Exploratory Experimentation of Three Techniques for Rotating a 3D Scene by Primary School Students

David Bertolo
Université de Lorraine
LCOMS, EA 7306
Metz, F-57006, France
david.bertolo@univ-lorraine.fr

Sébastien Pelurson
Université Grenoble Alpes
LIG, CNRS
Grenoble, F-38000, France
sebastien.pelurson@imag.fr

Laurence Nigay
Université Grenoble Alpes
LIG, CNRS
Grenoble, F-38000, France
laurence.nigay@imag.fr

Robin Vivian
Université de Lorraine
PErSEUs, EA 7312
Metz, F-57006, France
robin.vivian@univ-lorraine.fr

http://dx.doi.org/10.1145/2820619.2825024

Abstract
Multi-touch mobile devices are now commonly used in any area, including education. In this context we focus on applications for 3D geometry learning in primary schools. Manipulating a 3D scene based on a 2D input touch space is one key challenge of such applications for pupils. In this paper we present the results of an exploratory experimentation with pupils. We compare three different interaction techniques for rotating a 3D scene based on different interaction metaphors by using: multi-touch input, movements of the tablet captured with a gyroscope sensor and movements of the head captured by a camera-based head tracking. We ran the exploratory experiment with 28 pupils in a primary school to compare these three techniques by considering the performance and the subjective preferences. Results indicate worst performance for head-tracking and similar performance for multi-touch input and gyroscope-based movement. Qualitative results indicate participant preference for multi-touch interaction.

Author Keywords
3D user interface, child-computer interaction.

ACM Classification Keywords
H.5.2. [Information Interfaces and Presentation]: User Interfaces – Interaction styles; G.4 [Mathematical Software]: User interfaces.

Introduction

Assimilating 3D geometry is a complex activity for pupils [5]. 3D geometry interactive applications allow various viewpoints of the shapes. Such interactive applications help the pupils to develop the three dimensional mental model of the shape [1]. In this context, the dedicated interactive application described in [3], with no menu and direct touch interaction on tablet, can help pupils to solve 3D geometry problems. However, manipulation of 3D objects with a 2D input space is still a challenge. Moreover, Hinrich et al. [7] show that interactions used by children and adults are different. The main challenge is to make practicable for children to transform inputs into a 3D motion. A first approach to perform 3D manipulation employs dedicated widgets. For instance the tBox widget [4] for 3D manipulation can be easily and efficiently operated by touch inputs on a tactile screen. A second approach consists of focusing on multi-touch inputs for managing simultaneously several degrees of freedom (DOF). For example the multi-touch technique described in [9] allows the user to directly manipulate 3D objects with three or more points: the method fully captures the traditional 2D RST (Rotate-Scale-Translate) multi-touch interaction, but also extends these same principles to 3D interaction. Moreover Rousset et al. [10] define two new techniques for 3D rotation with two fingers for novice users. The two techniques allow an integral control of the 3 axes of rotation and satisfy a new property: surjection. Beyond 2D interaction on a tactile screen, a third approach consists of extending the input possibilities by using other sensors, now widely available on mobile devices. In [8] Hürst et al. compare a joystick-based navigation and an accelerometer-based navigation to explore a virtual world. The results underline that the accelerometer-based navigation was not well perceived by users because of unwanted motions during navigation: Hürst et al. suggest using a gyroscope sensor to minimize this effect. Moreover in [6] camera-based head tracking is used for exploring a 3D scene displayed on a mobile device screen. The qualitative user study based on four example demonstrators of the face-tracking technique on both a smartphone and a tablet demonstrates the ease and intuitiveness of the face-tracking technique. To address the diversity of interaction techniques for 3D manipulation, we conducted an exploratory experimentation. Based on comments by pupils during a previous experimental study, we compare three different interaction techniques for rotating a 3D scene in the context of 3D geometry learning on tablets.

Experiment with pupils

In a previous experimental study with pupils [2], 7 pupils (mean age = 11.6) were asked to describe interaction techniques on a tablet for changing the point of view on the 3D scene. We received 3 different answers for changing the point of view:

- Use fingers on the screen as a direct way to rotate the scene (multi-touch);
- Take the tablet in the hands and use it as a movable window to navigate around the scene (gyroscope);
- Incline the head in front of the screen of the tablet analogous to watching through a window (face tracking).

The first technique corresponds to directly rotating the scene. In contrast the two others solutions correspond to moving the observer, not the scene: they are quite proximal to actions performed in the physical world. These three pupils proposed techniques motivate us to compare them in the exploratory experimental study described in this paper.

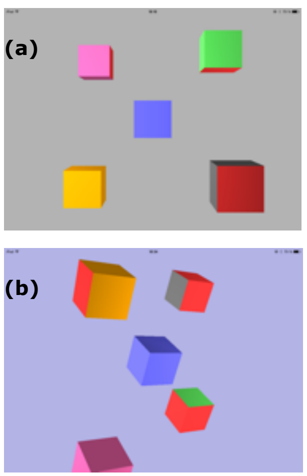

Figure 1. Test application with (a) no activated interaction technique, (b) an activated interaction technique.

Compared interaction techniques

We have implemented a first version of the three interaction techniques on iPad. The users can enable or disable a technique at any time. To enable or disable a technique, we implemented the same procedure: the user touches with one finger on each side of the tablet during 1s. The background color provides a permanent visual feedback about the activation state of a technique: If an interaction technique is enabled, the background is blue otherwise it is gray (figure 1).

THE MULTI-TOUCH INTERACTION TECHNIQUE

With this interaction technique, the user does not turn around the 3D scene but s/he turns the scene displayed on screen without moving, just like in a video game. The user controls the rotation of the 3D scene with two fingers by sliding them on the screen. A horizontal move turns the scene around the Y-axis and a vertical move around the X-axis in the frame of the screen [2].

THE GYROSCOPE INTERACTION TECHNIQUE

The gyroscopic sensor is used to modify the observer's position around the scene. We apply the video camera metaphor. The tablet acts as a window onto the scene: Moving the tablet in space changes the viewpoint onto the scene. So to use this interaction technique, the users have to physically move in order to turn around the scene. This technique reinforces the 3D effect of the perceived scene.

THE FACE TRACKING INTERACTION TECHNIQUE

By using the built-in front-facing camera, whenever a face is detected, the tracking starts and runs in the background, if the technique is activated (blue background of figure 1). We use the Head-Coupled Perspective (HCP) technique as demonstrated by the i3D application available on iTunes and described in [6]. We automatically rotate the scene according to the relative position of the device with regard to the tracked face of the user [6]. We have adapted the angle of rotation in order to partially see the back of the 3D scene. By partially breaking the consistency of the metaphor, the user can therefore perform all the observation tasks during the experiment. As for the previous technique, this technique reinforces the 3D effect of the perceived scene. Francone & Nigay [6] describe subjective usability results and preferences of the users testing the technique on tablet and smartphone (i3D application). The study here enables us to test this first version of the technique in the context of a task to be performed with pupils.

Participants and apparatus

Twenty-eight pupils from an entire class of a primary school were recruited to participate (13 males and 15 females, mean age = 11). The class has been chosen according to the french school curriculum in 3D geometry. All the pupils except one have used a multi-touch mobile device before the experiment. Each pupil had an iPad for the tests. The tablets were equipped with 1 training application and 5 test-applications for each interaction technique (namely multi-touch, gyroscope and face tracking) to be compared. Each test application included 5 cubes with different colors. Each cube had from zero to four red faces (figure 1).

Task and procedure

During the experiment pupils had to find all the cubes with one and only one red face: They answered a multiple-choice questionnaire to give their answers. The experiment was split into the following 3 phases:

<u>Phase 1</u>: Pupils have completed a questionnaire stating if they own a multi-touch mobile device or if they have already used one (with the frequency of use). Based on these two

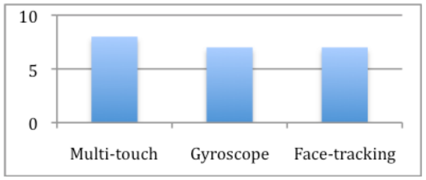

Figure 2. Median number of cubes with one and only one red face found by the pupils per interaction technique.

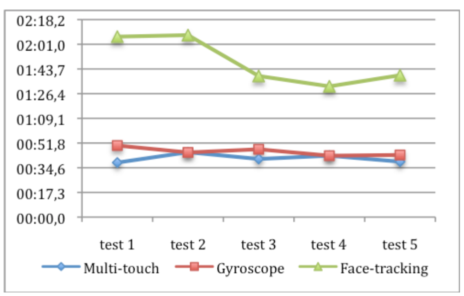

Figure 3. Evolution of the mean time (min.:sec.) to complete the task per interaction technique.

criteria, we constructed four groups of 5 pupils and two groups of 4 pupils.

Phase 2: One week later, the experiment took place in the primary school. Two researchers were present and time was recorded for each pupil and each test. Six sessions (six groups) were done on two consecutive days. Each session was split in the same way: (1) Explain the experiment and the task; (2) For each of the three interaction techniques: (a) Presentation of the interaction technique and a 2-minute training period with it; (b) 5 tests with time recording. At the end of each session a post-test questionnaire was provided to rank the interaction techniques as well to gather opinions on fun, intuitiveness and difficulty of use. We used a 4-point Likert scale. If pupils found an interaction technique difficult to use, they have to explain the reason in the questionnaire. At the end of the questionnaire, they were asked to propose any improvement or new idea.

Phase 3: We organized a debriefing with the entire class. Pupils were free to express themselves.

Results

In addition to the time for each test, we computed the success of a task with 1 point for each correct cube, -1 for a wrong cube and 0 for a missing one (figure 2). We also computed the preference ranking score for each technique using two separate methods (figure 4) (1) the number of pupils who ranked the interaction technique in first position; (2) the following formula: $S = 1 \times a + 0.5 \times b$, where a and b are the number of times the technique has been ranked respectively in first and second position.

Performance: error and time

Figure 2 shows that pupils have found nearly the same number of cubes (with one and only one red face) with each interaction technique. Statistical analyses (ANOVA) did not reveal significant differences between interaction techniques ($F(2\text{-}81) = 0.669$, $p = 0.515$). The two new techniques for the pupils (gyroscope and face tracking techniques) are as effective as the well-known multi-touch technique if we consider only the success of the tasks. Students have been timed during each of the five tests per technique. The mean time to complete the task is 41.2s for the multi-touch technique, 45.8s for the gyroscope technique and 108.6s for the face tracking technique. The mean times are similar for the multi-touch and gyroscope techniques. In comparison, the face tracking technique took nearly 2.5 times more to complete the task. Figure 3 shows the mean time to complete the task for each test and technique. The mean times for the multi-touch and gyroscope techniques are similar and remain almost constant. Contrastingly, the mean time for the face tracking decreases during the tests.

User preferences

Figure 4 shows that pupils preferred the multi-touch technique. As explained, we applied two methods to establish the ranking. With the first method that takes into account only the first choice of the pupils, the scores were 17 for the multi-touch technique, 10 for the gyroscope technique and 1 for the face tracking technique. With the second method based on a weighted system of ranking, the scores were 21.5 for the multi-touch technique, 19 for the gyroscope technique and 1.5 for the face tracking technique. Pupils found the multi-touch technique very easy, the gyroscope technique easy and the face tracking technique difficult. The feedback is positive regarding fun and intuitiveness. The pupils reported the use of the different techniques as very enjoyable for the multi-touch technique and enjoyable for the gyroscope and face tracking techniques. Similarly, they suggested that multi-touch is very intuitive, while the gyroscope and face tracking

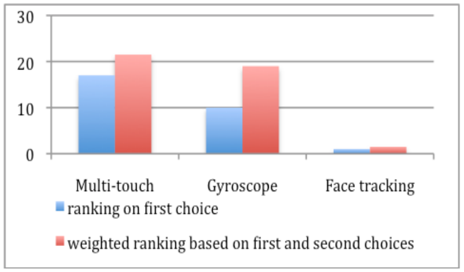

Figure 4. Ranking of interaction techniques preferred by the students with two methods: first choice only; weighted system of ranking taking into account the first and the second answers of the pupils.

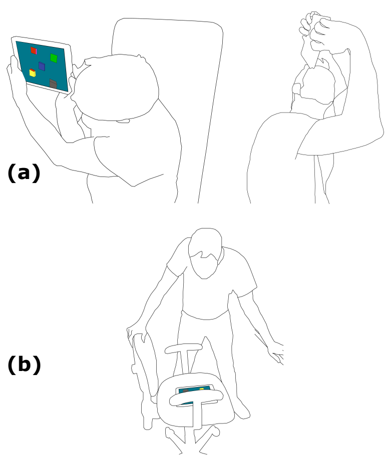

Figure 5. (a) Two positions observed while using the gyroscope technique; (b) One position observed while using the face tracking technique: The tablet is set on a chair.

techniques are judged intuitive. The last question of the questionnaire was concerned with new interaction techniques and/or improvements of the techniques. Most of the pupils suggested ideas for the three proposed techniques: for instance incline the tablet to move the point of view but without physically moving as in our implementation. Some pupils proposed using vocal commands. But the most interesting answer was provided by 4 pupils who suggested using eye tracking after all!

Discussion

We explain the obtained performance results and user preferences based on two main reasons: expertise and technical issues.

Compared techniques: expertise

All the pupils except one are used to manipulating tactile and multi-touch devices as tablets or smartphones. For them multi-touch is used everyday. During the debriefing, the pupils told us that they use their multi-touch devices daily, at home, in the bus, at school. Hence they use it everywhere and frequently: "it's simply normal". Several pupils explained to us that multi-touch is the first interaction they think of when using such a device. So for them multi-touch is the most familiar interaction. In the study described in [11], the users thought of the WIMP paradigm as a reference. Contrastingly a new generation of users think of the multi-touch paradigm as a reference and the pupils stay faithful to it, as underlined in [11] for the case of the WIMP paradigm.

Twenty-five of the twenty-eight pupils use their mobile devices to play video games. They use sensors like the accelerometer in racing car games to simulate a wheel. Even if children used to play games with the accelerometer sensor, they have no real strategy for using the gyroscope or face tracking techniques correctly. We allowed pupils to stand up and to move when using the different techniques. Nevertheless, for instance with the gyroscope technique, only 10 students attempted a standing position. We have observed some uncomfortable positions taken by the pupils while using the gyroscope technique (figure 5-a). This observation may have influenced their choices for the preferred technique.

For the face tracking technique, it was the first time that the pupils experienced it. This technique was totally new for the pupils and they needed to learn how to use it. The observed decreasing mean times (figure 3) confirmed this training effect. We can induce that with more sessions, time will have continued to decrease.

Finally, we observed that pupils, due to the fact that they are experts in multi-touch interfaces, controlled the 3D scene effectively using direct interaction. In contrast, with the gyroscope and face tracking techniques they have the feeling of loosing this direct control.

Compared techniques: technical and design issues

The second reason is related to technical and design issues. For the multi-touch interaction, pupils suggested using only one finger for touch interaction.

For the gyroscope technique, pupils did not appreciate the option of simultaneously managing 3 DOF. They found this option useless and a source of unwanted moves. They suggested constraining the point of view movements to around the Z-axis.

Finally the face tracking technique is quite sensitive to variations of light. We were careful to maintain the same conditions of light in the classroom during the experiment. Nevertheless the tracking mechanism was sometimes not stable. Moreover, we did not include a mechanism that assists in finding the initial position (such as a dedicated window showing the tracking of the face as in the i3D application available on iTunes). Pupils have used their reflection on the tablet screen to find the right position. This made use of the technique longer and more difficult for pupils. We can quote the pupils: “The application lost my head!”, “hey, it’s frozen!” or “The camera doesn’t find my head anymore”. During the debriefing, pupils suggested adding a small window to provide a visual feedback of the head position in the field of view of the camera. It is interesting to note that pupils found ways to cope with the shortcomings of the implemented face tracking technique: A pupil was upset about the time taken to complete the first test. So he decided to put the tablet on his seat and tried to find a right position. One of his hands was on the table and the other on the top of the back of the chair (figure 5-b). From this moment, his movements were restricted and he efficiently used the face tracking technique. After a while the other pupils of his group adopted the same strategy. For this group, the mean time for completing the task with the face tracking technique was 64.5s.

Conclusion

As part of an exploratory experimentation, we have compared three interaction techniques for rotating a 3D scene with cubes. Our results show that the gyroscope technique is as efficient as the multi-touch technique. We cannot conclude on the face tracking technique due to technical issues. As part of a future more controlled experiment to explore different interaction metaphors for 3D rotation, we first need to implement a new version of the gyroscope and face-tracking techniques (robust and complete window-in-hand and peephole techniques). These two techniques could be compared with the currently most efficient multi-touch techniques for novice users [9]. In addition a longer controlled experimental study should be conducted to observe if the time to complete the task decreases and if the opinion of the children evolves as they become experts with the techniques.

References

[1] Bakó, M. Different projecting methods in teaching spatial geometry. In *Proceedings of CERME’03*.

[2] Bertolo, D., Vivian R. and Dinet J. A set of interactions to rotate solids in 3D geometry context. In *CHI’13 Extended Abstracts*, ACM, 625-630.

[3] Bertolo, D., Vivian R. and Dinet J. A set of interactions to help to resolve 3D geometry problems. In *Proceedings of SAI'13*, IEEE, 738-743.

[4] Cohé, A., Dècle, F. and Hachet M. tBox: A 3D transformation widget designed for touch-screens. In *Proceedings of CHI’11*, ACM, 3005-3008.

[5] Duval, R. Geometry from a Cognitive Point of View. In C Mammana and V. Villani (Eds.), *Perspectives on the Teaching of Geometry for the 21stCentury*, 1998, Kluwer Academic, 37-52.

[6] Francone, J. and Nigay L. Using the User’s Point of View for Interaction on Mobile Devices. In *Proceedings of IHM’11*, ACM, No. 4.

[7] Hinrichs, U., Carpendale, S. Gestures in the wild: studying multi-touch gesture sequences on interactive tabletop exhibits. In *Proceedings of CHI’11*, ACM, p. 3023-3032.

[8] Hürst, W. and Helder M. Mobile 3D graphics and virtual reality interaction. In *Proceedings of ACE’11*, ACM, No. 28.

[9] Reisman, J. L, Davidson, P. L. and Han, J.Y. A screen-space formulation for 2D and 3D direct manipulation. In *Proceedings of UIST’09*, ACM, 69–78.

[10] Rousset, E., Berard, F. and Ortega, M. Two-finger 3D rotations for novice users: surjective and integral interactions. In *Proceedings of AVI’14*, ACM, 217–224.

[11] Wobbrock, J.O., Morris, M.R. and Wilson, A.D. User-defined gestures for surfaces computing. In *Proceedings of CHI '09*, ACM, 1083-109.