ART 03

# Usability Evaluation of Tangible User Interfaces for Augmented Reality

Miguel Dias[2], Joaquim Jorge[1], José Carvalho[1], Pedro Santos[2], José Luzio[1]
*[1]IST/UTL, [2]ADETTI/ISCTE, Lisboa, PORTUGAL*
*{Miguel.Dias, Pedro.Santos}@adetti.iscte.pt, jorgej@acm.orgl, {jecc,jcl}@mega.ist.utl.pt*

## Abstract

*This paper presents the usability evaluation results of Mix It, a test bed for authoring in Mixed Reality Environments. While augmented and mixed reality interfaces have been around for a few years, considerable work needs to be done in usability assessment of novel interaction techniques for augmented environments. We have conducted usability evaluations for simple manipulations using simple geometric transformations (translation, rotation, scaling). Even though the results are preliminary and the user group is comparatively small, experimental results proved useful in deriving guidelines and further developments and experimentation with synergistic interaction using multiple modalities.*

## 1. Introduction

While augmented-reality systems have been around for a few years, much work remains to be done in usability assessment of novel interaction techniques for augmented environments. Chris Hand [5] presented a comprehensive survey were he discusses some of the design issues for free-space three-dimensional user interfaces. However, interactions in mixed reality environments, presents a largely different set of issues especially those having to deal with tangible interaction as we address in the present paper. In 1997 Hinckley et al [6] presented a formal user study of interactive 3D rotation comparing mouse-driven Virtual Sphere with multidimensional input devices and found out that multidimensional input tasks presented a clear advantage over conventional devices. While user interfaces in immersive and mixed reality environments are not new, not many usability tests have been systematically conducted so far. Kato et al in a usability study [7] present five main objectives for tangible interfaces. Object affordances should match physical constraints to task requirements. Moreover, interfaces should support parallel activities when reasonable as well as providing aids for physically-based interaction techniques, based on proximity and "obvious" spatial relations. Furthermore objects should by their form support spatial and two-handed manipulation. We have tried and incorporate many of these principles, especially the last two in the present paper to create an enticing experience. Klinker et al. [9] have also used mobile augmented reality for presentation and product design in the automotive industry. While they found the approach useful and especially suitable for view manipulation in large display scenarios, they identify some problems such as marker cluttering that arise in supporting complex interactions in semi-constrained environments. In a similar application Shelton and Hedley [12] report usability findings for the use of Mixed Environments in classroom settings. Their findings underscore the importance of physical inspection and direct "control" over the environment. In a similar vein Schmaslstieg et al demonstrated an augmented environment for teaching geometry [13] using the *studierstube* platform. Similarly, Wiedenmaier and Oehme test-bed can be used to conduct virtual assembly tests in augmented reality settings [14]. However, the need for authoring (creating and manipulating objects and their representation) was not addressed in so thorough a manner as navigation and exploration of the environment. In the present work we try and tackle the challenges involved in adding and manipulating content in mixed environments. We have developed a test bed for user interactions using the Mix It environment.

## 2. Authoring Augmented Reality Worlds

The set-up of our usability evaluation experiment requires the possibility to author a user specified Augmented/Mixed Reality scenario. To achieve this, we have used an AR Toolkit [1] based tool, developed by our team, referred to as **Mix It**, which supports the association of different 3D virtual objects to respective markers for real-time registration. This tool adopts the metaphor of the Magic Book described in the literature [2] where, at run-time, a user can look at an ordinary paper book with fiducial markers printed on the pages and observe, through video or optical see-through glasses, virtual objects registered over those markers (Figure 3). Mix It supports multiple Magic Books that can be created, managed, changed, deleted and printed by the user. The tool comprises the **Mix It Editor** and the **AR Viewer**. With the Mix It Editor, the user can interactively associate any 3D virtual object to square black and white markers, which are all different and automatically produced by the tool. These associations (marker + 3D object) can be arbitrarily structured by the user into Books (Figure 1).

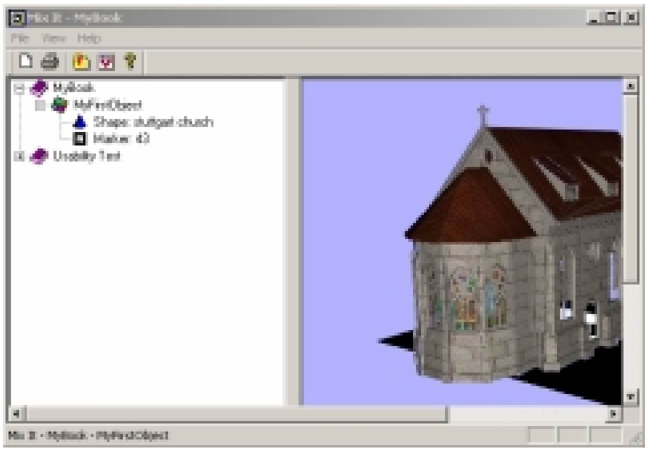


**Figure 1 Associating a 3D object to a marker in the framework of a "Magic Book" in Mix It.**

The Mix It Editor then produces a database with the necessary data, so that the run-time module (AR Viewer) is able to recognize the pattern inscribed in a given marker and, in real time, view the associated 3D object as soon as the video camera is in sight of that fiducial marker. The Editor supports VRML 97 Objects/Scenes, including object animation. Within the Editor it's also possible to define and control different 3D object proprieties in the local reference frame of the marker, such as, object Translation, Rotation and Scale (Figure 2). These features proved to be of interest for the preparation of the usability test cases.

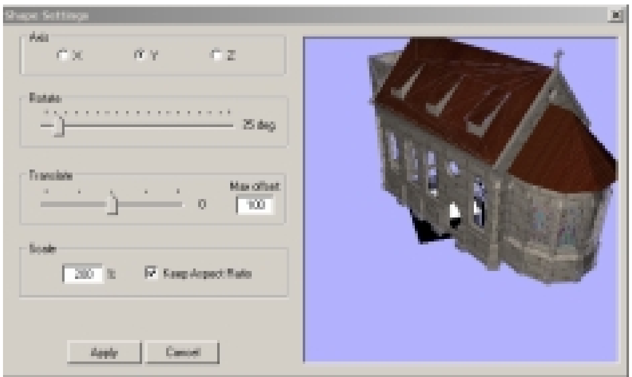


**Figure 2 Changing object proprieties in the marker reference frame in Mix It.**

The existing system is currently appropriate for static usage in indoor settings and it consists of an analogue video input/output link and battery powered video see-through glasses and a base station computer. The input/output video is processed by the base station computer, running **Mix It Editor** (for scene preparation) and **AR Viewer** (for Tangible Interaction in Mixed Reality). The typical hardware and software platforms required by our system, are as follows:

- Video See-Through Head Mounted Display: Olympus Eye-trek FMD 700, Multimedia Glasses (800x600 pixel);
- Web Cam, requiring a VGA cable to be connected to the base station computer;
- Base Station Computer:
    - Hardware - CPU: Intel Pentium IV 2.5GHZ; RAM: 1 Gbyte; Graphics card: NVIDIA GFORCE4 440 GO 64 Mbyte;
    - Software - MS Visual C++ 6.0 enterprise edition; ArToolkit 2.5.2; Video Input - Direct X 8.1; Graphics - Open GL and Open VRML;
- Indoor Tracking method - Computer vision-based approach (ArToolkit) with sparsely placed fiducial markers.

## 3. Finger Gesturing and Tangible User Interaction

Users generally require simple real-time user interaction in Mixed Reality. Having this in mind, we have developed a Tangible Interface as simple as possible, similar to the ones found in [2] or [3], which is suitable for our user interface requirements and is referred to as the **Magic Ring** (see Figure 3). The idea behind this tool is to provide an approximation to finger gesture tracking by computer vision means. This Tangible Interface has a specific marker attached and, as a visual aid, when it is recognized by the system, a blue circle will be displayed on top of it (Figure 4). Instead of just registering virtual objects to real ones, as in the mentioned works, we also add novel uses for this interface, since it is the only physical means of user interaction that will trigger the functionalities of the system. This is achieved by detecting the trajectories of the centers of the reference frames associated to the fiducial markers of the Magic Rings (whose pose is provided by AR Toolkit), thus deriving the free hand and finger gestures of the user.

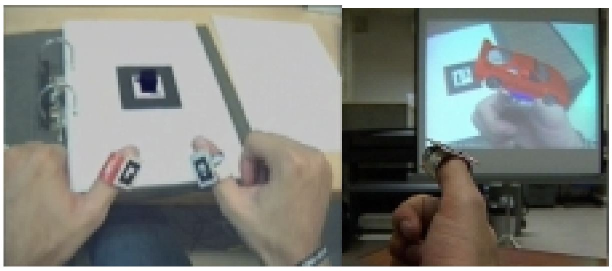


**Figure 3 Using Magic Rings in both thumb fingers to interact with a "Magic Book" (left); Picking an object with the finger using a Magic Ring (right).**

Typically, we use a ring in the right and in the left thumbs (Figure 3). The AR Toolkit library provides us the real time spatial evolution of the 3D coordinates of the centre of the reference frames superimposed onto the visible markers of these rings, relatively to the camera reference frame. From this kinematics law, we can estimate the fingertips' 3D coordinates trajectory, which can be used as an input for different kinds of operations and geometric transformations. One of the possibilities is, for example, to use the finger to pick and drop any virtual object placed on a marker (Figure 3). Additionally, we can also project these same 3D coordinates to known 2D coordinates of the visualization window, enabling the use the Magic Ring gesturing just like a mouse cursor, and opening the possibility to provide user interaction for a wide range of interaction tasks, such as object picking, moving and dropping, object scaling and rotation or, for interaction with "augmented" menus, including menu manipulation, menu items browsing and menu option selection (Figure 4). This is an alternative approach to the one found in [4], that uses a tracked "mixed-pen" metaphor for this type of user interactions.

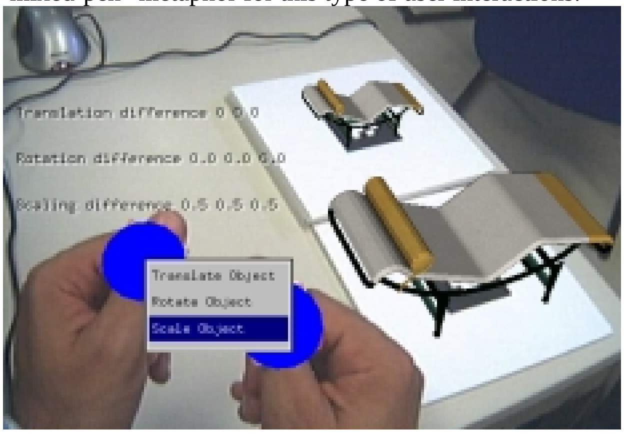



**Figure 4 Popping a menu, by pressing the marker in the left thumb using the marker in the right thumb. The options are scrolled by moving the right thumb up and down. An option is selected by maintaining still the right thumb, for a specific time duration.**

By using two Magic Rings in both thumbs (Figure 4), a menu is activated when the user presses the marker in his/her left thumb using the marker in his/her right thumb. The menu is displayed next to the left thumb (Figure 4). The menu is then tracked to this finger marker so that when the user moves it, the menu bar will follow. The user is now able to use his/her right thumb to scroll the menu items. This is done by simply moving his/her finger along the local 'y' axis so that its 2D window 'y' coordinates match the same 'y' coordinates of the corresponding menu item. The visual result of this interaction is similar to the case of using a mouse cursor to scroll/browse through a menu. Finally, the user can now select a menu item, by means of a time-out and a blinking mechanism for the selected option feedback. Its associated menu function will then be executed, which could well be a nested menu. After the menu option is selected, any kind of system action can be associated to it and invoked such as, in our case, 3D object translation, scaling or rotation.

## 4. Usability Evaluation Methodology

The usability testing experiment was designed to assess the usefulness of Tangible interaction in an Augmented Reality setup, by means of evaluating the way users perform simple editing tasks on a 3D object (a chair was selected for the test case). The editing tasks were chosen to be the following basic object transformations:

- Isotropic scale;
- Planar translation (that is, translation on the local XY plane);
- Rotation relative to one of the main local axis: XX´, YY´ or ZZ´.

Testing focussed on user performance evaluation, and therefore we used metrics, more specifically two. The first one was the time it took for each user to complete each of his/her tasks. This would give us a measure of how efficiently each of the individual transformation could be done via our interface, not only by itself but also in relation to the other transformations. To identify problems with the interface and their seriousness, the other measurement we decided to take, was the number and type of errors made by each individual subject. The types of error we considered beforehand were:

- Failing to activate the menu
- Failing to select a menu option
- Leaving "task mode" before completing the task
- Erroneous activation of the menu
- Taking too long (10 seconds) to realize the task is not being correctly executed
- Other errors (to be seen during the tests)

During the experiment, users were free to talk with the testers (though these tried to avoid giving back any help to the users while their performances were being evaluated). It is worth noting that some of our users were taking a Human-Computer Interfaces course and had some familiarity with heuristic evaluation, so their comments on the interface were most welcome. Also, after their test each user was asked to answer an 18-question questionnaire with regard to the usage of the system.

Each subject performed an experiment randomly chosen from a set of seven different tests, whose sole difference was the order between the Scaling, Translation and Rotation transformations. This order of tasks was randomly selected so as to perceive the ease of use of tasks against each other and to avoid any learning effect that could arrive from a predefined order of execution.

During the tests, one of the authors was taking notes of the errors performed by the users while another was filming the procedure. As mentioned, the tests were clocked.

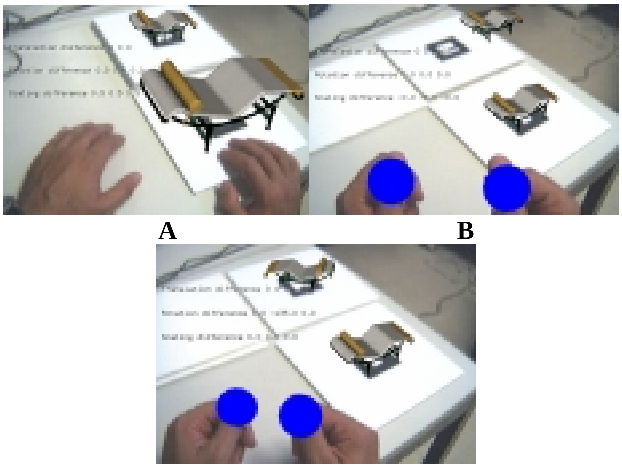
## 5. User Experiment

Each subject was shown a set-up the same type of the one depicted in Figure 5. He/she was instructed to perform the three consecutive editing tasks, with the order specifically predefined for them.  For each task, the subject could see in

AR a near object, a far object and some status messages. The task was such that the subject should manipulate the near object, by selecting and executing the appropriate transformation, so that after completion its size and its position and orientation relative to the associated marker would match those of the far object. This was done by looking at both objects and judging the similarity between both. As an aid, the status messages showed the differences in translation steps, rotation angles or degrees of scale between the near and the far objects. These should be set to zero for each experiment (that being, in fact, the condition by which we considered the task to be completed). To achieve this, the subject should: first select the appropriate transformation from the menu; then, if applicable, select the axis for the appropriate degree of freedom; and, finally, execute the transformation. This had to be done with the least possible outside interference.

In Figure 5, we depict one of the seven mentioned types of experiment, which in this case consisted in the following sequence of transformations:

A. Isotropic scale of 50% reduction in size;
B. Translation of 100 units along the positive XX´ axis:
C. Rotation of 215 degrees in the clockwise direction, around the local ZZ´ axis.



A B C

**Figure 5 Set-up of the usability experiment: A – First test: To scale the near object so that it matches the far object size; B – Second test: To translate the near object so that its relative position matches that of the far object; C – Third test: To rotate the near object so that its orientation matches that of the far object.**

The experiment was run on a sample of 16 unpaid users in two runs. The users were students in their early 20´s, selected from the undergraduate course of Intelligent Multimodal Interfaces of IST, Instituto Superior Técnico, and from the undergraduate course of Mixed Reality and Applications of the degree in Engineering of Telecommunications and Informatics of ISCTE, Instituto Superior de Ciências do Trabalho e da Empresa, both in Lisbon. On the first day we had a run of a preliminary trial with five users, who were not considered on our final results. That preliminary trial allowed us to correct problems in the experimental setup, script and tutorial instructions provided to users. On the second day, the other eleven test users (ten male, one female) were shown a demo of what could be done with the system, in a single session of 15 minutes. The facilitator showed the three tasks – translation, scaling, and rotation – in their various forms, i.e. using the different axes and degrees of freedom of transformation. He also showed the ‘Do’s’ and ‘Don’ts’ of the system. Subsequently, one at a time, the test subjects were evaluated. For each subject, 15 minutes were given for him/her to properly train each of the tasks and their various aspects with the help of the facilitator (but for the case of a different experiment than the one assigned to the him/her). The user was then shown the three tasks to be made, and was asked if he/she understood what was meant to do. Then, after concluding training and making sure the subject was ready, he/she was given 5 minutes (maximum) to complete the proposed task.

After this process has concluded, each test user was asked to answer a questionnaire relating of the system.

## 5.1. Translation

Upon activation of the Translation test through the menu, as described, the user must first select an axis for the selected degree of freedom (only the XX´ or the YY´ where used in this experiment), with an appropriate interaction as in Figure 9A. Then, once the Rings and the near and far objects are all in sight, a ruler appears attached to the left Ring (Figure 6). This ruler has three zones where the right Ring can be positioned, while the left Ring remains fixed: Left - Resets the near object to the initial state; Center – Translates the near object in the local negative XX´ axis; Right – Translates the near object in the local positive XX´ axis. There is a parabolic law for the variation of the acceleration of the object, as follows: if the right Ring is positioned in the center of Right or Center ruler zones, as depicted in Figure 7, the acceleration is maximum. If it is positioned near one of the borders, it is minimum.

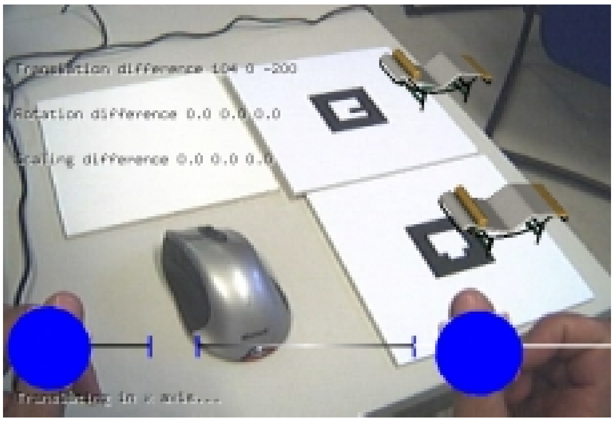
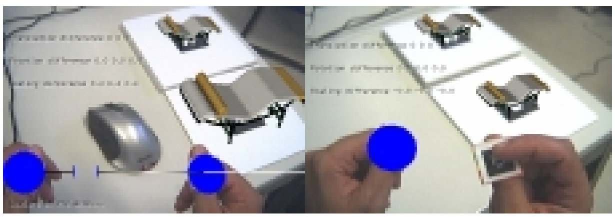



**Figure 6 Translation test (XX´ direction): There are three ruler zones where the right Ring can be positioned (the left Ring remains fixed): Left - Resets the near object to the initial state; Center – Translates the near object in the negative XX´; Right – Translates the near object in the positive XX´.**

**Figure 7 Ruler to control the Acceleration of the degree of freedom.**

### 5.2. Isotropic Scaling Test

The scale transformation does not require an initial selection of any degree of freedom, since it is isotropic. Once the option is activated via the menu and both Rings and the near and far objects are in sight, a ruler appears attached to the left Ring (Figure 8), much in the same way as with the Translation test. This ruler has also three zones where the right Ring can be positioned, while the left Ring remains fixed: Left - Resets the near object to the initial state; Center – Grows the near object; Right – Shrinks the near. One way to terminate a given interaction is to occlude one of the Magic Rings with the index finger, as depicted in Figure 8B.

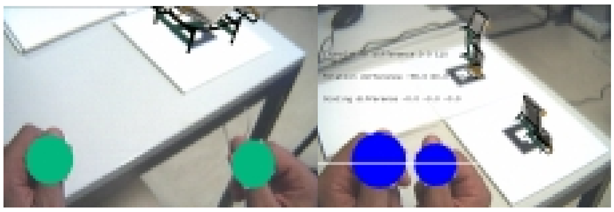


**A** **B**

**Figure 8 Scaling test on the near object: A – Tangible interaction; B – Terminating the Tangible interaction by occluding the Magic Ring with the index finger.**

### 5.3. Rotation

The Rotation tests comprise three possible and independent tests, since Rotation can be regarded as relative to one of the three main local axis.



**A** **B**

**Figure 9 Rotation test on the near object (local YY´ axis): A - The user first sets the desired axis with a gesture; B – Subsequently, the user issues a circular motion with both hands, as if turning a vertical steering wheel and within the boundaries of a displayed circle.**

All these tests require an initial Tangible interaction for the definition of the degree of freedom: XX´ axis, YY´ axis or ZZ´ axis, as in Figure 9A. Then the user is invited to issue a circular motion with both of his/her hands and with both rings on sight, within the boundaries of a displayed circle, using the following metaphors:

- Rotation relative to local YY´ axis: perform a circular motion with both hands, as if turning a vertical steering wheel (Figure 9);
- Rotation relative to local ZZ´ axis: perform a circular motion with both hands, as if turning a horizontal steering wheel (Figure 10);
- Rotation relative to local XX´ axis: circular motion with both hands, as if lifting a crane (Figure 11).

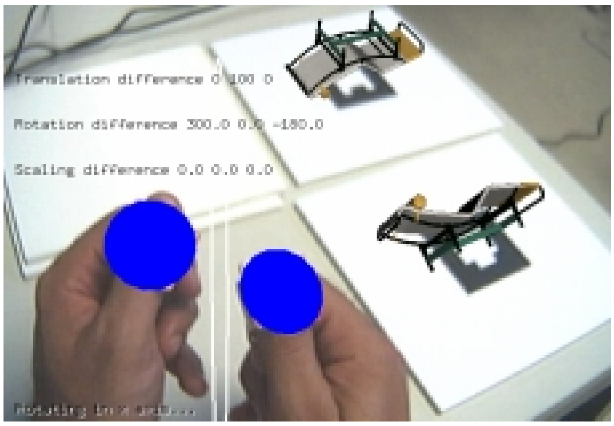



**Figure 10 Rotation test on the near object (local XX´ axis): The user issues a circular motion with both hands, as if lifting a crane, within the boundaries of a displayed circle.**

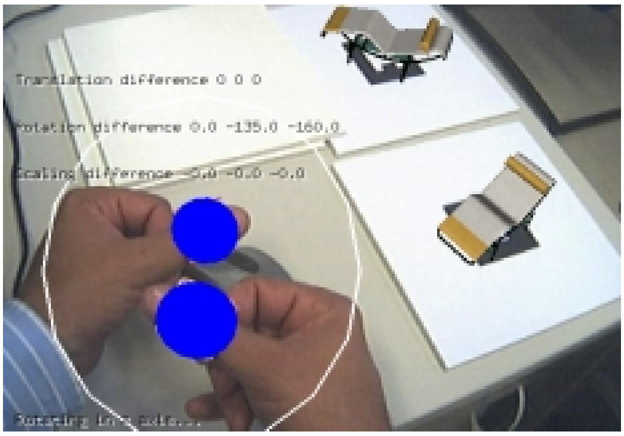


**Figure 11 Rotation test on the near object (local ZZ´ axis): The user issues a circular motion with both hands, as if turning a horizontal steering wheel, within the boundaries of a displayed circle.**

## 6. Evaluation Results and Analysis

The following figures depict the number of observed errors per task:

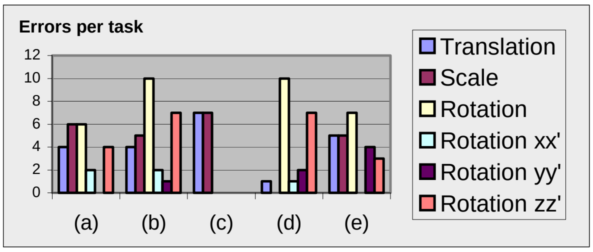



**Figure 12.1 Observed Errors per Task: (a) Menu activation failure; (b) Menu option activation failure; (c) Kept setting the value the opposite way for some time; (d) Couldn't select the axis for some time; (e) The rings were out of the work area for some time**

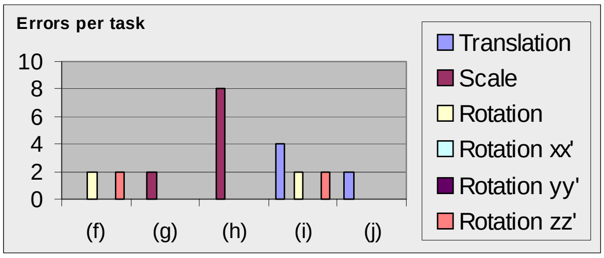



**Figure 13.2 Observed Errors per Task: (f) Selected another axis in the middle of rotation; (g) Left the task mode by allowing the timeout; (h) Lack of precision on picking the right value on the bar; (i) Choosing wrong axis; (j) Thought that the axis had been selected**

As we can see in the figures, the 'Menu activation failure' was quite a common error. This was partially due to the way the menu was activated: by putting one ring in front of the other and then touching it with a decisive move. Some of the subjects didn't separate the rings afterwards to allow the menu to unveil. In some cases the computer vision tracker didn't help, by losing sight of the marker.

The 'Menu option activation failure' was quite common too, in part because the subjects had to hold the finger position for a while so the system would timeout on the selected option. Some subjects moved their fingers a bit, and the focus moved out of the selected option.

'Kept setting the value the opposite way for some time', was also common. We think it was due to the misalignment between the axis of the value bar with which the user interacted with the object and the axis of the object reference frame.

'Couldn't select the axis for some time' was very common in rotation tasks. This was because the system wasn't recognizing properly the gestures to set the axis of the rotation, from the subjects. To make an axis selection, subjects had to hold their hands in specific positions, until the blue circles superimposed onto the visible markers changed to green (Figure 8), with which the subjects had some problems. For several times the facilitator was forced to reset the experiment so as to explain the gestures to the subjects, or even abort the whole experiment due to the subject's inability to perform the selection. In fact, few subjects showed a natural inability to control the relative position of the hands and fingers for this type of gestural interaction, that is, to define an axis of rotation.

'The rings were out of the work area for some time' had also a good representation. The reason why this happened was because there were some involuntary or necessary movements that made some markers become occluded or partially captured by the vision layer, thus loosing the registration of the markers, resulting in what we thought to be some disorientation, and by observation, some system mistakes.

'Selected another axis in the middle of rotation' has happened only a couple of times. It was caused when the subjects moved their rings outside the delimited area (circle, see Figure 8, 9 and 10) for rotating tasks, thus making a change of axis possible (this is a system feature).

'Left the task mode' was a rare mistake. It was made by not having one or both ring markers visible for some time (such as in Figure 7), therefore letting the system terminate the operation through timeout.

'Lack of precision on picking the correct value on the bar' was a very common error in scaling. A reason for this was the relatively high speed of value change in scaling operations (again a system feature).

'Choosing the wrong axis´ was not so common. It was caused by what we think to be some confusion of the way of selecting the axes, prior to the transformation proper. The subjects referred that the operation of defining the axes, especially for rotation, were confusing.

'Thought that the axis had been selected' occurred one time. We think it was due to distraction of the user.

We believe that what also caused many errors were the poor indoor lighting conditions, in one of the two experiment sites, which caused the markers not to be recognized, from time to time.

### 6.1. Time Analysis

The observed Task Times were a bit higher than expected, but given the unfamiliarity of the test subjects to the user interface and the reported problems, they were justified.

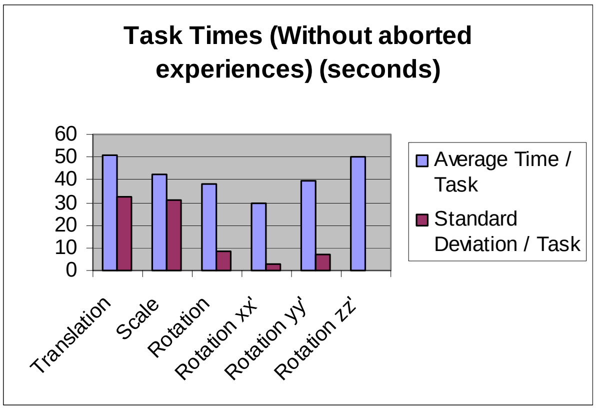



**Figure 14 Observed Task Times, excluding aborted experiences**

As can be seen in Figure 12, the tasks took more or less the same effort for the subjects. Translation took the most time, and we think it was due to the lack of synergy between object axis and value scale axis, judging by the reported errors.

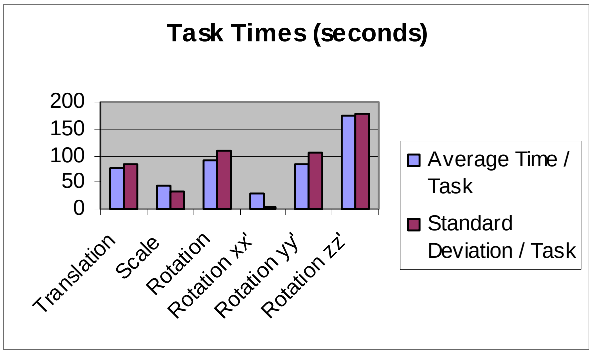



**Figure 15 Observed Task Times, including aborted experiences**

Figure 13 depicts the same diagram as the previous one, with the inclusion of the aborted experiences. There we see that, for the tested subjects, the easiest task was scaling, followed by translation. Rotation was the most time--consuming task. We think this is due to the way the axes had to be selected with a Tangible interaction. It was not perceived as very "natural" for the subjects, and since they were novice users they quickly forgot some of those aspects.

It is apparent that the rotation on the z-axis was the most time consuming. We noticed in the tests that it was partly due to the fact that the system was not easily recognizing the corresponding gestures.

### 6.2. Questionnaire and Observed Results

Right after testing the system on their three tasks, the 11 subjects individually filled an 18-question questionnaire. We enumerate here our most important preliminary conclusions and our observations during the tests.

We must first point out that there was one user that we should distinguish from the other subjects by the fact that he was already experienced with the interface in question (he was one of the developers of the system and one of the authors). His answers were not much different from the other subjects, though.

In our observation we noticed that several issues were raised, and that subjects had some problems while dealing with the Tangible interface.

Rotations were especially problematic. Several subjects in their answers to the questionnaire mentioned the recognition problems resulting from one hand occluding the marker on the other hand, while trying to cross hands. Also, we observed that some subjects tried to use the 'steering wheel' metaphor, suggested by the interface, to rotate the object in a relative way, rather than in an absolute one.

Another inconvenience was that the translations permitted by the interface were based on the object's local reference frame. Therefore, after a rotation, the direction of the produced translation would not coincide with the direction of the user's hand gesture, and this made the process confusing. Sequential rotations were affected too. Subjects pointed out this issue both during testing and while filling the questionnaire.

We observed that the interaction for the initial axis selection task was also a problem. Most subjects had a problem positioning the markers so as to have the system recognize their intention, even when it was correct. A user pointed out in the questionnaire that the way to select a given axis was depended on the operation at hand (rotation or translation).

Marker tracking problems related to the lighting also plagued our experiment, forcing the facilitator to intervene in the middle of the experiment in some cases.

When asked if they found the system to be helping them making mistakes or at least not helping them avoid them, subjects gave balanced answers: 6 said 'no' while 5 said 'yes'.

If "the device was too complicated to use effectively" was a controversial question: 2 totally agreed, 3 partially agreed, 3 partially disagreed and the remaining 2 totally disagreed.

Even with these issues in mind, most subjects agreed that "the system response to (their) input was acceptable": 4 people "totally agreed" and 6 "partially agreed" to that. One user "partially disagreed", arguing "It's not very easy sometimes to make the computer do what we want."

To the sentence "I found the input device easy to use", the majority of subjects (10 out of 11) "partially agreed". Only

one user has "partially disagreed", saying that "the gestures are not totally natural".
Nine out of the 11 subjects also agreed (at least partially) that "the input device was ideal for interacting with the augmented environment". Overall, 8 of the subjects rated the input device as "good" versus 3 who found it to be "bad". On a similar question, 9 subjects voted the system as being "good" versus 1 who found it "bad" (one of the first saying he would have preferred to vote on an intermediate option rather than voting "good").
When asked if they found "the display device appropriate for the task", 6 subjects partially agreed and 4 totally agreed; none disagreed.
Some final user comments were: "(The system has) great potential for applications in augmented environments." "If what is intended to be evaluated is the mixed reality system, I think it to be very interesting and with lots of potential! But in what refers to the interface, I think it would be possible to develop more interesting and natural solutions".

## 7. Conclusions and Future Directions

From the results we have obtained through the experiment, we can say that despite some user frustration (that could be recognized both during the experiments and after questionnaire analysis), most subjects positively adhered to the concept of Tangible Interaction in Augmented Reality and thought that this is a user interaction paradigm with much potential. Learning from these preliminary results, we now have to design better Tangible interfaces and better gestures to tap into that potential, namely by developing gestures that match and align with the virtual objects degrees of freedom in augmented reality. We have designed simple geometrical editing tasks on a 3D object, as a starting effort regarding usability evaluation, but this raises an interesting idea of the definition of standardized test tasks and usability evaluation metrics, to enable the comparison of different Tangible Interfaces and Gesture-based interaction techniques, developed by different research groups. Different standard tests could also be developed, taking into account different usage scenarios and targeting various non-expert end-users. We aim also to address multi-modality in the user interface. In fact, our current research has been the incorporation of spoken English recognition into our system, which is already achieved. We have replaced the menu with voice commands for operation selection and, have made the same substitution for the choice of the axis of the degree of freedom, of a given geometrical transformation. A similar experiment and user evaluation has been made with the new system to compare with the current results and verify if the use of the voice recognition modality, complemented with the gesture modality, is beneficial for the task at hand. Positive results have been achieved, which will be reported in a future paper.

## Acknowledgments

The authors want to thank Rafael Bastos, Luis Monteiro and Rui Silvestre for their collaboration in the development of the Mix It application.

## References

[1] Billinghurst, M. Shared Space Homepage, June 2003 www.hitl.washington.edu/research/shared_space/download/
[2] Billinghurst, M., Kato, H., Poupyrev, I., "The MagicBook: A Transitional AR Interface", in Augmented Reality: the Interface is Everywhere, SIGGRAPH 2001 Course Notes 27, 2001
[3] Brewster, S. et al, "Multimodal 'eyes-free' interaction techniques for wearable devices", Demonstration at ACM/SIGCHI 2003, Ft. Lauderdale, Fla, USA, April 2003.
[4] E. Dubois, L. Nigay, J. Troccaz, O. Chavanon, L. Carrat: "Design Space for Augmented Surgery, an Augmented Reality Case Study". Proceedings of INTERACT'99, Edinburgh, A. Sasse & C. Johnson Eds, IFIP IOS Press Publ., 1999, pp. 353-359.
[5] Hand, Chris, "A Survey of 3-D Interaction techniques", Computer Graphics Forum, 16(5), p 269-281, Dec. 1997.
[6] Hinckley, K., Tullio, J., Pausch, R., Proffitt, D., and Kassell, N., "Usability analysis of 3D rotation techniques", Proceedings of the 10th Annual ACM Symposium on User Interface Software and Technology (UIST '97), 1-10
[7] Kato, H., Billinghurst, M, Poupyrev, I., Imamoto, K., Tachibana, "Virtual Object Manipulation on a Table-Top AR Environment", Proceedings of the International Symposium on Augmented Reality (ISAR 2000). Oct. 5-6 2000.
[8] Kawashima, T., Mamoto, Kato, H. Tachibana, K. Billinghurst, M. "Magic Paddle: A Tangible Augmented Reality Interface for Object, Manipulation", Proc. on ISMR2001, pp.194-195, 2001
[9] Klinker, Gudrun, Dutoit, Allen, Bauer, Martin, "Fata Morgana – a Presentation System for Product Design", Proc. on ISMR2002, Darmstadt.
[10] Grasset, R., et al., "MARE: Multiuser Augmented Reality Environment on table setup", SIGGRAPH 2002, Conf. Abstract. And Applications, pp 213, 2002
[11] L. Nigay; E. Dubois, J. Troccaz : Compatibility and Continuity in Augmented Reality Systems. I3 Spring Days Workshop, Continuity in Future Computing Systems, Porto, Portugal, April 23-24 2001.
[12] Shelton, Brett E. Hedley, Nicholas E., "Using Augmented Reality for Teaching Earth-Sun Relationships to Undergraduate Geography Students", ART02, The First IEEE International Augmented Reality Toolkit Workshop, Darmstadt Germany, 29 September 2002
[13] Schmalstieg. Dieter. Kaufmann,Hannes, Reitmayr, Gerhard, Ledermann, Florian, "Geometry Education in the Augmented Classroom", Demonstration presented at ISMAR 2002, Darmstadt, Germany.
[14] Wiedenmaier, Stefan,Oehme Olaf, "Test Bed for Augmented Reality Supported Assembly", Demonstration presented at ISMAR 2002, Darmstadt.