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Research paper

Using Continuous Spatial Configuration for Bezel Issues in a Multi-Mobile System

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Abstract

With the rapid moving technology and innovation, the current digital technology such as smartphones and tabletop system have become vital necessities to accommodate people's daily activities. As a more robust alternative to tabletop system, the multi-mobile system is also benefiting humans' interaction by combining multiple mobile devices to become a shared and larger touch surface display. This paper demonstrates the study on effects of bezels on a multi-mobile system which allows users to perform collaborative drawing task with mobile devices in an ad-hoc manner. Unfortunately, gaps and physical design of the mobile devices between the mobile displays cause inherent design problems to the multi-display structure. Before conducting the experiments, two prototypes have been designed; high-fidelity prototype (without solution) and iterative prototype (with the continuous spatial configuration). Two user studies have been conducted with the prototypes by observing groups of students performing an interactive drawing task and the findings were compared. Results from the first user study show gaps and disjointed objects were observed in the drawing outcomes, while in the second user study, where the Continuous Spatial Configuration was implemented as a solution to this bezel issue, the gaps and spaces between the screens were eliminated by 94.8%. From this study, it is believed that implementing the Continuous Spatial Configuration in the prototype designs can improve the user experience in the context of collaboration beyond the use of expensive tabletops systems.

Keywords: *Bezels; gap; interaction; mobile devices; multi-mobile system; screen display.*

1. Introduction

With the fast moving transformation in this edge of innovation, digital technology develops a vital requisite to accommodate people's daily lives. With the rapid rise of generation in multi-platform media, the available technology has presents numerous types of smart gadgets and tablets such as smartphones, computers, tabletop system which are currently experiencing popularity attentions and also exploiting mobile world to accommodate the user's needs for their daily activities [1]. The vibrant use of digital technology supports in searching and unlocking massive of information collection and communication data that will positively impact on individual, organizations and business management.

Human communication is at ease of reaching out each other through the access of smart gadgets. Hence, the importance of human interpersonal communication cannot be neglected. Along with the integration of technology and human communication, mobile gadgets have brought collaborative work to next level, for instance, people use mobile gadgets for conferencing and discussion for a group work [2]. People usually apply collocative technology for collaborative works, such as video discussing and conferencing, completing a group task, etc. Collocative technology encourages excellent interaction and communication whereby a team of workforce shares a common goal by sharing ideas, information, and work.

Tabletop system is an example of a collaborative work space that provides a large touch screen which is capable of multi-touch interface [3]. Tabletop provides larger display surface as compared to mobile device [4]. However, the tabletop system is costly compared to mobile devices. Tabletops also have poor portability as its huge physical size makes it difficult for it to be carried around. Due to this, researchers have begun to develop multi-mobile system by stacking mobiles phone together in order to provide similar co-located collaborative benefits as tabletop system, which is referred to as the multi-mobile system [5].

Multi-mobile connects multi mobile devices together in a groupware environment to create one large display [6]. The extended surface allows multiple users to interact and work, similar to the tabletop system. Fig. 1 shows the multi-mobile system. It has been used in multiple different areas, especially for collaboration purposes, for instance, slide presentation, general discussion and also entertainment. Multi-mobile system provides users to have multi-user interaction and multi-object manipulation for collaborative purposes that have the similar user experience as provided by tabletop system. However, there are still issues and challenges related to the current design of collaborative multi-mobile system and applications, such as the inclusiveness of the gaps and spaces between the mobile devices. This interactive issue has significantly affected the user experience and interaction of multi-mobile users.

This study focus on the relationship of human's factors with the abundance of mobile devices and tablets available in the market for maximal utilization on the interaction and collaboration purpose, and meanwhile aims to study the interactive issues which caused by the bezel of multi-mobile display and hence design a solution to solve the bezel issues. A multi-mobile system comprises the capabilities of an interactive tabletop technology has been introduced in this study to adhere the existing problem whereby the user interaction and collaboration among mobile devices' users are restricted due to the gaps and spaces between the screens and bezels issues as compared to the interactive tabletop technology. When group of people working collaboratively, especially group drawing on the multi-mobile system (the mobile phones are arranged in 2 x 2 grid patterns), the bezels are blocking the participants' view and hence distracted their user experience. Hence, the multi-mobile system has been introduced. Nevertheless, the multi-mobile system which comprises the features of mobile devices and tabletop technology helps smoothening project discussions, multiple tasks distribution, and enhancing collaborative work.

Fig. 1: Multi-mobile System

2. Related works

Human-Computer Interaction (HCI) is the study of the ways in which computer technology has influences human works and activities. Nowadays, the term "computer technology" often relates to the use of multiples technologies application, from computer desktop with screens and keyboards to telecommunication gadgets which involved mobile phones and tablets, home and personal appliances, automobiles built-in navigation systems and also embedded sensors and servomechanism such as automatic lighting [7]. Hence, this study focuses on how the co-existence of abundance mobile devices and tablets gadgets in the market which can be utilized in future impromptu work collaborations.
Multi-mobile system is a system that uses an application to connect multiple mobile devices as a groupware environment to create a large shared display [8]. Fig. 2 shows the example of a multi-mobile system laid in a 2x2 grid.
The large shared display provides bigger working space and allows multiple users to work together on it, similar to a tabletop technology. Unfortunately, multi-mobile system faces a main interactivity challenge which is the inclusiveness of the gaps and spaces between the mobile devices. These gaps and spaces resulted from the bezel. Bezel is the physical design of outer frame for computing gadgets as shown in Fig. 3.

Fig. 2: A multi-mobile System Lay in a 2x2 Grid

Unfortunately, the spaces and gaps between the bezel causes inherent design problems to the multi-display structure [9]. The thickness of bezel can be distracted during a collaborative work. Usually, users are confused with the space and gap between the mobile screens either to be included or excluded. Hence, the bezels of the devices negatively affected the user's viewing experience.

Fig. 3: Bezel

The bezel helps to hold the digital screen, and also help to reduce unintentional inputs on the screen [10]. Moreover, it's uncertainty that occurs during the output of It is essential for mobile devices developers and designers in evaluating the overall perimeter of the device and its possible ramifications [11]. Newer device designs such as the iPad and Samsung S8 have narrow bezels which allowing for more screens when it comes to multi-mobile system [12]. This has improved the situation, but the narrow bezel still result in discontinuation of work. Therefore, the bezel becomes an increasingly important design factor for consumers.
Bezels are uncertainty that occur during the output of huge images like maps or any other illusions protracted on shared monitors [13]. Bezels are usually blocking the users view when the collaborative activity happens between two or more screens [14]. Hence, the users are confused with the inclusiveness of the gap and space between the mobile displays. Therefore, there are several studies discussed about how to handle the bezel challenges. In one of the research studies, the researchers used spatial multiple display setting to resolve the bezel issue. In brief, they used spatial relationship to create an illusion of a continuous space between the screen displays, and therefore, the invisible space between the displays is counted as part of the application space. [16]. However, the size of the invisible space affected the user experience on behavioral engagement. Users' action depended more on each other in a small playing distance, as there was less uncertainly in the application. Fig. 4 shows the configuration view to select the distance between devices.

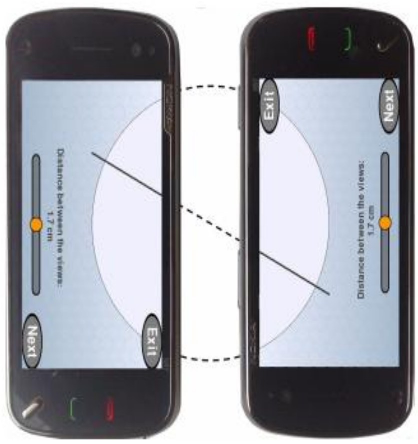

Fig. 4: Configuration view to select the distance between devices [15]

In another research study, the researchers proposed to use overlay method to conFig. the bezel issue. This proposed method impacted the whole perception of the bezels design which including the grid covering the upper layer of a single image that encircles the overall display screen [16]. The proposed overlay method was extended as ePan and GridScape by the researchers to further study about the issue [16]. The ePan technique allows the users to manage the whole virtual canvas with finger drag motions. The canvas is located right behind the display panels, and gets translated within the displays. The users use finger drag motions to view the image on the mobile display. Fig. 5 shows a close-up view on a road junction by implementing ePan.

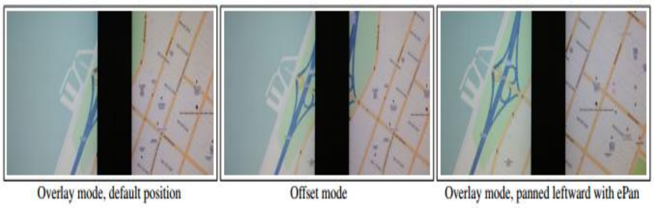

Fig. 5: Close-up views on a Junction. Left (Overlay Mode, Default Position): The Junction is Hiding Behind a Bezel. Middle (Offset Mode): The Junction can be Revealed by Switching to Offset Mode. Right (Panned Leftward): The Junction can be Revealed by Invoking Epan Through a Simple Drag Gesture [16].

Meanwhile, the GridScape technique allows users to translate the digital canvas 'behind' the screen display virtually. By creating a motion parallax effect with the depth, there are movements occurs like walking or leaning against the front wall which will eventually cause the bezels to reveal at the level surface. However, when there is any alteration from the user's judgment, those formerly hidden areas of the canvas will be exposed tremendously while the other areas will be shut off [17]. Fig. 6 shows GridScape technique.

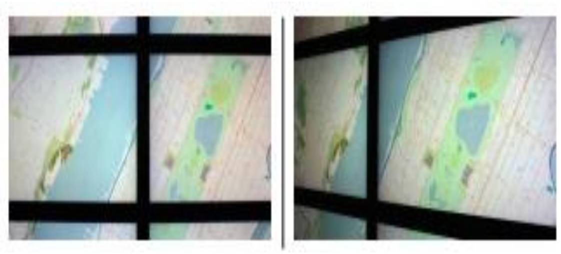

Fig. 6: Revealing the Same Junction in Fig. 5 by Performing Physical Navigation using Gripscape [17]

In overall, the researchers found that both ePan and GridScape technique improved the performance as compared to basic overlay and offset modes.

3. System Design

The main challenges which causing by the existence of bezels in a multi-mobile system was identified. Users can become distracted about the existence of the space and gaps between the mobile displays when a group of people are doing a collaborative work. Therefore, in this study, two versions of prototype were designed and developed for the user studies to study the bezels effects on a multi-mobile system and to propose a solution that can be used to address the bezel issues. The first prototype, which was a high-fidelity prototype and was aimed to study the effects of bezels on a multi-mobile system; while the second prototype which was an iterative prototype, has featuring the implemented proposed solution, continuous spatial configuration to address the bezels issue.
These prototypes were made based on the client-server architecture. Fig. 7 shows the overall concept of the prototypes. When the drawing application is opened on all mobile devices, they will connect to the Wi-Fi network automatically. When the devices are connected, the devices start to calibrate for server and client roles. The first touched device started as server and it takes that role and also to become the Client 1. The next touched device then looks for a running server, if the server (Client 1) is already activated; it connects to that server and becomes Client 2 and so on, and hence, the server knows the relative location of each of the clients in this 2 x 2 device grid and maps a global coordinate system for the integrated display. 2 x 2 grids have been used as a standard layout throughout the user studies in order to conserve the results and findings.

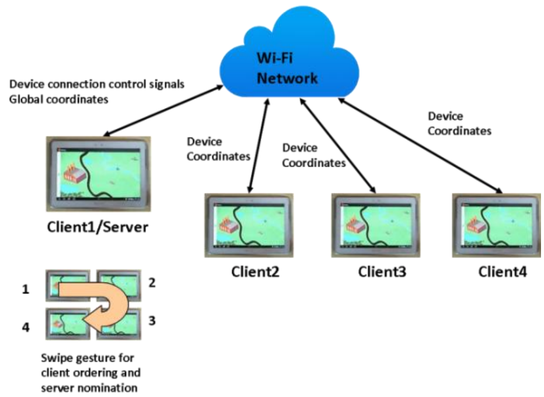

Fig. 7: The client-server Architecture

When all of the devices are connected, the prototype is ready for the user studies.

4. The User Studies

There were two user studies conducted; first user study was designed to observe the challenges surrounding bezels in a multi-mobile system (without solution); second user study was designed to evaluate the effects of applying the continuous spatial configuration solution on the bezel issues (with solution). The user studies required human participants to validate the prototype design. Therefore, an Interactive Drawing Application (IDA) was developed for this study, where groups of people performing drawing tasks collaboratively were observed in both studies. The two user studies were conducted with the exact same procedures and settings.

4.1 Participants and Design

Two groups of sixteen full-time undergraduate students who were enrolled in the university's computer science program were recruited for both user studies. The age of the participants for both user studies ranged between 20 to 25 years old. All of the participants were recruited to complete the evaluation task with the Interactive Drawing Application (IDA) on two versions of prototypes. They were divided into group of four based on their current existing relationship and friendship to encourage intense interactions and specific drawing tasks.

4.2 Task Materials

The Interactive Drawing Application (IDA) for a multi-mobile system was designed for the user studies. The application was installed on four mobile tablets. The target of this application was to conduct a simple drawing task and the application consisted of two main interfaces, Fig. 8 (i) connection page which enabling users to connect the four screens; Fig. 8 (ii) drawing canvas which featuring a white drawing space and a selection of 12 different colors.

(i)

(ii)

Fig. 8: Interface of the application.Connection page. (ii) Drawing canvas.

5. Procedure

Two user studies were conducted in the Multimedia Studio of the Faculty of Computer Science & Information Technology at our university. Both user studies used the same procedure and repeated with high-fidelity prototype (without solution) and iterative prototype (with solution). During the study, two experimenters were involved, one of them responsible to interact and communicate with the participants during the testing period, while the other one in charge all the study materials and cameras setting. The experiment were set up in the center of the laboratory, a rectangular table (120cm L x 50cm W x 90cm H) was used. A total of three video cameras were used to capture the evaluation sessions in the laboratory in three angels: (a) The activities happened in the laboratory space (recorded by two digital cameras in two angles); and (b) close-up angle to observe the tablets activities (recorded using a webcam which was mounted on the ceiling in order to have a clear view of the screen display).

Two groups of sixteen participants with identical demographic background were invited to complete the evaluation test tasks with IDA for five minutes in both prototypes design of a multi-mobile system. All of the participants were requested to sign a consent form before the evaluation session and the experimenter explained the study information and procedure.

Before the evaluation task, each participant was given a tablet which arranged in grid pattern and they were requested to complete the tasks in the shared screen of four tablets. The evaluation task is a drawing task which they need to draw a rectangular shape on the shared screen.

When the task was completed, an interview was then conducted to preserve the participants' experiences and memories. They were requested to share their user experiences towards the evaluation test task and the prototypes. After that, questionnaires were distributed; in which included the demographic background, satisfaction level, drawing experience and review of the prototypes interface design. All sessions were recorded for analysis purposes. The same procedure was employed in two user studies and two versions of prototypes in to order to preserve harmony data.

6. Results and Discussion

This section discusses the results and discussion of the user studies that conducted with the prototypes. The collected data was analyzed and fundamentally comprised the quantitative and qualitative data into useful results.

6.1 Task Completion Time

The method of calculating the total duration of time that participant taken on the evaluation test tasks was used to tabulate the task completion time. The task completion included task completion time, instant of requested termination from participants and termination as a result of time limit which was five minutes for the individual drawing task (Task 1) and fifteen minutes for group drawing task (Task 2).

Table 1: Comparison of Task Completion Time for Task 1

Participants	User Study 1 (without solution)	User Study 2 (with solution)
1	117	90
2	110	93
3	88	88
4	81	98
5	77	70
6	79	78
7	105	80
8	74	98
9	76	60
10	78	80
11	60	77
12	86	83
13	105	82
14	79	80
15	90	55
16	93	60
Total	**1398**	**1272**

Table 2: Comparison of Task Completion Time for Task 2

Participants	User Study 1 (without solution)	User Study 2 (with solution)
1	1026	886
2	921	903
3	841	828
4	840	734
Total	**3626**	**3351**

From the Table 1 and Table 2, there is a 9% (7.9 seconds) and 7.6% (69.2 seconds) of improvement in the average time taken for the participants to complete the Task 1 and Task 2 by using two versions of prototypes. By using the iterative prototype design with the continuous spatial configuration solution, the participants were able to reduce the time taken to complete a task and allowed the task to become easier to complete as the line drawn can be connected to each other.

Task completion time is reduced because the hint line is provided at the end of both screens; therefore, the participants did not have to hesitate or estimate where to connect and therefore made less error. Furthermore, the solution helps to reduce the participants' mental load as they no need to keep guessing on next destination. Reducing in error making also contributed to reduce in task completion time as the participants required less time for deleting errors.

6.2 Total Number of Moves

The method of calculating the total number of moves was tabulated from the evaluation tasks' video recordings. Total number of moves included both functional and non-functional moves whereas functional moves included select the menu buttons, colors, draw and erase and non-functional-moves included wrong move and insensitive touch.

Table 3: Comparison of Number of Moves for Task 1

Participants	User Study 1 (without solution)	User Study 2 (with solution)
1	25	20
2	24	20
3	22	22
4	20	19
5	24	17
6	20	20
7	25	20
8	12	20
9	13	13
10	12	12
11	19	15
12	23	13
13	29	15
14	11	13
15	15	13

16	27	16
Total	**321**	**266**

Table 4: Comparison of Number of Moves for Task 2

Participants	User Study 1 (without solution)	User Study 2 (with solution)
1	1026	886
2	921	903
3	841	828
4	840	734
Total	**3626**	**3351**

Based on the Table 3 and Table 4, there were averagely 22.4% (4.8 moves) reduced for Task 1 and 33.9% (117.3 moves) reduced for Task 2 which performing by the participants.

Participants required lesser move to perform the inter-screen task with the help of spatial configuration for bezel issue. This happened because less mistakes and less trial-and-error were done by the participants. Moreover, less mistakes and less trial-and-error by participants also result in reduction of non-functional moves.

6.3 Observation

Observation was used as one of the techniques to gather data and information from users during user studies. The procedure throughout the process was recorded by video cameras and can be analyzed by stating the users' views and users' interactions. Fig. 9 displays the drawing outcomes by using high-fidelity prototype in Task 1

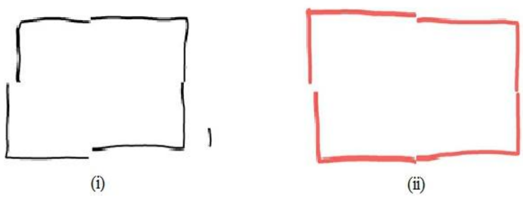

Fig. 9: Two Drawing Outcomes using High-Fidelity Prototype During Task 1 Made Up of Four Different Mobiles Combined (I) User 1 And (Ii) User 2

From the observation, there were gaps and disjointed lines found in the drawing outcome for individual drawing task (Task 1) due to the obstruction of bezels. Bezels between the tablets were distracting the participants from performing the task and the participants were hard to estimate the line which has to be drawing in the next screen to form a rectangular shape. Furthermore, the lines were not connected to each other. Drawings from Fig. 9 are a result of two users who were involved in the test and the drawings clearly show that there are gaps and distances between the lines. Euclidean distance was employed to each of the drawings to calculate the gaps distance between the lines [18]. The gaps between the lines were labeled as D_1, D_2, D_3 and D_4 respectively where D was represented distance between the gaps. Fig. 10 showed the distance between gaps on a grid when Euclidean distance was applied.

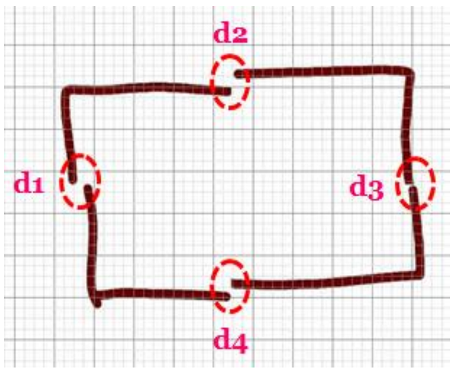

Fig. 10: Applying the Euclidean Distance to the Drawing

Ten drawings were selected randomly and the total distance four gaps distance, D_{total} is recorded as 20.38 (M = 2.04, SD = 0.62). Similarly, there were sixteen participants recruited to perform the same task with the iterative prototype design with continuous spatial configuration. Random pick of two drawings is shown in Fig. 11.

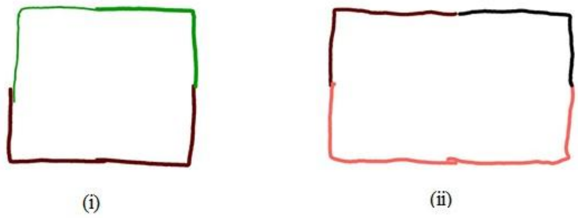

Fig. 11: Drawing Outcomes using Iterative Prototype

From the observation in second study, there were only significant gaps and disjointed line found in the drawing outcome after applied the solution. Furthermore, it is found that most of the lines between the tablets' bezels were connected and hence the participants could produce a rectangular shape with no gaps between the lines as the lines were linked to each other on the adjacent screens. Similarly, Euclidean distance was applied to all ten drawings from the study and the calculated total distance between four gaps, D_{total} is recorded to have an average value of 1.06 (M = 0.11, SD = 0.23), compared to 20.38 previously, before the Continuous Spatial Configuration was applied.

Table 5: Comparison of Euclidean Distance for Task 1

Drawings	User Study 1 (without solution)	User Study 2 (with solution)
1	2.314	0
2	2.611	0.02
3	1.831	0
4	1.567	0
5	1.286	0
6	1.989	0.383
7	2.953	0
8	2.077	0
9	1.054	0.656
10	2.696	0
Total	**20.38**	**1.06**

Table 5 shows that there was a 94.8% (19.32 gap distance) reduced for the gap distance between the drawing with the application of spatial continuous configuration between two prototypes. With this improvement, users are able to perform the drawing tasks more efficiently and encouraging intensive interaction and collaboration. Additionally, in order to improve the users' visual feedback on the screens and the discontinuity on multi-tablet screens, the space between the screens and bezels has been eliminated from the drawing outcomes.

In addition, there was another group drawing evaluation to study the effects of the Continuous spatial Configuration implementation on the prototype. The drawing outcomes from the user study using high-fidelity prototype was saved and presented in the Fig. 12.

Fig. 12: Drawing Outcomes from User Study using High-Fidelity Prototype

From Fig. 12, there were gaps and disjointed objects found in most of the drawing outcomes, for instance, a disjointed house and tree in Fig. 12. There are several reasons that contributed to this phenomenon such as visual feedback from the participants and discontinuity in the multi-tablet screens. Participants assumed that the space between the bezels was included in the drawing, therefore they tended to draw the objects between the screens, and unfortunately the bezels were actually hindering their visual. Hence, the gaps and disjointed objects were discovered.

Another reason that contributed to this result is the discontinuity in multi-tablet screens. The tablets were initially designed for personal uses and a group task was included in the user studies, therefore the findings shows that there were gaps and disjointed objects in the drawings. This phenomenon could happen because of the space between screens and bezels caused visually separation to the users. Users were observed that they found it difficult to estimate the space between the screens and bezels during the group task evaluation.

On the other hand, a second user study was conducted after the Continuous Spatial Configuration solution has been implemented into the iterative prototype. Fig. 13 shows one of the drawing outcomes.

Fig. 13: Drawing Outcomes from User Study using Iterative Prototype with Solution

In comparison to the drawing outcomes from user study with high-fidelity prototype, there were visibly showed that almost no gaps and disjointed objects were found in the drawing outcomes during this user study with the implementation of the spatial continuous configuration because the spaces and gaps between the screens has been eliminated from the final drawing outcomes. Moreover, in order to improve the user visual feedback on the screens and the discontinuity on multi-tablet screens, the space between the screens and bezels has been eliminated from the drawing outcomes.

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