two selection techniques. The Touch on Screen technique was the slowest selection technique to perform this task. There was an implementation issue with the Touch on Screen technique described in chapter 3 which might be the reason that it took more time than the other two selection techniques to complete the task. We originally thought that Touch on Screen selection technique would be good for selecting a particular part from the document at a varying distance but due to an implementation issue with this selection technique, participants were unsuccessful in selecting the part when the mobile device was at a far distance from the document. From the video coded data we observed that participants were moving the mobile device very close to the document to make the selection of the part using this selection technique. With the Finger Pointing selection technique, participants were having problems focusing on the part with respect to mobile device camera so it took more time than the Device

Pointing technique but it was faster than the Touch on Screen technique. There was not any significant difference between the hit distances for the Touch on Screen technique and Finger Pointing technique for all the three parts which were at a varying distance on the document. So the result was, there was no difference in how far the device was held from the target in Finger Pointer and Touch on Screen technique. From the video coded data we observed that two participants held the mobile device very close to their eyes to make the selection of the part from the document using Finger Pointing selection technique and five participants moved the mobile device very close to the document thereby blocking the image target and were unsuccessful to make the selection. The results from the questionnaire data showed that Device Pointing technique was the most preferred and appropriate selection technique for this task followed by the Finger Pointing technique. From the results of the task 1, if the implementation of the Touch on Screen selection technique can be made better by using high contrast image targets, then the Device Pointing and Touch on Screen selection technique would be good for selecting individual parts at a varying distance from the document and view them as virtual objects on other documents for the UCMV system.

The second task was conducted to determine which selection technique was the most suitable and preferred by the users if two parts are very close to each other on the document. For this task, Device Pointing technique and Touch on Screen technique were most appropriate and preferred by the participants. The time taken to complete this task was approximately same for all the selection techniques; however the Finger Pointing selection technique was not suitable because it made incorrect part selection in 7 cases. The reason for incorrect part selection was, when participants were trying to make selection of a part by pointing their finger which was very close to another part, the finger did the wrong part selection from the document. Questionnaire data showed that both Device Pointing and Touch on Screen selection technique were preferred and most appropriate for this task. We assumed that the Touch on Screen selection technique would not be good for this task as the size of the finger of the some participants with respect to the size of the screen of the mobile device may do the wrong selection of the part on the screen but from the results we observed that both Touch on Screen and Device Pointing

selection technique were good for this kind of task. If a document contains very small parts close to each other than the Touch on Screen selection technique might not be good as the size of the finger of some participants might be large enough to make the wrong selection on the screen of the mobile device.

In the third task our research objective was to determine which selection technique was the most suitable and preferred by the participants for region selection on the large sized documents. Touch on Screen was most preferred by the participants as compared to other selection techniques. Participants were facing problems to select a region with the Finger Pointing technique as they were not able to focus on the document and mobile device camera simultaneously. The Touch on Screen technique was the fastest for this task as compared to other two selection techniques. There was no difference how far the device was held from the document to select a near or far region for Touch on screen and Finger Pointing technique. Using Finger Pointer selection technique 4 participants hold the mobile device very close to their eyes and some participants hold the device very close to their finger to make the region selection but were not able to select it. From the video coded data we also observed that while using the Device Pointing selection technique, participants moved the mobile device back and forth across the region for its selection, since there was an implementation issue with this selection technique for this task. In prior work by Reilly et al. (Reilly et al., 2009) region selection using the Device Pointing technique was successfully applied by participants. An alternative method of implementing the Device Pointing selection technique for this task can be done by creating virtual points around the region that is to be selected. When the virtual points are hit by the mobile device, they can be stored in an array and if the first virtual button stored in the first index of the array matches the value of last virtual button in the last index, it indicates that the region is selected.

In this thesis the concept of UCMV was explored to determine how the information can be linked across the multiple paper documents using a mobile device. The concept of UCMV was inspired from the Coordinated and Multiple Views information visualization. Three selection techniques: Device Pointing, Finger Pointing and Touch on Screen were used to relate the information across the multiple paper documents. Since it was a Boeing

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sponsored project, so we used the airplane mechanic document set for our UCMV prototype. Design Exploration of the UCMV was conducted to determine the strengths and weaknesses of each selection technique. These three selection techniques were assumed to be best suited for a particular kind of task. In the controlled study of the UCMV, a task set was designed to determine which selection technique was the most suitable and preferred by the participants for a variety of tasks. The controlled study helped us to evaluate the three selection techniques and to determine which selection technique is best suited for a particular task. 18 participants were recruited for the controlled study to determine how the participants use the selection techniques to perform different kinds of tasks. Data such as software logged data, questionnaire data, interview data and video coded data of the participants were recorded to analyze which selection technique was better for a particular kind of task. In the design exploration phase of the UCMV, Device Pointing technique was assumed to be the most suitable technique for selection of near targets and regions. From the results of the controlled study we found that Device Pointing technique was a good selection technique which can be used by the airplane mechanics to select a discrete airplane part from the document and visualize it as a virtual object on another document. There was an implementation issue with this technique for region selection on airplane schematic. More refined implementation of this selection technique may lead to different results for this selection technique for region selection on the documents. Touch on Screen selection technique was assumed to be well suited for selection of near and far targets/regions but from the results of the controlled study we found that Touch on Screen selection technique was well suited only for selecting regions on the documents. There was an implementation issues with this selection technique as described earlier to select a single part from the document. High quality image targets or the document set should be used which may lead to different results for this technique for a single part selection. Finger Pointing technique was assumed to be well suited for selecting a part which are at the distance of arm's length but from the results of the controlled study we found that this selection technique was not suitable and preferred by the participants for any task used in the task set to evaluate the UCMV.

For future UCMV systems, high quality image targets/documents set with distinct features should be used. The tasks in the task set that we used were based on single selection only; more complex set of tasks should be used to evaluate the UCMV system in future. There were some implementation issues with the selection techniques in this UCMV system, so more refined implementation of the selection techniques should be done to evaluate the system in a better way. We used the airplane mechanic scenario as described in the previous chapter of the thesis to evaluate the UCMV system; however UCMV can also be applied to other scenarios for example shopping scenarios, medical scenarios, inventory management scenarios, etc. For example consider a grocery superstore where the manager of the superstore wants to analyze the weekly sales/profit ratio of a particular product mentioned on the weekly flyer, when a product is selected by the manager from the document using a mobile device, sales/ profit results can be represented in the form of scatter plots, bar graphs, pie charts etc. on the large displays or other digital media. Another example where the UCMV can be applied is in medical scenario where we have multiple X-Ray documents. One document contains the detailed X-Ray figure of fractured shoulder of a person and other document contains the X-Ray figure from the neck to the abdomen, UCMV can also be used to see the fractured shoulder on the document which contains the X-Ray figure from the neck to the abdomen, virtual object on the document will indicate the injured shoulder of a person.

7.2 Future Work

The current UCMV system provides good support for relating multiple paper documents through a mobile device using three types of selection techniques. The focus of the controlled study was on the selection techniques used in this interaction sequence, not the act of seeing correlations in the AR view. Since in the controlled study, we considered tasks that were based on the single selection only where participants selected a part from one document using a single selection technique and the selected part was located on the other document as a virtual object. In future studies of the UCMV more challenging and integrated tasks should be conducted where participants would perform the multiple selections from the document using the selection techniques following a sequence. It would help to determine how the participants perform the multiple selections using the

three selection techniques with the mobile device on the documents. Another example of a task which can be used is a group task where Finger Pointing and Device Pointing technique give a visual indication of selection to the collaborator. This would help us to determine how the selection techniques are used by the participants when there is a visual feedback on the screen of the mobile device. Population of the participants with and without experience to the smart phones devices should be considered in future studies of the UCMV. We considered only one document set (airplane mechanics) for our UCMV prototype, in future studies of UCMV other scenarios for example shopping store, inventory management, etc. can also be considered for the evaluation of the UCMV system. Based on our evaluation study of the prototype, we present preliminary recommendations that can be considered in future development of UCMV systems.

7.2.1 Document Set/Image Target

UCMV system needs to have good quality set of documents or the Image targets. Document set that we used were not of very high quality. The document set contains little overall contrast so the mobile device camera was not able to recognize the target features easily. Therefore, we were having problem in the implementation of the selection technique, for example selecting a part from the catalog or the cockpit diagram using Touch on Screen Technique as described earlier in chapter 3.Unity game engine (http://unity3d.com/) and the Vuforia image tracking plug-in (http://www.qualcomm.com/solutions/augmented-reality) were used to develop the UCMV prototype, the document set has to satisfy high rating (minimum 3 star rating out of 5 star rating) specified by the Vuforia image tracking plug-in. A very high quality of Image targets or the document set should be used for the implementation of the UCMV system. The quality of the image target can be determined by gray scale histogram quality indicator. If the image target has good overall contrast and the histogram of the image is wide and flat then the quality of the image target is good and contains good distinct features which can be tracked by mobile device camera easily. Otherwise if the overall contrast is low and the histogram is narrow and spikes, then it indicates that it doesn't contain good features (https://developer.vuforia.com/resources/dev-guide/image-target-enhancement-tricks).

7.2.2 Implementation of the Selection Techniques

For the efficient working of the UCMV prototype, more refined implementation of the selection techniques should be done to have better working UCMV prototype. We were having problems in the implementation of selection techniques for various tasks described below.

When a participant had to select a region on large airplane schematic (Appendix B), Device Pointing selection technique was not working properly as there was an implementation issue with it. We were tracking the distance and angle between the side wall markers and actual document set as described in chapter 3, region selection using Device Pointing technique was hard to implement with this approach. To overcome this problem participant were asked to swipe/move the mobile device across the region to make the region selection on the document. A better approach discussed in the previous section of this chapter can be used to implement this selection technique for the region selection task on large documents.

For the task when participants have to select individual parts from a document, we were having problem in the implementation of Touch on Screen technique due to bad quality of Image targets. As the qualities of image targets were not good, so participants had to move the mobile device very close to the particular part for its selection. Good quality high contrast image targets as described above should be used in future for the development of the UCMV prototype.

7.2.3 Design recommendations for future building of UCMV

High quality document set/image target as described in previous section of this chapter should be used for the future development of the UCMV system. More refined implementation of the selection techniques used in the UCMV should be done as described earlier in this chapter. More complex set of tasks should be used to better evaluate the UCMV system in future. The task set we used was based on single selection only, more complex set of tasks should be used in the future where participants have to perform multiple selections on the documents using different selection techniques following a sequence. In our UCMV we used only documents set to link the information across the paper documents, in future evaluation of UCMV other digital media such as

table tops, large screens etc can be used in combination with the paper documents to relate the static/ digital information. For example information selected with the mobile device from the paper document can be used to project meaningful information in the form of graphs, pie charts etc. on the large screens displays. Other devices such as tablets, iPads can be used along with the mobile device in future evaluation of the UCMV. Since we used only the airplane mechanic scenario to evaluate our UCMV, it can be applied to other scenarios as explained in the previous section of this chapter.

7.2.4 Future Research Questions

1. To evaluate the UCMV system with more challenging set of tasks and more refined implementation of selection techniques in a scenario involving multiple paper documents which are used in the daily life of people.
2. To have a better understanding of how people correlate multiple paper documents with and without the use of the UCMV system.

7.3 Conclusions

UCMV was designed to serve as a tool for relating the multiple paper documents digitally through a mobile device. We described three selection techniques that can be used to link these documents through a mobile device. These three selection techniques were assumed to be best suited for a particular task. Touch on Screen technique was assumed to be best suited to select distance parts or regions on the documents because we could just tilt the device to make the selection. Device Pointing technique was assumed to be best suited to select nearby parts or regions and to select a part which is very close to another part because the participants simply have to tap the mobile device on the document to make the selection. Finger Pointing technique was assumed to be best suited to select a part at a varying distance on the document as the participants only have to point to a particular part by their finger to make the selection. We also found that selecting regions would not be well served by finger pointing because it would be awkward to move the device and the pointing finger in tandem.

A design exploration study using a basic prototype was conducted to refine the features of the prototype and to help identify tasks and document sets to use in a formal study.

Design exploration helped to determine the task set and layout of the documents that we used in our controlled study. Design exploration also led to more refined implementation of the selection techniques for the tasks that were used in the controlled study. Since no data was captured in design exploration, data was logged in the software for the controlled study to have the better understanding of the behaviour of the selection techniques for a particular task. Then a controlled study was performed with the 18 participants to determine which selection technique was most appropriate and preferred by the participants for a particular task. The research objective of controlled study was also to determine how these three selection techniques should be used together to perform activities involving a range of inter-document correlation actions. Data was captured in the controlled study in the form of logged data, questionnaire data and video recordings. Touch on Screen technique was found to be most suited to select regions on any paper document. Device pointer technique was found to be best when the participant wants to select a particular part from a paper document (a discrete selection). Both device pointing technique and touch on screen technique were found to be most suited to make the selection if two parts are very close to each other on the document.

Future work will further refine the design of UCMV for various document set. With the addition of new task set, document set and more refined implementation of selection techniques ,UCMV can be applied to a range of inter- document collections for performing various activities with the three selection techniques that were used.

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Appendix A: Ethics Board Approval

DALHOUSIE UNIVERSITY
Inspiring Minds

Social Sciences and Humanities Research Ethics Board
Letter of Approval

Date: March 6,2012.

To: Savneet Singh Arora , Computer Science
    Dr. Derek Reilly, Computer Science

The Social Sciences Research Ethics Board has examined the following application for research involving humans:

Project # 2012-2641 (version 2) (R# 1010391)

Title: Ubiquitous Coordinated and Multiple Views: Design Exploration and Selection Techniques

and found the proposed research involving human participants to be in accordance with Dalhousie Guidelines and the Tricouncil Policy Statement on *Ethical Conduct in Research Using Humans.* This approval will be in effect for 12 months from the date indicated below and is subject to the following conditions:

1. Prior to the expiry date of this approval an annual report must be submitted and approved.
2. Any significant changes to either the research methodology, or the consent form used, must be submitted for ethics review and approval *prior to their implementation.*
3. You must also notify Research Ethics when the project is completed or terminated, at which time a final report should be completed.
4. Any adverse events involving study participants are reported immediately to the REB

Effective Date: March 6,2012.   signed:
Expiry Date: March 6,2013.

IMPORTANT FUNDING INFORMATION - *Do not ignore*
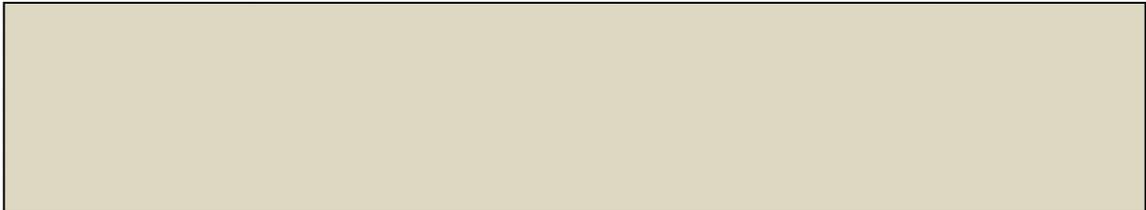
Dalhousie Research Services · Research Ethics · 6299 South Street,2nd Floor, Suite 231,PO Box 15000 · Halifax, NS, Canada · B3H 4R2   Tel: 902-494-3423 · Fax: 902-494-1595 · Email: ethics@dal.ca · www.dal.ca/~research

Appendix B – Informed Consent

Ubiquitous Coordinated and Multiple Views Study

Investigators:
Savneet Singh Arora, MCS student, Faculty of Computer Science (sarora@cs.dal.ca)
Derek Reilly, Assistant Professor, Faculty of Computer Science (reilly@cs.dal.ca)
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Contact Person:

Savneet Singh Arora, MCS student, Faculty of Computer Science (sarora@cs.dal.ca)

We invite you to take part in a study being conducted by Savneet Singh Arora and Derek Reilly at Dalhousie University. Your academic (or employment) performance evaluation will not be affected by whether or not you participate. There is no risk involved in participating in this study beyond that inherent in working in an office environment. The study is described below. Participating in the study might not benefit you, but we might learn things that will benefit others. You should discuss any questions you have about this study with Savneet Singh Arora.

This study will take about 90 minutes. The facilitator will describe a range of techniques for connecting paper documents with digital, and show a set of short videos illustrating each technique.

You will be compensated $15 for participating in the study; you can withdraw from the study at any time without consequence. A researcher is always available over the study or afterward by email or to meet in person to answer any questions you may have or address any problems that you may experience with the tasks.

All personal and identifying data will be kept confidential. Anonymity of textual data will be preserved by using pseudonyms. All data collected in the logs and questionnaires will use pseudonyms (e.g., an ID number) to ensure your confidentiality. The informed consent form and all research data will be kept in a secure location under confidentiality in accordance to University policy for 5 years post publication.

In the event that you have any difficulties with, or wish to voice concern about, any aspect of your participation in this study, you may contact Catherine Connors, Director, Office of Research Ethics Administration at Dalhousie University's Office of Human Research Ethics for assistance: phone: (902) 494-1462, email: catherine.connors@dal.ca.

"*I have read the explanation about this study. I have been given the opportunity to discuss it and my questions have been answered to my satisfaction. I hereby consent to take part in the study. However, I understand that my participation is voluntary and that I am free to withdraw from the study at any time.*"

Participant   Researcher

Name: _____   Name:

_____
Signature: _____   Signature:

_____
Date: _____   **Date:**

_____

"I understand and consent that my participation in the experiments will be video recorded for the purpose of analysis. I understand that this is a condition of participation in the study, and I understand that this video record will not be used in publication or presentation of results."

Participant   Researcher
Name: _____   Name:

_____
Signature: _____   Signature:

_____
Date: _____   *Date:*

_____

Please select one of the options below:

☐ *"I agree to let you directly quote any comments or statements made in any written reports without viewing the quotes prior to their use and I understand that the anonymity of textual data will be preserved by using pseudonyms."*

Participant   Researcher
Name: _____   Name:

_____
Signature: _____   Signature:

_____
Date: _____   *Date:*

_____

<u>**Or**</u>

☐ *"I want to read direct quotes prior to their use in reports and I understand that the anonymity of textual data will be preserved by using pseudonyms."*
(if this option is chosen, please include a contact email address:
_____)

Participant   Researcher
Name: _____   Name:

_____
Signature: _____   Signature:

_____
Date: _____   *Date:*

_____

If you are interested in seeing the results of this study, please check below and provide your email address. We will contact you with publication details that describe the results.

☐   *"I would like to be notified by email when results are available via a publication."*

(if this option is chosen, please include a contact email address: _____)

Appendix C – Post Condition Questionnaire

Please rate how strongly you agree or disagree with each of the following statements by placing a check mark in the appropriate box.

1. **The interaction technique was easy to use.**

☐Strongly ☐Agree ☐ Undecided ☐ Disagree ☐ Strongly Disagree
Agree

2. **The interaction technique is familiar given my experience with other apps.**

☐Strongly ☐Agree ☐ Undecided ☐ Disagree ☐ Strongly Disagree
Agree

3. **The interaction technique helped me connect information in one document to information in another.**

☐Strongly ☐Agree ☐ Undecided ☐ Disagree ☐ Strongly Disagree
Agree

4. **My attention was more focused on the document than on the device.**

☐Strongly ☐Agree ☐ Undecided ☐ Disagree ☐ Strongly Disagree
Agree

5. **Please rate how well-suited the interaction was to each task by placing an X in the appropriate column for each task row.**

#	Description	Very poorly	Poorly suited	Neutral	Well-suited	Very well-

		suited				suited
1						
2						
3						
4						

6. **Please provide any comments about your experience using the interaction technique:**

_____

_____

_____

_____

Appendix D – Recruitment Notice

We are recruiting participants to take part in a research study examining interaction techniques for Augmented Reality using mobile devices. We are looking for students, faculty or staff, or their family or friends. No previous experience with mobile devices (like smartphones) is required.

The study will be conducted in either the Mona Campbell Building at Dalhousie University and will take about 60 - 90 minutes to complete. You will first meet with a researcher to go over the study details, give consent to do the study, and receive training on a range of mobile interaction techniques. You will then complete a set of tasks with various interaction techniques. You will be answering questions about your experience in a brief interview after the tasks. Compensation is $15 for participation in the study.

If you are interested in participating, please contact Savneet Singh Arora (sarora@cs.dal.ca).

APPENDIX-E

DALHOUSIE UNIVERSITY
Inspiring Minds

Social Sciences and Humanities Research Ethics Board
Letter of Approval

Date: July 23, 2012.

To: Savneet Singh Arora, Computer Science
    Dr. Derek Reilly, Computer Science

The Social Sciences Research Ethics Board has examined the following application for research involving humans:

Project # 2012-2769 (R# 1011674)

Title: Ubiquitous Coordinated and Multiple Views- Study (Phase 2)

and found the proposed research involving human participants to be in accordance with Dalhousie Guidelines and the Tricouncil Policy Statement on *Ethical Conduct in Research Using Humans.* This approval will be in effect for 12 months from the date indicated below and is subject to the following conditions:

1. Prior to the expiry date of this approval an annual report must be submitted and approved.
2. Any significant changes to either the research methodology, or the consent form used, must be submitted for ethics review and approval *prior to their implementation.*
3. You must also notify Research Ethics when the project is completed or terminated, at which time a final report should be completed.
4. Any adverse events involving study participants are reported immediately to the REB

Effective Date: July 19, 2012.   signed:
Expiry Date: July 19, 2013.

IMPORTANT FUNDING INFORMATION - *Do not ignore*

To ensure that funding for this project is available for use, you must provide the following information and FAX this page to RESEARCH SERVICES at 494-1595

Name of grant /contract holder _____ Dept. _____
Signature of grant / contract holder _____
Funding agency _____
Award Number _____ Dal Account # (if known) _____