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A Study on the Natural Manipulation of Multi-touch Gestures for 3D Object Rotation Using a Large Touch Screen

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Abstract. Providing the natural mapping between multi-touch gestures and digital content manipulations is an important factor of friendly user interfaces. Although, in the literature, there are some guidelines available for 2D digital content, the guideline for the manipulation of 3D contents is yet to be developed. In this research, two sets of gestures were developed for experiments. For comparative studies of age differences, 30 participants, including adults and children, were invited to carry out three tasks relevant to rotating the digital model of a green turtle to explore its features. The results showed that simpler gestures could facilitate the mapping between 2D control movements and 3D content displays, especially for children without intrinsic mental models of virtual contents manipulation. Although participants tended to visually observe the feedback angle of the contour and use the head of green turtle as a manipulation reference, it may not be easy to identify and manipulate the 3D object without a clear convex shape or image. In addition, offering a robust mechanism for gesture inputs is necessary for universal control of such a system. While manipulation, providing a synchronized mapping instruction for three axes rotation on screens is a useful 3D objects rotation solution for touch-screen design.

Keywords. Gesture, Large multi-touch screen, Rotation of 3D digital contents

1. Introduction

With the advent of multi-touch technologies, many museums around the world have applied such technologies to facilitate interactive exhibitions. Since visitors may not have chances to learn the system in advance, providing the natural mapping between multi-touch gestures and digital content manipulations is an important factor of friendly user interfaces. Although, in the literature, there are some guidelines available for 2D digital content, the guideline for the manipulation of 3D contents is yet to be developed. Therefore, the objective of this research is to study the appropriate settings of rotating virtual 3D contents using multi-touch gestures.

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2. Literature Review

2.1. Gesture interface and research issues

"Gesture" is a kind of natural behavior in the course of interpersonal interaction and also a kind of nonverbal body information. It is an honest and natural means of expression, and hard to fake [1]. People can communicate with each other with the aid of these body motions, further understand each other, and then express their real inner intentions. Facing the computer touch screen, the most natural and convenient mutual communication between human and machine relies on the operation interface of touch gesture. The touch screen possesses many advantages [2][3] and there are many successfully application in the literature, such as the minority health information system [4], auxiliary equipment control interface [5], intelligent household power management system [6] and electronic voting system [7]. In recent years, more and more researchers have successfully improved the communication mode between the Alzheimer's disease patients and the nursing staff [8] and facilitated the interaction between human and 3D visualization [9] by utilizing the characteristics of touch screen, in combination with the multimedia digital content.

Recently, there is a trend to use multi-touch interfaces with large screens for exhibition in museums [10]. The installations are either in the form of kiosk [11] or tabletop [12][13][14]. The researchers also started to adopt the touch method to manipulate the 3D objects on the screen of a mobile device [15] or use the mobile phone as the controller to manipulate the 3D objects on the screen [16]. Moreover, if the control and feedback systems are properly constructed, the users can easily manipulate the camera lens location of the 3D object [17] or make movements in the large-sized 3D virtual setting [18] by using the 2D gestures. Although there are numerous researches discussing the issues relevant to touch area and touch modes on the screen, appropriate mapping between the gesture types and digital content manipulations still require in-depth research and experiments to find the best combination.

2.2. Types of touch gestures

The interface gestures should be as close as possible to the stereotypes held by humans to achieve intuitive interaction [19]. Using a single finger to tap and select objects to fulfill the manipulation on the touch screen is the basic gesture. The normal methods to drag and move the items on the touch screen include tap-to-select, slide-to-scroll, spin-to-scroll and flick-to-nudge operations [20]. Through the gestures moving on the planar screen to drag, move and spin the object rotation axes, the objects will move along with the gestures and keep moving until the gestures stop. In other words, the object will stop running after the finger leaves the screen. Spin or arc scroll consists of multiple short-distance and continuous actions, which usually slide on the screen in clockwise, counterclockwise or irregular directions.

The flick-to-nudge gesture is a very natural kind of gesture [20]. The gesture movements on a large-sized touch screen, the drag-and-drop gesture is more like operating the movement of copy-paste than the gesture of pick-and-drop [21]; In addition, in the case of the multi-screen controlled by a single system or multiple systems, if the matching between the gestures and feedback is not natural, it would result in irregular lagging phenomena due to lack of intuition and reduce the usability of the interaction. In the application in the large touch screen like screen wall, it may cause difficulties in operation when determining the target locations to move or put the manipulated objects [21].

2.3. Summary of literature review

In the past, the gestures of touch are mostly for interacting with 2D digital contents, such as images or visualized information. As more and more digital contents are created in 3D, it is necessary to develop gestures for 3D manipulation [22][23]. Rotation for 2D contents is limited to turning with respect to a single axis. However, rotations of 3D contents involve multiple axes, which require natural mapping between gesture movements on a touch screen and real-time state changes in the virtual environment (Figure 1). In addition, whether single touch or multi touch is applicable for 3D manipulation remains an open question that deserves further studies. The literature has pointed out differences in gestural patterns between adults and children who manipulated 2D content on a tabletop [13][24]. For example, although children interacted more rapidly and more frequently with the table, it was still difficult for them to comprehend and employ the right gestures [24]. In the following sections, the experiment design and results are presented in detail to address this issue.

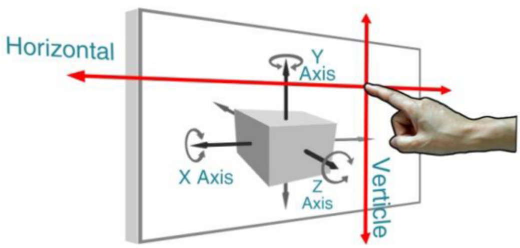

Figure 1: The mapping between 2D gesture movements and 3D content rotations

3. Experiment Design

3.1. Experiment setup and tasks

In the experiment, a 3D model of a green turtle was constructed and displayed on a 23 inch large multi-touch LCD screen, which was tilted vertically on the table and was similar to the public setting of some natural science museums. In order to study the behaviors, two systems of mapping between controls and displays were developed for experiments (Figure 2).

In the first system (1-point dominant), dragging horizontally or vertically with single touch point corresponded to the rotations of two axes, respectively. This action was similar to the gesture used in the sphere image gallery on many websites (Figure 3). Usually, a sphere coordinate system was used in the sphere image gallery. However, in this research, the Cartesian coordination system was employed due to the asymmetric contour of a green turtle. In addition, the rotation of the third axis could be controlled by using two touch points with a distance. The distance directly affected the rotation rate.

In the second system (2-point dominant), holding one point on the screen and moving the other point horizontally or vertically corresponded to the rotations of two axes, respectively. This gesture was similar to the conventional gestures for 2D object rotation (Figure 4). In addition, the rotation of the third axis would start and maintain a constant rate if a user touched the screen using one contact point.

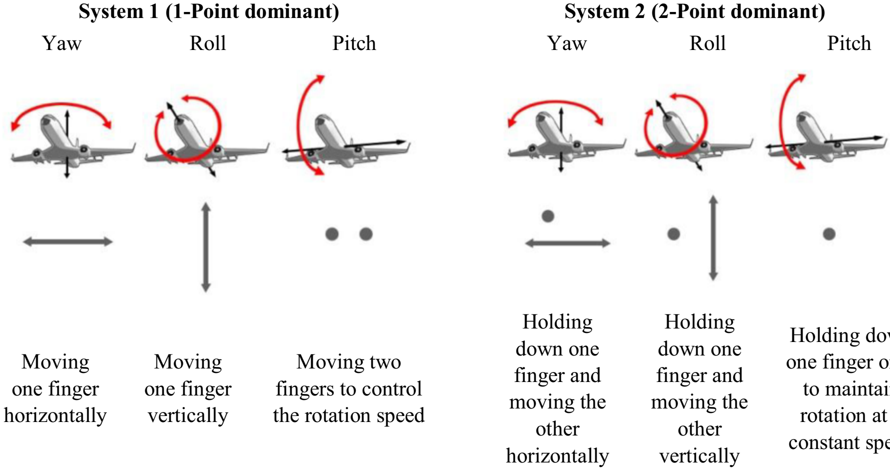

Figure 2: Two systems of mapping between gestures and object rotations

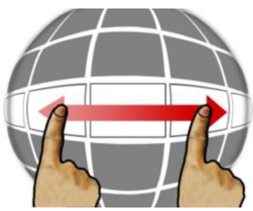

Figure 3: The gesture in sphere image gallery

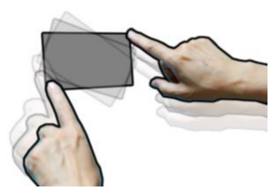

Figure 4: The gesture for 2D image rotation

There were three tasks for rotating the model of a green turtle (Figure 5). All three tasks started at the original posture with its head facing left. The first task was to observe the lower part of the head from its front, which was the easiest task. The second task was to observe the right eye and the top shell. The third task was to observe the bottom shell and the tail from its right and rear side, which as the most difficult task.

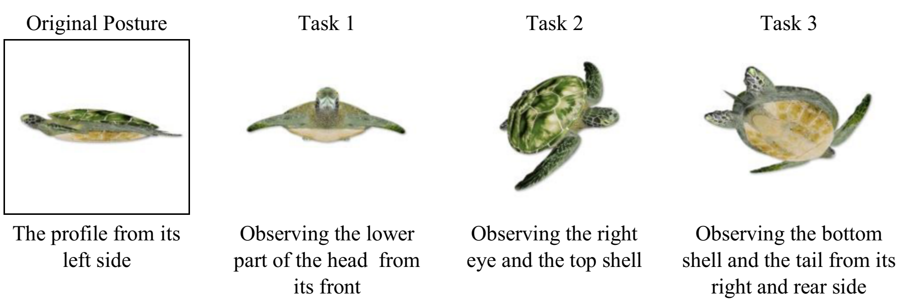

Figure 5: The three tasks of rotating the model of a green turtle

3.2. Participants

In addition, 30 participants were invited to carry out three tasks relevant to rotating the digital model of a green turtle to explore its features. In order to study the age difference in performing the tasks, these participants included 15 adults and 15 children. They were separated into two groups. Their missions were to use different operation modes to complete three tasks of adjusting the 3D object into designated visual angles. The adult group consisted of 7 males and 8 females at an average age of 26.9 years old (Sd=7.8). In the adults group, 11 experimental participants had learned the 3D software (e.g., Maya, 3D Max, Pro-E, Rhino and Sketchup), 15 participants had experiences in touch-screen operations, and 11 participants had experiences in smart phone operations. The children group consisted of 8 males and 7 females at an average age of 10.5 years old (Sd=1.6). None of them had learned the 3D software, but 6 participants played 3D games. In addition, 11 participants had experiences in touch-screen operations and 10 participants had experiences in smart phone. In order to counter balance the learning effects, each age group was further divided into two groups. The first group was asked to fulfill the first set of mode first and then the second mode, while the second group was asked to fulfill the second mode first, and then the first mode. After the experiment, the participants were asked to follow the instructions to practice the pitch, yaw and roll movements for about 20 minutes. During the experiment, the operation time was counted from the tap-to-select movement of the participant for each task. Three groups of recording equipments were used in the experiment to observe the behaviors of the participants. The Camtasia software was used to record the complete task actions of the 3D objects. The Webcam camera fixed on top of the screen recorded the gesture movements of fulfilling the tasks. Furthermore, a digital camera was used to record the limb movements of the participants. The participants were then asked to fill out a questionnaire on evaluation of the system usability and overall work load based on a 7-point Likert scale. Post-experiment interviews were used to collect their opinions and thoughts upon different systems.

Table 1: Participant data

Group	Number	Male	Female	Age yr.	Experiences		
					Had Learned 3D Software	Touch-Screen	Smart Phone
Adults	15	7	8	26.9 (7.8)	11	15	11
Children	15	8	7	10.5 (1.6)	0 (6 played 3D Game)	11	10

( )=(SD)

4. Results

4.1. Task completion time

For the completion time of task 1, there was a significant difference between adult and child groups ($F(1,59)=8.277$, $P<0.05$). Adults spent less time to rotate the model. In addition, there was an interaction between two factors ($F(1,59)=7.412$, $P<0.05$). For the first set of mapping, adults and children yield the close results. However, for the second set of mapping, children spend much longer than adults. Since task 1 is the easiest one among three tasks, this result indicates the second system is not natural enough for children without prior knowledge. Furthermore, there were no significant differences for task 2 ($F(1,59)=0.139$, $P>0.05$) and task 3 ($F(1,59)=0.823$, $P>0.05$). When the task becomes complicated, neither prior knowledge nor system differences contribute to the performance of rotations.

Table 2: Task completion time by System and Group

Task	System 1 (1-Point dominant)		System 2 (2-Point dominant)		Average	
	Adult	Child	Adult	Child	Adult	Child
1	37.20(21.50)	38.07(26.13)	19.73(12.67)	51.13(24.11)	28.47(19.48)	44.60(25.58)
2	123.33(70.10)	105.87(46.30)	140.47(74.31)	142.47(114.78)	131.90(71.51)	124.17(87.98)
3	98.00(69.30)	116.73(78.61)	113.53(92.58)	131.87(74.15)	105.77(80.74)	124.30(75.48)

Unit=Seconds, ()=(SD)

4.2. Subjective evaluation

There were significant differences in the comprehension of mapping ($F(1,59)=10.736$, $P<0.05$) and reasonability ($F(1,59)=7.01$, $P<0.05$) between two combinations of gestures. The first combination is easier and more intuitive than the second one. In addition, there were significant differences in the perceived mental loading ($F(1,59)=4.713$, $P<0.05$) and frustration ($F(1,29)=4.546$, $P<0.05$) between two systems. The second system yielded more mental loading ($F(1,59)=10.742$, $P<0.05$) and frustration ($F(1,59)=4.129$, $P<0.05$), especially in the adult group. Based on the comments from participants, the reasons could be summarized as follows. Since the rotation was not limited to one axis, gestures that required multiple touch points would hamper the real-time visibility of rotation effects on a large screen. In addition, rotating 3D contents by 1-point dominant gestures was more natural than 2-points dominant gestures. The results showed that using conventional gestures for 2D object rotation, which uses relative movements of two touch points, was not appropriate for the 3D environment.

Table 3: Subjective evaluation by System and Group

Criteria	System 1 (1-Point dominant)		System 2 (2-Point dominant)	
	Adult	Child	Adult	Child
Comprehension	5.40(0.91)	5.53(1.46)	4.73(1.28)	3.80(1.86)
Reasonability	5.27(1.44)	5.93(1.03)	4.47(1.13)	4.80(1.90)
Mental Loading	4.13(1.06)	3.60(1.76)	5.07(1.03)	4.40(1.72)
Frustration	3.40(1.24)	2.47(1.92)	4.53(1.64)	3.13(1.96)

Unit=7-point Likert scale, ()=(SD)

4.3. Behavior analysis in gesture types

In order to study the differences in gestures, four major types of gesture movements, i.e., horizontal, vertical, inclined, and circular, were identified (Table 4). There were significant differences in the types applied for two systems ($F(1,239)=42.312$, $P<0.05$). Moving fingertips horizontally and vertically was the gestures applied frequently, even though the systems would respond the actions of incline and circular movements. In addition, there were significant differences in gesture types and interaction ($F(1,239)=18.309$, $P<0.05$) among adults and children group. The first two gestures of the adult group were horizontal and vertical gestures.

However, the first two gestures of the children's group were inclined and horizontal gestures. Furthermore, it is interesting that, among all gestures, horizontal and vertical gestures contributed to more than 80% of movements in the adult group, but less than 60% of movements in the children group.

Table 4: System and age differences in the percentage of gesture types

	Horizontal	Vertical	Inclined	Circular
System 1	41.1(21.1)	33.2(12.1)	20.8(13.3)	5.0(7.4)
System 2	39.6(24.8)	25.9(14.9)	24.6(19.4)	9.8(11.1)
Adults	51.1(22.4)	31.1(12.2)	14.1(14.0)	3.7(7.9)
Children	29.6(17.9)	28.0(15.6)	31.3(14.6)	11.1(10.0)
Average	40.3(22.8)	29.5(14.0)	22.7(16.6)	7.4(9.7)

Unit=%, ()=(SD)

4.4. Behavior analysis in the locations of touch points

In order to study the locations of touch, the percentage of touch points were recorded with respect to four parts, i.e., outside of the contour, head, limb, and body (Table 5). There were significant differences in the touch locations ($F(1,239)=22.645$, $P<0.05$). The first two locations of touch were outside the contour and turtle head for both systems. Similarly, there were significant differences in touch locations and interaction ($F(1,239)=4.608$, $P<0.05$) among adults and children group. For the adult group, the first two locations were outside the contour (49.4%) and head (25.9%). For the children group, the first two locations were outside the contour (34.3%) and limb (27.4%). Compared to the adult group, the locations of touch points were evenly distributed for children. This indicated that participants in different age groups tended to use different parts as the reference point of rotation.

Table 5: System and age differences in the percentage of touch locations

	Outside the Contour	Head	Limb	Body
System 1	36.7(26.7)	29.5(21.8)	25.3(18.1)	8.5(9.4)
System 2	47.0(32.9)	20.3(14.9)	18.4(15.3)	14.3(17.4)
Adults	49.4(31.4)	25.9(21.1)	16.3(12.9)	8.4(14.5)
Children	34.3(27.4)	24.0(17.1)	27.4(18.9)	14.4(13.4)
Average	41.8(30.2)	24.9(19.1)	21.9(17.0)	11.4(14.1)

Unit=%, ()=(SD)

5. Discussion

5.1. Gesture changing frequency

Overall, the children group yielded higher frequency of gesture changing then the adult group (Table 6). Participants in the adult group appeared to use their prior knowledge about object manipulation in 3D physical spaces or 3D digital contents to overcome the difficulty of tasks. When their prior experience or knowledge did not seem to be available or not workable, they tended to follow instructions carefully. Children, on the other hand, seemed to use intuitive gestures and to try to explore the relationship between system responses and gestures, adjusting their gestures dynamically. These differences were significant when comparing the behavior in System 1 versus System 2. For example, while using System 1 to complete the first task, the fast adult (A07) used three strokes of gestures, with short distances, to complete the task. However, the fast child (C01) used a long stroke only. It was obvious that the adult followed the instructions carefully. But the child would rather to follow the intuition. On the other hand, while using System 2, the fast adult (A18) used five short strokes to complete the task. The instructions were followed, therefore, the task completion time even decreased compared to System 1. However, the fast child (C10) used two long strokes that changed directions frequently. In this time, the intuition didn't work. Therefore, the task completion time was much longer than using System 1.

Based the analysis of behaviors in this section and previous sections, adults and children differed in the gesture changing frequency, in the diversity of gesture types, and in the touch locations with respect to the object contour. Therefore, offering a robust mechanism for gesture inputs is necessary for universal control of such a system.

Table 6: Gesture changing frequency

Group	System 1 (1-Point dominant)	System 2 (2-Point dominant)
Adults	7.14(6.66)	6.26(6.70)
Children	13.46(14.4)	12.71(13.7)

()=(SD)

5.2. Frustration and recovery experiences

During the time of completing the tasks, while the cumulative effects of 3D rotations became complicated after intensive operations, participants tended to stop for checking the instructions or even tried to manipulate the model with arbitrary gestures due to losing patience. This was the indication of frustration and pressure of completing the tasks.

As for recovery of controls, when they got lost after performing several rotations in different axes, they would try to find the mapping to regain controls. For example, in the first task, there was no significant change in the viewing angle of the turtle head from the original posture to the target posture. Therefore, System 1 was significantly more intuitive than System 2. However, whilst completing tasks 2 and 3, the changes in the viewing angle of the turtle head increased. Participants tended to get confused among the mapping between finger movements and rotation angles. In such a case, System 1 did not have the advantages over System 2. The duration of recovery depended on the logical thinking capability and the prior knowledge of the participant. To overcome the dependency on prior knowledge, simple gestures would be easier to facilitate the mapping between 2D control movements and 3D content displays, especially for children without intrinsic mental models of virtual contents manipulation.

5.3. Observation in the needs of natural mapping instructions for spatial manipulation

According to the participants' opinions and thoughts in post-experiment interviews, instead of reading the precise angle values shown on the top of the screen, participants tended to visually observe the feedback angle of the contour and use the head of green turtle as a manipulation reference, while the 3D object was in the orientation with a clear and convex shape. However, when a clear convex shape or image was not available in certain orientations, such kind of operation mode may not be easy to manipulate the 3D objects. Furthermore, even the model of green turtle had been rotated almost accurately to the orientation, adults still tried to meet the target angle as closely as possible, by reading and checking the precise angle values. In addition, although all participants had basic geometry curriculum when they enrolled in elementary schools, eleven adults had 3D software experiences, and six children had 3D gaming experiences, some participants still reported frustration and needed to check the instructions to facilitate rapid completion of tasks. Therefore, providing a synchronized mapping instruction for three axes rotation on screens is a useful 3D object rotation solution for touch-screen design.

6. Conclusion and Recommendation

6.1. Conclusion

In summary, the results showed that using conventional gestures for 2D object rotation was not appropriate for the 3D environment. Rotating 3D contents by 1-point dominant gestures was more intuitive than 2-point dominant gestures. While the cumulative effects of 3D rotations became complicated after intensive operations, simpler gestures could facilitate the mapping between 2D control movements and 3D content displays, especially for children without intrinsic mental models of virtual contents manipulation. Therefore, for rotation in Cartesian coordinates, moving one fingertip horizontally or vertically on a 2D touch screen could correspond to the rotation angles of two axes for 3D contents, the gestures of relative movement between two fingertips could be used to control the rotation angle of the third axis. Based on behavior analysis, adults and children differed in the diversity of gesture types and in the touch locations with respect to the object contour. However, visually observing the feedback angle of the contour and using the head of green turtle as a reference are possible only when the 3D object is in the orientation with a clear and convex shape. In addition, offering a robust mechanism for gesture inputs is necessary for universal control of such a system. While manipulation, providing a synchronized mapping instruction for three axes rotation on screens is a useful 3D object rotation solution for touch-screen design.

6.2. Recommendations for further research

Based on the result of observation and post-experiment interviews, participants in different age groups tended to use different parts as the reference point of rotation. Therefore, it may be necessary for the user to select the viewing angle and the reference point first at their convenience. In such a case, a single-touch movement may be used to control the direction and the rotation angle of the reference point. Whether changing viewing angles and reference points is natural for rotation operations is an important issue. In addition, explore 3D objects manipulation accuracy also deserves further research in the future.

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