UNIVERSITI PUTRA MALAYSIA

A COLLOCATED MULTI-MOBILE COLLABORATIVE SYSTEM WITH HOVER CONNECTIVITY INITIATION AND SEAMLESS MULTI-TOUCH INTERACTIVITY

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By

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Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfillment of the requirement for the degree of in Master of Science

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April 2018

Chairman : Noris Binti Mohd. Norowi, PhD
Faculty : Computer Science and Information Technology

This research focuses on the collocated multi-mobile system (CMMS) which combines multiple mobile devices to become one shared large surface that could provide tabletop interactivity and group collaboration. However, several usability issues are yet to be discovered: (i) the cumbersome and confusing process to calibrate and align display of multiple mobile devices (ii) the lack of multi-touch gesture that can span across the boundaries of multiple mobile devices. Hence, this research aims to study the performance and user experience of connectivity initiation and multi-touch interaction on a CMMS. The research creates a new way to align the display and to allow multi-touch support to spans across multiple screens. The research methodology used is the User-Centered Design (UCD) approach where the process starts from understanding requirements, designing, prototyping and evaluating through a usability test. There are three main studies were carried out which covered the preliminary study, connectivity initiation study and multi-touch study for CMMS. The studies used quantitative and qualitative approaches. During preliminary study, it was found that the initiating process to connect multiple mobile device was time consuming, confusing and cumbersome. The preliminary study also observed that users tended to perform a multi-touch gesture on multiple screens but currently multi-touch gesture is not applicable to existing multi-mobile systems. The first connectivity initiation study was conducted to evaluate several approaches to perform connectivity initiation. Two best approaches were identified based on its performance and users experience on the medium-fidelity prototype. The hover and the swipe approach were found to be the two of the best approaches in terms of shorter time completion, higher user preference ratings and lower perceive workload index. These two approaches were then implemented for designing the high-fidelity prototype. The first multi-touch study also showed that user preferred the seamless multi-touch setting when evaluate using medium fidelity prototype. The second connectivity initiation study was then conducted to compare between the hover and swipe approach based on users' feedbacks. It was found that the hover approach was able to reduce the time required to perform the connectivity initiation by 25%, compared with the swipe approach. The user rated the hover approach better in term of perceive workload rating compare to swipe approach. The second multi-touch study also found that user experience was significantly improved when multi-touch across the devices was

enabled. It was found that the seamless multi-touch setting help reduced the time completion by 25.29%, reduce the average movement by 20.18% and reduce the error rate by 58.3%. In general, the results supported that hover approach and seamless multi-touch interaction had improved the issues surrounding the connectivity initiation and multi-touch for CMMS. The findings of this research can contribute to the growing body of research on CMMS by implementing the proposed solution to further address similar issues in their research works.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia, sebagai memenuhi keperluan untuk ijazah Master Sains

SISTEM KOLABORATIF SETEMPAT PERANTI MUDAH-ALIH MENGGUNAKAN KAEDAH SAMBUNGAN HOVER DAN INTERAKSI MULTI-SENTUHAN MERENTASI SEMPADAN

Oleh

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April 2018

Pengerusi : Noris Binti Mohd. Norowi, PhD
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Penyelidikan ini memberi tumpuan kepada sistem kolaboratif setempat peranti mudah-alih yang menggabungkan pelbagai peranti mudah-alih untuk menjadi satu permukaan yang lebih besar justeru boleh memberikan interaktiviti tabletop dan kolaborasi kumpulan. Penciptaan peranti mudah-alih membolehkan penciptaan sistem kolaboratif setempat peranti mudah-alih; Walau bagaimanapun terdapat beberapa masalah kebolehgunaan ditemui (i) proses rumit dan mengelirukan untuk mengkalibrasi pelbagai peranti mudah-alih (ii) kekurangan sokongan multi-sentuhan untuk memanipulasi objek dari luar sempadan pelbagai peranti mudah-alih. Oleh itu, penyelidikan ini bertujuan untuk mengkaji prestasi dan pengalaman pengguna untuk mengkalibrasi pelbagai peranti mudah-alih dan sokongan multi-sentuhan untuk sistem kolaboratif setempat peranti mudah-alih. Penyelidikan ini akan mencadangkan cara baru untuk mengkalibrasi paparan dan juga membolehkan sokongan multi- sentuhan yang boleh merentangi pelbagai skrin peranti mudah-alih. Metodologi kajian yang digunakan adalah pendekatan reka bentuk berpusatkan pengguna. Terdapat tiga kajian utama yang dijalankan iaitu kajian awal, kajian proses mengkalibrasi paparan dan kajian interaksi multi-sentuhan. Kesemua kajian menggunakan pendekatan kuantitatif dan kualitatif. Kajian awal untuk inisiasi sambungan paparan menunjukkan bahawa proses penyambungan paparan banyak memakan masa, mengelirukan dan sangat rumit untuk dilaksanakan oleh penguna. Kajian awal juga mendapati bahawa pengguna cenderung melakukan multi- sentuhan merentangi luar daripada sempadan skrin yang ditetapkan. Kemudian dalam kajian pertama proses inisiasi sambungan, beberapa cara untuk inisiasi sambungan paparan diuji untuk mencari dua kaedah terbaik berdasarkan prestasi dan pengalaman pengguna. Kajian kedua proses inisiasi sambungan membandingkan kedua-dua kaedah yang dipilih dari kajian pengguna pertama proses inisiasi sambungan. Kaedah hover didapati dapat mengurangkan masa penyelesaian sebanyak 25%. Kaedah hover juga mempunyai indeks bebanan kerja yang rendah daripada kaedah swipe. Untuk interaksi multi-sentuhan, kajian pertama interaksi multi-sentuhan menunjukkan pengalaman pengguna bertambah baik apabila pelbagai sentuhan merentas peranti diaktifkan dengan menggunakan prototaip berskala kecil. Kajian kedua interaksi multi-sentuhan juga menunjukan bahawa pelbagai sentuhan merentas peranti boleh mengurangkan masa penyelesaian sebanyak 25.29%, mengurangkan purata pergerakan sebanyak 20.18% and

mengurangkan kadar ralat sebanyak 58.3%. Akhirnya, penemuan kajian ini boleh menyumbang kepada penyelidikan dalam sistem kolaboratif setempat peranti mudah-alih untuk menangani isu-isu yang serupa dalam kerja-kerja penyelidikan di masa hadapan.

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I certify that a Thesis Examination Committee has met on 3 April 2018 to conduct the final examination of Teo Rhun Ming on his thesis entitled "A Collocated Multi-Mobile Collaborative System with Hover Connectivity Initiation and Seamless Multi-Touch Interactivity" in accordance with the Universities and University Colleges Act 1971 and the Constitution of the Universiti Putra Malaysia [P.U.(A) 106] 15 March 1998. The Committee recommends that the student be awarded the Master of Science.

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This thesis was submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfillment of the requirement for the degree of Master of Science. The members of the Supervisory Committee were as follows:

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Date:

Declaration by graduate student

I hereby confirm that:

- this thesis is my original work;
- quotations, illustrations, and citations have been duly referenced;
- this thesis has not been submitted previously or concurrently for any other degree at any other institutions;
- intellectual property from the thesis and copyright of thesis are fully-owned by Universiti Putra Malaysia, as according to the Universiti Putra Malaysia (Research) Rules 2012;
- written permission must be obtained from supervisor and the office of Deputy Vice-Chancellor (Research and Innovation) before thesis is published (in the form of written, printed or in electronic form) including books, journals, modules, proceedings, popular writings, seminar papers, manuscripts, posters, reports, lecture notes, learning modules or any other materials as stated in the Universiti Putra Malaysia (Research) Rules 2012;
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Signature: _____ Date: _____

Name and Matric No.: Teo Rhun Ming (GS41200)

Declaration by Members of Supervisory Committee

This is to confirm that:

- the research conducted, and the writing of this thesis was under our supervision;
- supervision responsibilities as stated in the Universiti Putra Malaysia (Graduate Studies) Rules 2003 (Revision 2012-2013) are adhered to.

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Signature: _____
Name of
Member of Supervisory
Committee: Professor Dr. Rahmita Wirza O.K Rahmat

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS

AVG	Average/ Mean
CMMS	Collocated multi-mobile system
FCSIT	Faculty of Computer Science and Information Technology
GPS	Global Positioning System
HCI	Human Computer Interaction
IBM	IBM Usability Questionnaire
IR	Infrared Receiver
LED	Light Emitted Diode
NASA-TLX	Perceived Workload Index Questionnaire
NFC	Near Field Communication
PC	Personal Computer
QLED	Quantum Dot Light Emitting Diode
RGB	Red Green Blue
STDEV	Standard Variation
SUM	Summation
TCP	Transmission Control Protocol
TV	Television
UCD	User-Centered Design
UI	User Interface
UPM	Universiti Putra Malaysia
VR	Virtual Reality
WIMP	Windows, Icons, Menus, Pointer
WLAN	Wireless Local Area Networking

CHAPTER 1

INTRODUCTION

1.1 Introduction

In recent years, the monitor has been the cornerstone of technology providing users with visual information. The monitor was mostly used to display content such as text, picture, video, and graphics. The monitor has already been widely used by many modern types of equipment such as television, tablet, and smartphone. Over the years, the size of the monitor has been increased due to advance in manufacturing technology. Currently, the largest monitor in the world was claimed by Samsung's QLED TV measured at about 88 inches (Collie, 2017). Some studies indicated the monitor size could affect the gameplay immersion. The finding from Thompson's work showed that a larger monitor display screen will provide greater game immersion than that of the small screen (Thompson, Nordin, & Cairns, 2012). However, a larger monitor can be costly and expensive. Furthermore, a large monitor is also heavy to carry around due to its large size with embedded hardware.

Another way to create a large monitor is by combining multiple small screens to create a large single display. The setup was called the multi-display solution. The benefit of this multi-display solution was that it can help to reduce the cost. The multi-display solution also has the benefit of improving user productivity. Previous study Truemper et al. (2008) showed that users could perform multi-task more often on the multi-display solution compare with single display solution. However, both large display and multi-display are unable to perform interaction with the content. The interaction on the monitor is mostly indirect as users cannot directly manipulate the content in the monitor display. Instead of that, they must use an external input device such as a keyboard or a mouse to interact the content on the monitor. Fortunately, a display monitor that is used today was now equipped with touch technology. Users were now able to interact directly with the content by using touch input. The interaction was more direct without sacrificing so much space and also much more robust than any other input (Albinsson & Zhai, 2003). Several examples of such devices are the tabletop, tablet, and smartphone.

Collocated multi-mobile system (CMMS) is a synchronous and coherence system which connects multiple devices and turn into a single groupware environment that shares resources such as the display area and computing power (Lyons, Pering, Rosario, Sud, & Want, 2009). Lyons et al., (2009) defined that collocated multi-mobile system used the displays of several mobile devices to bind together in creating one big display. The extended screen size creates an extensive environment that allows multiple users to interact with the system. Figure 1.1 shows one of the collocated multi-mobile system (CMMS). The CMMS has been used in various areas especially for collaborative purposes such as presentation, discussion, and entertainment (Lucero, Holopainen, & Jokela, 2011; O. Liang, Norowi, & Mansor, 2016; Kauko & Häkkilä, 2010). This is useful when people intend to share or present information in a visual and interactive manner. The CMMS could be a better solution that performs similar functionalities as

the multi-touch digital tabletop system that can be found on market. Therefore, this thesis helps to enable users to experience tabletop by using existing technology such as the mobile devices.

Figure 1.1 : Collocated Multi-Mobile System (CMMS) that Stitch All Small Pieces of the Map into One Large Map.

1.2 Problem Statement

There have been multiple studies done on the collocated multi-mobile system (CMMS). Previous study provided interactive ways to form CMMS, study social interaction with the game using CMMS and study interactivity and collaboration on CMMS (Barth & Pras, 2015; Kort, Poels, & Ijsselsteijn, 2007;
O. B. Liang et al., 2015). However, there is a lack of studies to find the most effective approach to perform connectivity initiation. Additionally, there are also few studies on user experience when performing multi-touch interaction on CMMS. Therefore, the main issue that will focus on this thesis is the connectivity initiation approach and the multi-touch interaction on CMMS.

The first issue aims at the lack of effective approaches to perform connectivity initiation without requiring external input to form a CMMS. Previous study was done by placing the devices under the vision system such as “HuddleLamp” (Rädle, Jetter, Marquardt, Reiterer, & Rogers, 2014). However, this system requires to set up external hardware which is a hassle and can only place in a fixed location, thus sacrifices its portability (Luyten, Verpoorten, & Coninx, 2007). This can put off some users as they need to buy extra equipment to set up the system. There are systems that place sensor around the mobile device to perform connectivity initiation. For example, “MagMobile” places magnetic sensor around the mobile device to provide better portability than “HuddleLamp” (Huang et al., 2013). To perform connectivity initiation, the user simply installs the plugin around the mobile device and place it next to each other. However, the installation effort is very unergonomic. Since the mobile device came with multiple different size and dimension, not all plugin can fit into many different types of mobile devices. Therefore, the research would like to find a new effective way to perform

connectivity initiation which does not require any external input but also provide better portability for the CMMS.

The next issue is that the current approaches to performing connectivity initiation are time-consuming and complicated. Past studies had indicated that using manual connection approaches such as bumping or using pinch gesture were complicated and time-consuming. To perform connectivity initiation, users require to perform a certain gesture manually. Example of study from Ohta & Tanaka (2015) required users to perform pinch gesture to form large tiles of the display with video or image played on it. A manual approach can be time-consuming because users must repeat the gesture if there are more than two mobile devices were used to form the CMMS (Ohta & Tanaka, 2015). Besides that, the manual approach could be difficult and hassle as users were likely to avoid it as shown in a previous study (Schmitz & Li, 2010). Another approach is the automatic approach which initiates connectivity automatically using the available sensor without requiring users to perform the gesture. Example of the automatic approaches were the "HuddleLamp", "Dynamic Display Tiling" and "Tracko" (Rädle et al., 2014; Li & Kobbelt, 2012; Jin, Holz & Hornbæk, 2015). However, connecting automatically still require a few extra steps such as required to place a fiducial marker on celling before connectivity initiation process proposed by Li & Kobbelt (2012). There also another type of approach for connectivity initiation which is the semi-automatic approach. The semi-automatic approach has both manual and automatic approach to initiate connectivity. Schmitz & Li (2010) created a system with a semi-automatic approach which required users to perform automatic approach using rear camera on multiple mobile devices along with using the manual approach on the final device to set up the system completely. However, the system is not straightforward especially when the user tries to perform the connectivity initiation manually. Therefore, the research would like to explore a new way to perform connectivity initiation that is less time consuming and less complicated.

Lastly, there is a general lack of basic gesture support that spans across the boundaries of multiple devices. Most of the multi-touch interaction on the collocated multi-mobile systems were limited to a single individual mobile device. The multi-touch interaction was defined as an interaction using one or two fingers simultaneously interacting on a touch input surface and also help facilitate collaboration in a multi-user environment (Bullinger & Behlau, 2009). Most of the CMMS applications lack the basic multi-touch support that spans across the boundaries of multiple devices. The CMMS mostly can handle those multi-touch interactions on a single device instead of multiple devices when it comes to direct manipulation interaction. Direct manipulation interaction is where the objects of interest such as files, images or videos are visible and can be acted upon by users via physical, reversible, incremental actions with immediate visual feedback (Shneiderman, 1982). Pinch to zoom and dragging are one of the examples of direct manipulation interaction (Balducci & Borghi, 2017). Some of this multi-touch interaction covered pinch to zoom, rotate clockwise or anti-clockwise and tapping etc. was used to interact the object on a tabletop system (Song-gook Kim, Kim, & Lee, 2007). The current CMMS can only perform simple cross-device interaction such as dragging and dropping across devices. Kurdyukova, Redlin, & André (2012) studied how users interact with the drag and drop on CMMS. The system can move the object using a simple gesture by dragging the object from one device across another device but the gestures that support interaction were limited (Kurdyukova et al., 2012). Figure 1.2

shows how proposes multi-touch interactivity that is not limited within device boundaries uses on the CMMS.

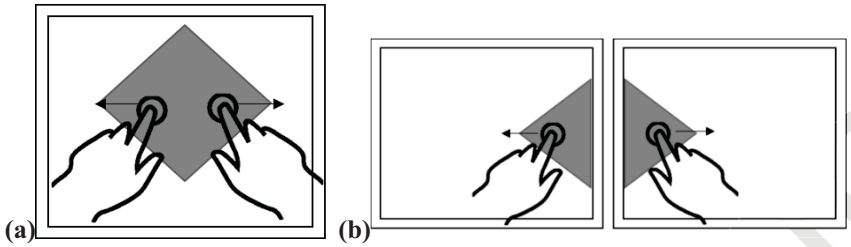

Figure 1.2 : (a) Multi-Touch Interaction on a Single Device. (b)The Multi-Touch Interaction that is Not Limited to Device Boundaries On CMMS.

1.3 Research Question

All these pertinent unresolved issues relating to the collocated multi-mobile system has led to the following research questions to be addressed in this study:

1. Which existing connectivity initiation approach is efficient and intuitive to set up the CMMS?
2. How to provide a better user experience for CMMS by enabling multi-touch interaction that could span across multiple mobile devices?

1.4 Research Objectives

The main aim of this study is to improve user interaction when using collocated multi-mobile system (CMMS). Two aspects which will be tackling is simplifying connectivity initiation and enabling multi-touch interactivity. To achieve the aim, four objectives were formulated:

1. To identify and introduce the most efficient and intuitive approaches to perform connectivity initiation on multiple mobile devices to form a collocated multi-mobile system without requiring external input.
2. To design a hovering approach that connects and align multiple devices by using mid-air hand hover.
3. To design and introduce seamless multi-touch interaction that spans across multiple mobile devices and evaluate between the individual and seamless multi-touch interaction for shorter task completion with higher user preference.
4. To evaluate the efficiency of the designed CMMS system and user experience for hover connectivity initiation approach and seamless multi-touch interaction for the collocated multi-mobile system.

1.5 Research Scope

The thesis is mainly focused on the connectivity initiation and seamless multi-touch interaction of the CMMS. The process to perform connectivity initiation includes the connection between mobile devices and the display alignment of the mobile devices. The connectivity between device uses the ad-hoc connection to connect multiple mobile devices using server-client setup. sThere are many different approaches perform by users to initiate connectivity. The approaches include using gestures, sensors or cameras to form a large composite display. The multi-touch interaction on CMMS focuses on bringing seamless multi-touch experience with spatially-aware interaction. Spatially aware interaction uses real-world spatial configuration as a referential domain to provide users more natural and familiar interaction with the object (Rädle et al., 2015). Seamless multi-touch interaction allows the user to perform multi-touch gesture across multiple devices and was not limited within the boundaries of a single mobile device. Figure 1.3 shows the area that this thesis will focus on for CMMS.

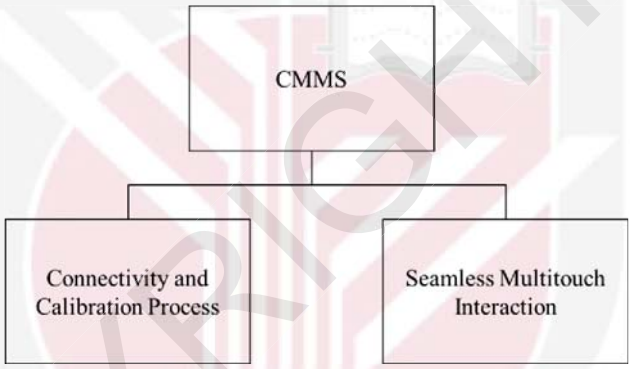

Figure 1.3 : The Area That This Thesis Will Focus on for CMMS.

1.6 Contribution

The core of this study is to provide an effective and useful solution to address connectivity initiation and multi-touch issue in CMMS. The study is significant because it fills the gaps reviewed in the current literature with regards to the connectivity initiation between multiple devices and multi-touch interaction in CMMS. The thesis presents the findings that can be used to identify which connectivity initialization approach is preferred by users according to the quantitative and qualitative data gathered during each user study. The study also provides a new way to create a composite display using the hover approach that can resolve the issues mentioned in the research problem. The thesis also presents studies on the effect of individual and seamless multi-touch interaction on a collocated multi-mobile system. The findings can be useful for any researchers or mobile developers that interest in developing their own CMMS which beneficial to the research on the connectivity initiation and cross-device interaction. The thesis also contributes to numbers of research on the collocated system, multi-device system and multi-touch interaction on the collocated system by implementing solutions

to help address some issues in their research. These findings imply that the findings of this research can help improve the user experience of the system.

1.7 Chapter Organization

Chapter two reviews the literature that focuses on previous research done on the collocated multi-mobile system. The literature review provides more understanding of the collocated multi-mobile system, the connectivity initiation, and cross-device interaction.

Chapter three describe the research methodology used in this research. The research methodology describes the research design, methodological framework, experimental procedures, research method, data collection technique and data analysis used for this research.

Chapter four explain the system design of hover approach and seamless multi-touch interaction for CMMS. This chapter explains more detail on the system design for hover connectivity initiation approach and seamless multi-touch interaction in a high-fidelity prototype of the CMMS.

Chapter five describes the preliminary study done before the user study to provide insight on the interaction between users and collocated multi-mobile system.

Chapter six focuses on the evaluation and discusses the findings on the connectivity initiation. There were two connectivity initiation study was conducted using medium and high-fidelity prototype respectively.

Chapter seven focuses on the user study and presents the findings on the multi-touch interaction. There were two multi-touch studies conducted using medium and high-fidelity prototype respectively.

Chapter eight is the conclusion of this thesis. This chapter describe the conclusion, implication, limitation and recommended suggestion for future study.

1.8 Summary

This chapter had discussed the detail of the issues regarding the connectivity initiation and multi-touch interaction on CMMS. The chapter also explicitly detailed the objectives and aim of this research. The scope of this research was mentioned. The significance of the study includes improving the user experience and usability of the connectivity initiation and multi-touch interaction of CMMS was mentioned.

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