A Study of User Experiences with Various 3D Interfaces for a Mobile Application

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***Abstract*--With the availability of OpenGL ES and low-power specialized graphics hardware, 3D graphics are increasingly incorporated into software for mobile devices. However, there is only a small body of research regarding effective user interfaces in this environment. The goal of this study is to analyze the effectiveness of several 3D mobile interfaces by conducting an experimental survey. Study participants were asked to solve a 3D graphical number placement logic-based puzzle using four different interfaces. Quantitative survey results are reported as well as conclusions to aid in the development and implementation of effective user interfaces for 3D software for mobile devices**

***Keywords*--3D graphics, user interface, mobile device, mobile development, OpenGL ES**

I. Introduction

Industry groups report that the worldwide smart phone applications market grew more than $2.2 billion dollars within the first six months of 2010 and application download numbers reached a total of 3.8 billion in only six months, compared to 3.1 billion in 2009[1]. However, prior work suggests that the mobile market is becoming saturated with repetitive and low quality applications[2]. The present study attempts to improve this situation by exploring options for effective 3D mobile interfaces. This is approached by creating a 3D puzzle and implementing different user interfaces to manipulate the 3D object

II. Prior Work

A number of related projects are reviewed and discussed below.

A. *Lab vs. Field Testing*

Kaikkonen et al. explored whether mobile device research can be conducted in a lab without adverse consequences compared to field tests[3]. It was concluded that mobile device research may be conducted in the lab, without construction of a complex field test.

B. *Different User Interfaces*

Bucolo et al. implemented three different controls to navigate a ball through a maze using the integrated camera that came with the mobile phone. The first control scheme used the traditional joystick to move the ball through the maze, while the second required users to “pan” the phone itself, and finally the third control scheme used a “tilt” action of the phone to move the ball. Results from the study showed that the traditional joystick control provided the fastest times but the least amount of user interaction with the mobile device, while the tilt controls were the most challenging but provided the greatest amount of user involvement [4].

C. *Interaction in the 3D World*

Chehimi et al. tested using the built-in accelerometer on the mobile device as a different control scheme to use while playing a 3D multiplayer game[5]. The accelerometer would be used to pilot a space ship through space. The accelerometer was used to turn left or right as well as up or down.

Winkler et al. used the built-in camera from the mobile device to play a 3D racing game and for map navigation[6]. The camera was found to be effective for this purpose.

D. *Finger Gestures*

Tests by Stößel et al. showed that people between the ages of 20-35 preferred more fingers to be used for a single gesture while people between the ages of 60-75 would prefer more finger presses to achieve the same goal[7]. For example, to zoom in on a map on a mobile device, the younger age group preferred the “pinch to zoom” finger gesture while the older age group preferred to double tap on the screen. For 3D interface research, it may be most effective to keep finger gestures to a minimum while interacting with 3D objects in the hopes that subjects of all ages will be able to focus on the 3D user interface rather than gestures.

III. Implementation

The 3D puzzle was developed on a mobile device that supported the Android OS. Android OS is open source, is well documented, and has a large support community[8]. Android OS currently supports OpenGL ES 2.0+ libraries, which were used to create the 3D and 2D look-and-feel of the puzzle. A 1x1x1 block used 12 triangles to create its overall cube shape, followed by 64 1x1x1 blocks to make the 4x4x4 puzzle. A textured image was imposed onto each side of the 1x1x1 block to show the user what value was associated to it. A separate thread was used to pick up finger presses from the user. This thread returned the screen coordinates and finger actions to the software to be handled appropriately. For the 3D games, the individual blocks were moved using simple linear and non-linear functions. For the 2D effect, all the 1x1x1 blocks were placed on the same plane with the camera placed on a vector normal to the plane.

When the user presses onto the screen, a vector is drawn from the camera. If this vector collides with a 1x1x1 block, a notification would appear requesting an action from the user. Upon each successful collision, the software checks to verify if the puzzle has been solved.

IV. Methodology

The present study required data from human subjects. Authorization for this study was received from the University of Scranton Institutional Review Board under protocol # 20-10A. The research tested different user interfaces on a mobile device used by students from The University of Scranton.

A. *Population Surveyed*

The students were drawn from required general education courses. Before participating in the research, the students were asked to answer a few background questions. These questions asked them their gender, age, and to rate themselves from 1-5 their experience with computers, mathematics, mobile devices, mobile games, and figure gestures on a touch screen. Figure 1 shows the results that were collected by this survey. The students varied in age (18-22) as well as major. From this population, 6 women and 12 men were surveyed. The students that participated in this study received extra credit in their general education course.

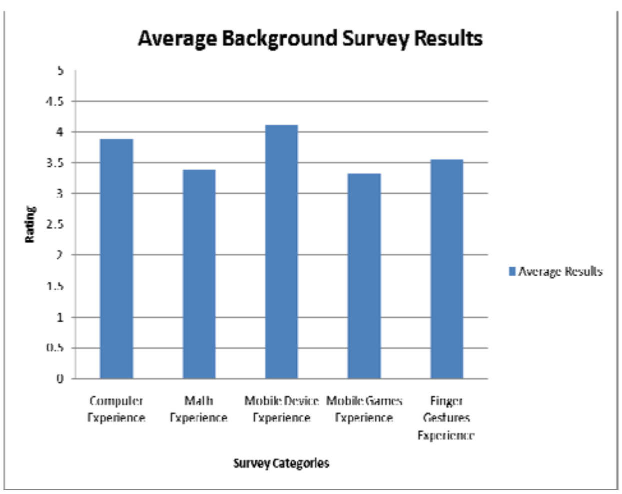

Fig. 1 This figure shows the averaged results of the background survey given to the participants before the experiment

B. *Mobile Device*

The mobile device used during the study was the HTC Incredible (Figure 2.) This mobile device contained a 1GHz Snapdragon processor, 8GB of internal memory, an 800 x 480 screen resolution, and ran Android 2.2.

Fig. 2 The front and back of the HTC Incredible smart phone

C. *3D Logic-Based Number Placement Puzzle*

The puzzle being created is a 4x4x4 Latin cube[9] that follows three rules. The rules are as follows: each row must contain the numbers 1-4 exactly once, each column must contain the numbers 1-4 exactly once, and along the remaining axis the numbers 1-4 must occur exactly once.

Each time a game starts, the program randomly creates a solved puzzle, based on the rules noted above. Then, the program traversed each of the individual numbered blocks and unassigned it with 10% probability. The testers were asked to correctly assign values to these unassigned blocks in order to solve the puzzle.

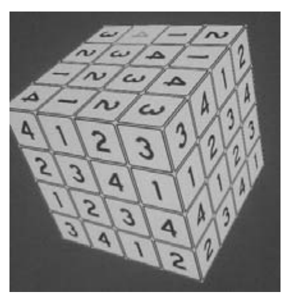

Fig. 3 A complete Latin cube using the numbers 1-4

D. *User Interfaces*

Focusing on how the testers would be able to interact with the inside of the puzzle, we created four different user interfaces.

1) *2D User Interface:* This user interface showed each layer at once on the mobile device. This interface gave a traditional look and feel for the testers to try out. If the puzzle were increased to a size larger than 4x4x4, this user interface would become difficult to interact with due to the small screen size of the mobile device. An example of this is as follows: if the puzzle were a

6x6x6, there would be six 6x6 Latin squares that need to be solved following the rules of a 6x6x6 Latin cube.

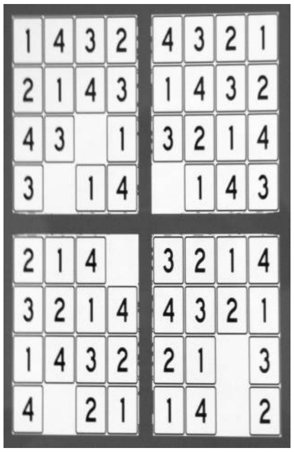

Fig. 4 The 2D user interface; which is able to show each individual layer on the screen at one time.

2) *Exploding Cube:* Upon a double tap, the larger cube containing all the numbers would split into smaller blocks containing their individual number. Upon another double tap, the smaller blocks would return and form the original cube.

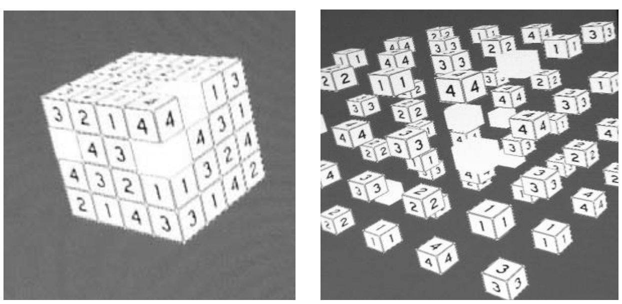

Fig. 5 The Exploding Cube user interface; which causes all the smaller blocks to “explode” outwards upon a double tap allowing the user to see the inner blocks

3) *FlipBook:* This user interface peeled off one layer at a time to expose the next inner layer. Once this front layer was removed, it was returned to the opposite side of the cube. Due to the Latin cube qualities, this does not violate any of the rules placed on the game since each individual row, column, and depth should still contain only one occurrence of the numbers 1-4.

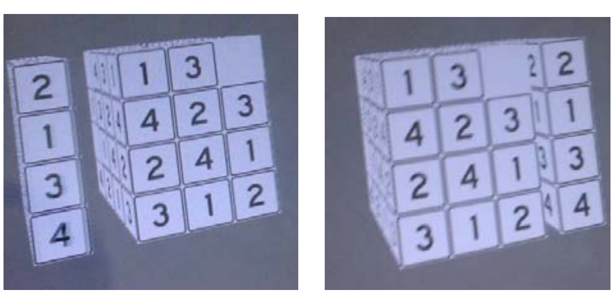

Fig. 6 The FlipBook user interface; will remove a layer from the front of the cube and replace it on the back of the cube ever time the user does a double tap finger gesture.

4) *Transparent Cube:* Upon a double tap, this user interface made the outer layer of the cube become transparent, which exposed the inner 2x2x2 cube. At this view, the tester could only interact with the inside cube. The outside cube is shown in wireframe to help display to the tester that they were looking inside the cube. If this puzzle were increased to a larger size, the user interface would have to make more layers become transparent. For example, in the 4x4x4 puzzle, the participants only needed to remove one layer. In a 5x5x5 puzzle, after removing one layer, there will still be a 3x3x3 puzzle remaining. Therefore, another layer would have to be removed to show the inner 1x1x1 block.

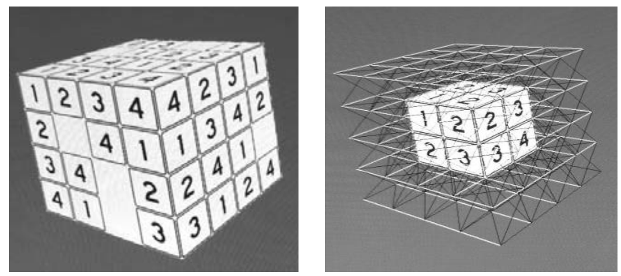

Fig. 7 The Transparent cube user interface; will make the outside layer of the cube become clear to allow the user to interact with the inner cube. The wireframe models remain on the screen to help illustrate to the participants that they are looking inside the cube

E. *Conducting the Experiment*

Each subject was given a brief introduction which explained what the study was about and what was expected of them. The subject was presented with the survey which obtained non-identifying information about his/her experience with smart phones and his/her mathematical background. Each subject was then given all of the user interfaces in a random order to solve a randomly generated puzzle. Each puzzle solution attempt was timed and documented.

F. *Obtaining Data*

After the participants solved all puzzles using the various user interfaces, they were given a questionnaire which asked them to answer various questions on each user interface. The results of the questionnaire were analyzed to draw conclusions.

Game 1:

Do you think this is an effective way to play the game?

Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
1	2	3	4	5

Do the user input gestures (tap, drag, etc.) make sense?

Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
1	2	3	4	5

Is it easy to visualize the 3-D object?

Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
1	2	3	4	5

Rate this game overall:

1	2	3	4	5

Any additional comments?

What did you like about the user interface?

What do you think needs improvement?

Fig. 8 After the participant completed the puzzle with each user interface, they were presented with this questionnaire-one for each user interface listed above.

V. Results

A. *Preferred User Interface*

From the results of the quantitative survey for each user interface the participants tested (Figure 9), the 2D user interface was preferred overall.

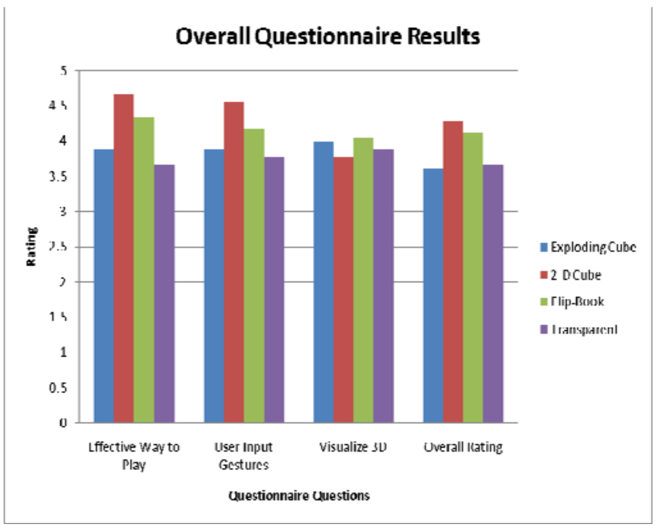

Fig. 9 The final results from all the participants in the study; shown here, the 2D interface is most preferred.

B. *Discussion*

Due to the small puzzle size, the 2D user interface provided a clear look at all the layers at any given time. It is suspected that performance using the 2D user interface would deteriorate for larger puzzle sizes, say 6x6x6. This would be due to congestion; for example, in the 6x6x6 case, the user would be interacting with 216 very small blocks. It may have been more meaningful to test these larger puzzle sizes, however, survey time constraints dictated a smaller size.

For time to puzzle completion, the mean (M) and standard deviation (SD) were calculated. The 2D and FlipBook (FB) user interfaces showed the characteristics [M_{2D} = 34.6s, SD_{2D} = 18.4s, M_{FB} = 52.2s, SD_{FB} = 14.8s] respectively. For the Exploding Cube (EC) and Transparent (T) interfaces, their times were more variable [M_{EC} = 80.7s, SD_{EC} = 62.3s, M_T = 78.6s, SD_T = 57.7s]. A small number of participants made time-consuming errors while using the Exploding Cube and Transparent interfaces.

C. *User Reactions*

While using the Exploding Cube user interface, participants made remarks on how the spacing between the cubes should be changed and slowed down. Although it was visually pleasing, some participants found it to be confusing and difficult to interact with. The FlipBook user interface implemented a realistic animation to peel off the layer and move it to the other side. This animation, which incorporates inertia, may have helped to give the user interface a more realistic feel than the others.

D. *Different Populations*

Further analysis from the results have shown that, in the personal background survey, subjects who reported higher numbers[1] on mobile device experience (MDE), mobile game experience (MGE) and finger gestures experience (FGE) favored the FlipBook user interface over all the others (Figure 10). The subjects with lower experience in those categories preferred the 2D user interface (Figure 11).

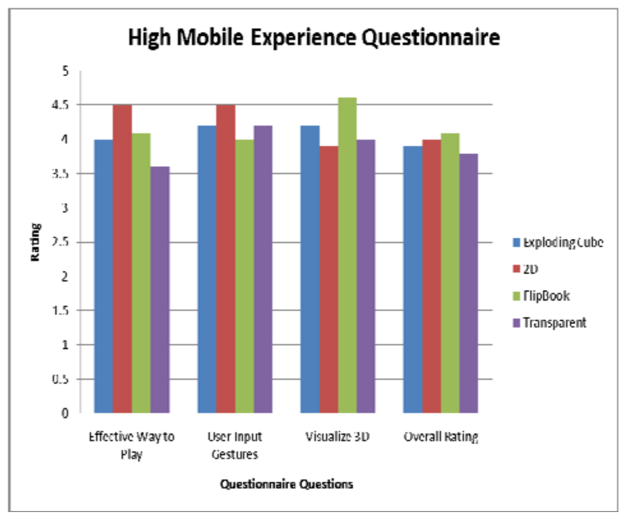

Fig. 10 Based on the background questions, the population with higher mobile experience preferred the FlipBook user interface and was able to visualize the 3D cube much better than using alternative interfaces

[1] Overall Mobile Experience is mobile device experience + mobile games experience + finger gesture experience. If Overall Mobile Experience is greater than 11 out of 15, the participants were considered to belong in the high mobile experience population.

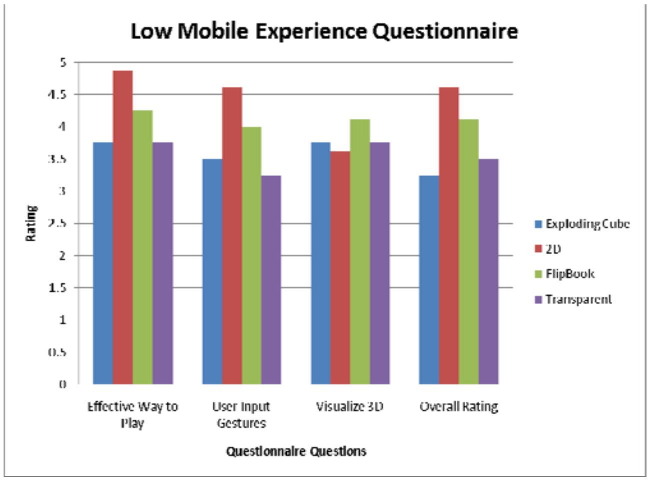

Fig. 11 Participants with lower mobile experience preferred a 2D interface even though it was slightly harder to visualize the 3D object

The average times to puzzle completion for males using the Exploding Cube and Transparent interfaces [$M_{EC,Males}$ = 61s, $SD_{EC,Males}$ = 21.4s, $M_{T,Males}$ = 63.7s, $SD_{T,Males}$ = 48.3s] were less than females [$M_{EC,Females}$ = 120s, $SD_{EC,Females}$ = 97s, $M_{T,Females}$ = 108.3s, $SD_{T,Females}$ = 67.7s], however, the average times for females using the 2D and FlipBook interfaces [$M_{2D,Females}$ = 29.2s, $SD_{2D,Females}$ = 2.6s, $M_{FB,Females}$ = 48.5s, $SD_{FB,Females}$ = 16.5s] were slightly less than the males [$M_{2D,Males}$ = 37.3s, $SD_{2D,Males}$ = 22.3s, $M_{FB,Males}$ = 54.1s, $SD_{FB,Males}$ = 14.2s]. This may be due to differences in background between participants of each gender. Differences in technical background (computing, mathematical, etc.) were not controlled for in this study. Males reported a stronger computer and mathematical background as well as more experience using a mobile device, playing mobile games, and using finger gestures (Figure 13).

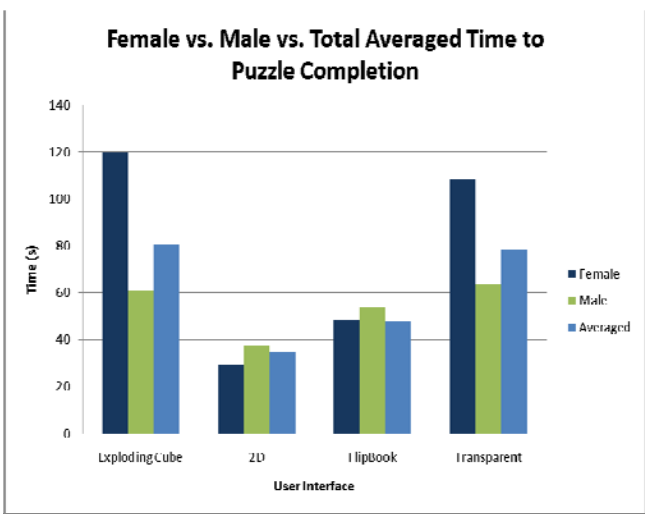

Fig. 12 Splitting the participants into females and males show a large difference in overall time between the two populations, especially involving the 3D user interfaces. Total Average time was generated by totaling all the times and dividing it by the number of participants

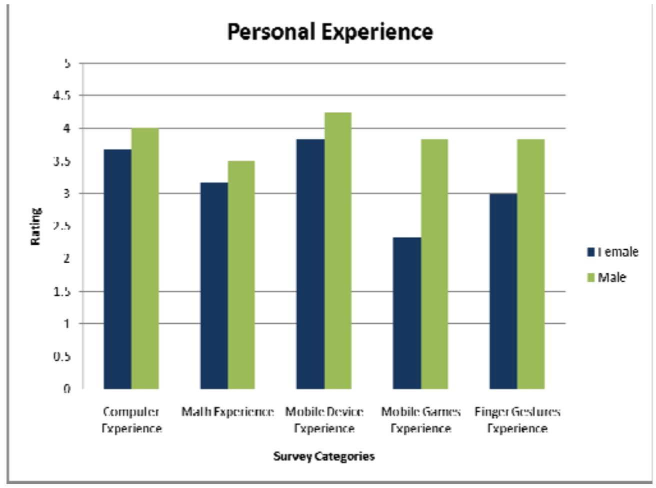

Fig. 13 This figure shows the results from the background survey between the females and males that participated in the study.

VI. Conclusions

From the research conducted, the 2D user interface produced the best results from the participants in the study. The screen size allowed a clear view of all four layers to solve the 4x4x4 puzzle. However, if this puzzle were to grow, say a 6x6x6 puzzle, it would not be practical to show all the layers on the screen at one time. Due to the small screen size, the layers would be far too small to interact with or observe.

The FlipBook user interface scored the best among the 3D user interfaces and was preferred by the participants who reported a higher overall mobile experience. The natural animation of the FlipBook, may have caused it to be preferred over the Exploding Cube and Transparent Cube user interfaces. This could be attributed to the FlipBook animation being realistic - incorporating inertia. Another factor may have been that the animation was not as abrupt as the other two 3D interfaces. For example, the Transparent Cube immediately made the outside layer into a wireframe layer as opposed to a gradual transparency over time.

It is important to note the time difference between the male and females. The males had relatively constant times on all the user interfaces where as the females took very different times on each one. Specifically on the 3D user interfaces, with the Exploding Cube interface, on average, the females took 120 seconds to solve the puzzle where, the males took 61 seconds. A similar effect was observed with the Transparent Cube; the females took 108.3 seconds and the males took 63.6 seconds to complete the puzzle. In the FlipBook user interface, the females' average time was 48.5 seconds and the males' average time was 54 seconds. A possible explanation for this effect may be that the FlipBook resulted in smaller spatial changes to the 3D object. Alternatively, the FlipBook animation was also less abrupt than the other 3D interfaces.

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