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Design and Evaluation of a Low-Cost 3D Interaction Technique for Wearable and Handled AR Devices

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Abstract—Techniques that enable user interaction with a mixed environment in natural way and low-cost may provide a great potential to increase the degree of virtual presence. In this paper, we present a low-cost 3D interaction technique based on ARToolKit planar marker in order to interact with mixed reality environment, and manipulate 3D virtual object. This proposed method that we called “2 in 1 Marker” offers a six-degree of freedom, and it allows the user to perform different interaction tasks. An evaluation study of the proposed interaction technique is given in this paper to evaluate the user performance using wearable and handheld devices.

Keywords—Augmented Reality, 3D Interaction Techniques, 3D Manipulation.

I. INTRODUCTION

For several years, man has desire to improve his way of interacting with the machine. The evolution of technology has enabled the development of new methods of interaction. In this sense, many researches in the field of Human Computer Interaction (HCI) have completely transformed our relationship with the machine. Thus, the development of technical and computer devices today allows the evolution of human machine interface from Graphic User Interface (GUI) concept to the emerging paradigm of Natural User Interactions (NUIs).

Interacting by hand is thereby in direct contact with the display surface, which can be a touch screen or an augmented physical surface. This is called tactile [1, 2, 3] or tangible [4, 5] interaction. We can also interact without contact with the display surface interaction. Some systems require only the position and orientation [6, 7, 8] of the hand, other ones need a learning gestures phase [9, 10].

Regarding the determination of the position and orientation of the hand or the gesture recognition, some works are based on the hardware aspect using a Kinect [11, 12], or a flystick [13, 14], or other materials, which gives accurate results, but with height cost. Other ones are vision based, using different vision algorithms [8, 10]. The accuracy is less important, however, with low cost.

There are different techniques used for hand gesture interaction. The most basic one is the simple virtual-hand used for manipulating virtual object. The Ray-casting [15] method is used for selecting object. The Go-Go [16] technique uses the metaphor of interactively growing the user's arm and non-linear mapping for reaching and manipulating distant objects. Follow-me technique [13, 14] is based on the tracking of the user's arm and reproducing its movement in order to manipulate a virtual object according to 3 manipulation zones. The hybrid technique Homer [17] (for Hand-Centred Object Manipulation Extending Ray-Casting) uses ray-casting for selection and then moves the virtual hand to the object for hand-centered manipulation. The depth of the object is based on a linear mapping.

In this paper, we proposed a low cost 3D interaction technique that allows the user to manipulate virtual objects using i-ARToolKit [18] markers, which is improved version of the ARToolKit library [19], followed by an evaluation study of this proposed interaction technique

to evaluate the user performance using multiple devices (Pc Tablet, HMD Stereo, HMD Optic).

II. 3D INTERACTION TECHNIQUE DESIGN

In order to allow users to interact with 3D virtual objects, we proposed a low-cost AR interactive system based on i-ARToolkit marker, those markers are used for both augmentation and interaction.

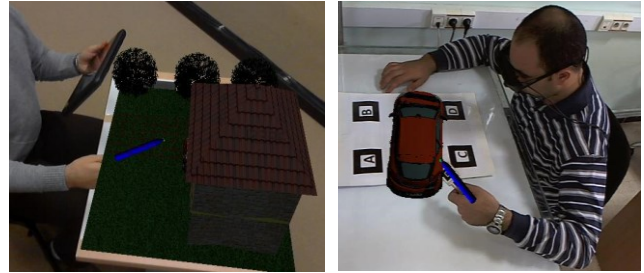


Fig. 1. Proposed interaction technique.

The main contribution of our proposed system is the introduction of “2 in 1” marker. This technique allows the user not just to manipulate 3D object, but also to control application and select manipulation functions from virtual menu by holding just one marker in the hand (Figure 1).

A. Interaction Marker Design

This module allows the user to interact with 3D models of the scene (virtual menu, 3D objects, etc.).

The main idea is to combine two (2) markers in one, where the user can switch between those two markers in order to control the application, or manipulate 3D objects without using any other devices or sensor (Figure 2).

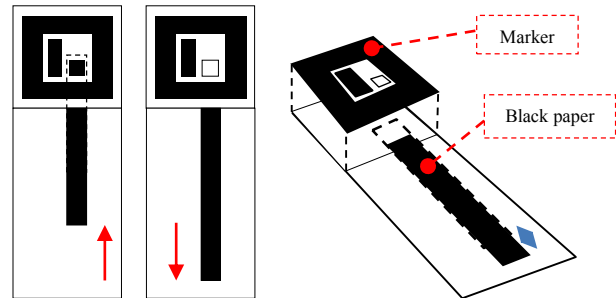


Fig. 2. Interaction markers principle.

As shown in figure 2 above, we have implemented an event, which activated when detecting a switching between markers. In this way, we have reproduced the two functions “MouseDown” and “MouseUp” for the mouse.

By the way, a 3D virtual stylus (figure 3) is added on the interaction markers, like a virtual hand, to guide the user when navigating, and controlling the application. In order to know which mode is selected, the color of the virtual stylus head (the small sphere on the top of the virtual stylus) is changed when switching between the two interaction's markers.

Along this paper, we consider the two modes "Activate mode" and "Inactivate mode" of the interaction marker proposed.

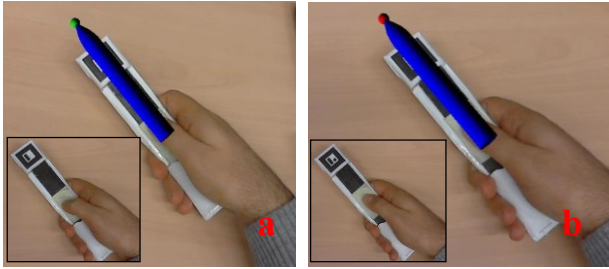


Fig. 3. Virtual stylus added for the two states of markers: a) inactivate mode, b) activate mode.

B. System Control and Manipulation Menu

In order to control the application, a virtual menu (Figure 4) is added on left side of the application. We have implemented two parts for this menu; the first one is to control the application, like select objects button, Wire/Solid button, and Show/Hide button.

The second part of this menu is used for object manipulation, as translating, scaling, or rotating over the three axes (x, y, z).

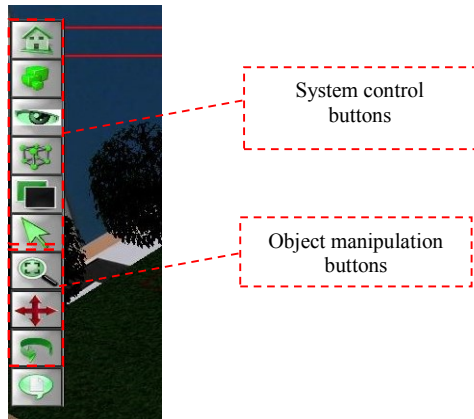


Fig. 4. 3D menu buttons.

To facilitate the interaction with the menu buttons, we applied the ray-casting method to select menu buttons.

Therefore, for every frame, we calculate the interaction stylus 2D position Stylus_2D(x2d, y2d) in the screen coordinate by projecting its 3D position Stylus_3D(x3d, y3d, z3d) on the 2D screen (Equations 1 & 2).

$$x2d = ((x3d / z3d) * Screen_Width) \dots\dots\dots(1)$$

$$y2d = ((y3d / y3d) * Screen_Length) \dots\dots\dots(2)$$

We have added a visual guide to the menu buttons in order to guide the user when performing different tasks. Therefore, in the normal state, all the buttons are in green color. When the stylus moves over such button, it becomes orange, and its name is displayed next to this button. If the user selects a function by switching to the activate mode of the interaction stylus, the color of this button is becoming red (see Figure 5).

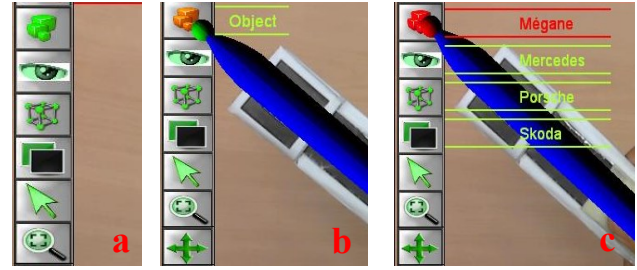


Fig. 5. Different states of the menu buttons: a) normal state, b) moving over state, c) selecting state.

C. 3D Object Manipulation tasks

1) Translating Objects

We have combined the Virtual Hand interaction technique and the Pulling the Rope technique to facilitate object translating (Figure 6). So, when the user moves his hand by holding the Activate Mode, we calculate for every frame the difference in the movement with the last frame for the three axes (x, y, z), and we add this difference to the object 3D position (Equation 3).

$$Object_3D_{x,y,z} = Old_Object_3D_{x,y,z} + (Stylus_3D_{x,y,z} - Old_Stylus_3D_{x,y,z}) \dots\dots\dots(3)$$

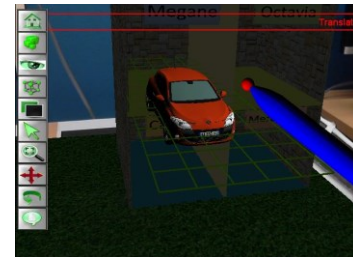


Fig. 6. Translating an object.

2) Rotating Objects

In order to rotate an object, three additional buttons are displayed when selecting the rotate button (Figure 7), to select which axe the user wants to rotate over. After selecting a rotation axe, the user can just move his hand from left to right, to rotate the object.



Fig. 7. Rotating an object.

3) Scaling Objects

As for the rotation task, the user can change the object scale by moving his hand over the x axe (from left to right) (Figure8).

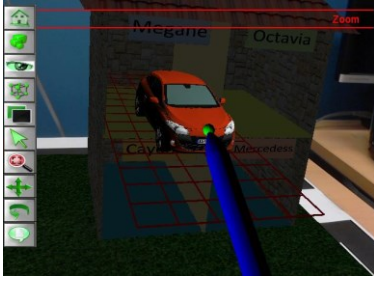


Fig. 8. Scaling an object.

III. EXPERIMENTAL STUDY AND EVALUATIONS

The developed 3D interaction system has been tested by a sample of users to collect a large amount of data needed to evaluate the behavior of the subjects using handled and wearable display devices.

A study has been conducted based on two evaluation aspects: the interaction techniques and the completion of tasks. The interaction techniques are manipulating, rotating and scaling, while the tasks include three experimental scenarios. Furthermore, user expectations and preferences have been measured regarding the speed, accuracy, and ease of use.

We present in the following subsections the experimental framework, methodology, and the results obtained from a statistical analysis of the obtained data.

A. Subjects and devices

The experiment consists of a practical test followed by a questionnaire. The participant was, then, given a detailed description of the developed system. An instructor coached them on how to use the different devices and how to perform interaction operations in the testing environment. After that, each participant trains to practice the three manipulation tasks without assistance and help. After completion of the practical test, they filled out a questionnaire (see Table 1).

TABLE 1. QUESTIONNAIRE FOR SUBJECT

Q1	How do you find 3D manipulations in terms of speed ?
Q2	Do you think that 3D manipulations are accurate?
Q3	How would you rate the 3D interaction technique in usability (ease to use)?
Q4	How much do you rate the intuitiveness of 3D interaction in terms of 3D translation, 3D rotation and scaling?
Q5	Do you think that the display size is sufficient?
Q6	How do you find the amount of information displayed on the screen?
Q7	Is the system comfortable for performing the interaction tasks?
Q8	How you rate the usefulness of the interaction technique in a mixed reality environment?

In this case, we have conducted our experiments with eight (8) subjects ranging from 25 to 45 years. The practical tests were conducted on several devices where the features are given in table 2.

TABLE 2. SPECIFICATION OF HARDWARE COMPONENTS

Device	PcTablet	HMD Stereo	HMD optic
Type	Handled	Wearable	Wearable
Model	MSI WindPad 110W	Vizux Wrap 920AR	Immersion Nvisor ST

Note that we have conducted a preliminary evaluation with only eight (8) subjects in order to demonstrate the feasibility of the approach. In future evaluation we intend to increase the number of the subjects with different level of experience.

B. Implementation

All computations such as the tracking, rendering and 3D interactions with virtual objects are performed on Windows 7 OS for both Pc-tablet and HMD devices. For graphic engine, we have used Direct3D for 3D rendering and scene management.

C. Tests of scenarios

We have built three different scenarios to cover different interaction situations in 3D physical space. According to Bowman [20], we use the basic canonical manipulation tasks “position”, “rotation” and “scaling” for task design. To identify the desired object for manipulation, another task “application control” is defined. This task is composed of two canonical tasks: “selection” and “validation”.

The scenarios are based on the same mixed reality environment. The latter consists of a two-store car park on a green texture ground. For the scene recognition, we have used six identical i-ARToolKit markers. The size of a marker is 20x20cm. The markers have been placed on a tabletop positioned at the center of a room.

All eight subjects completed the three scenarios. Each scenario is composed of a set of canonical tasks.

1) First Scenario - Positioning 3D object in space using visual guide

The user should translate a red car to the garage number 3 on the second floor. The user was assisted by a visual guide (horizontal virtual grid) to precisely insert the red car in correct position in the garage with reduced time (see Figure.9). The virtual grid is, first, in red color. Once, the red car is correctly positioned, the grid becomes green (see destination in Figure 9).

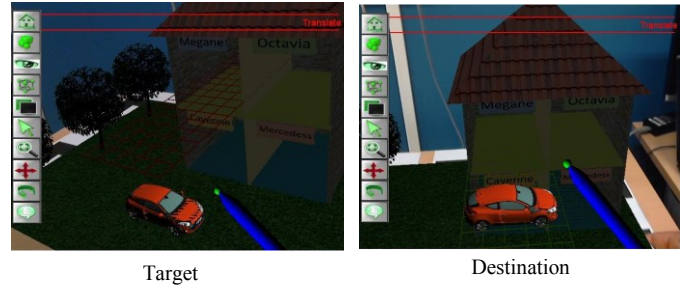


Fig. 9. Positioning 3D object in space using visual guide.

2) Second scenario-Rotating and Positioning 3D object in space

The user should rotate the green car by 90° around its vertical axis and translate it to the garage number 3 on the second floor, (see Figure 10).

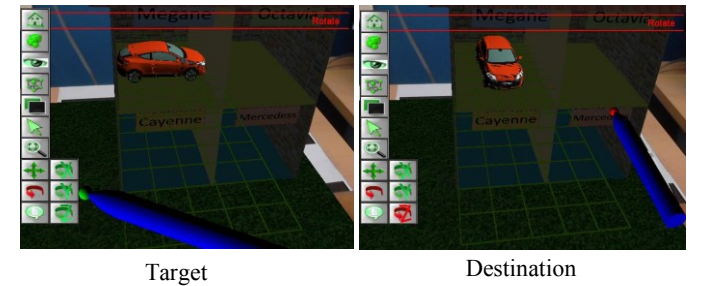


Fig. 10. Rotating and positioning 3D object in space.

3) Third scenario – Scaling, Rotating and Positioning 3D object in space

In this scenario, the user is led to zoom in the grey car and then translate it after rotating, into the garage number 4 on the first floor (see Figure 11).

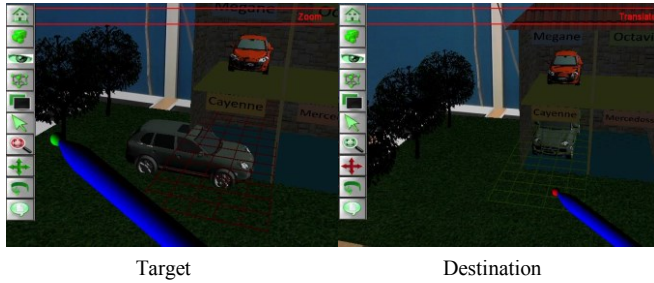


Fig. 11. Scaling and positioning 3D object in space.

D.Results

After performing our experimentations, an evaluation has been conducted on quantitative and qualitative data to study the performance of the 3D technique on the user's behavior. The quantitative data gathered from the questionnaires were analyzed with ANOVA test. This formal method is used in order to study the users' behavior for performing 3D manipulation tasks using two groups of AR devices: HMD and Tablet. The qualitative evaluation is based on a non-parametric analysis based on the questionnaires.

1) Quantitative evaluation

Two aspects have been considered in the quantitative evaluation. The first aspect concerns the evaluation of the 3D technique regarding the subjects' data. The second aspect analyzes the techniques' performance depending on tasks. In this case, two principles criteria have been evaluated: the task completion time and the number of canonical manipulation steps to perform a task. For the two criteria, we have measured the mean value of the eight subjects.

The evaluation of the mean completion time shown in Figure 12 shows some differences for the three devices. The completion of tasks using tablet takes more time than with the two HMD devices. For instance, the mean completion time for the scenario 2 using HMD video and HMD optical are respectively 60s and 72s but for the Tablet the mean completion time it is about 86s.

The same situation has been observed for the scenarios 3 ($t=72s$ for HMD video, $t=84s$ for HMD optical and $t=98$ for Tablet). The participants estimated that it takes more time when handling the device and executing tasks.

Also, we have observed, in Figure 12, that using HMD video, the completion time is reduced compared to HMD optical when performing the scenarios 2 and 3.

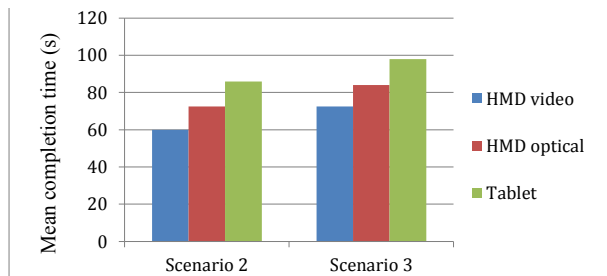


Fig. 12. Mean completion time per second.

The results of the evaluation for the overall mean number of interaction steps showed that users are able to perform manipulations in significantly less steps when using HMD video for the scenario 3 as

illustrated in Figure 12. Here, it has been observed especially, that the difference is in the positioning and scaling tasks. For the scenario 3, the mean number of manipulations μ using HMD video ($\mu = 5$, Standard Deviation: $SD = 1.02$) is lower compared to HMD optical ($\mu = 6$, $SD = 0.8$) and Tablet ($\mu = 7$, $SD = 0.8$).

We have found, also, a significant difference in scenario 1 and scenario 2 between HMD (video and optical) and Tablet for performing the corresponding tasks (see Figure 13). In the same situation, HMD video and optical both present the same performances in terms of interaction steps (example: for scenario 1 ($\mu = 3$, $SD = 0.82$), for scenario 2 ($\mu = 4$, $SD = 1.26$)). Figure 13 shows that there was no difference for the positioning using visual guide and for the positioning and rotation tasks for the wearable devices.

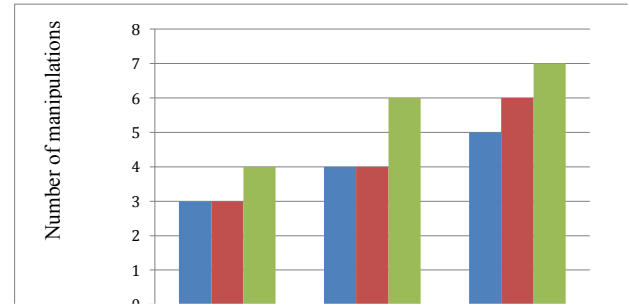


Fig. 13. Mean number of manipulations or steps per scenario

The evaluation of mean number of interaction steps, denotes that the significantly better performance of 3D interaction in the positioning in 3D space task could only be confirmed for the subjects using HMD video and optical. For the positioning & rotation tasks, the subjects achieved better results with wearable devices but less than for the positioning task.

2) Qualitative evaluation

In this evaluation the measure of users' performances have been realized. It is essentially based on the study of the ease of use of the 3D technique, the speed and the accuracy.

This study is based on data collected from the results of the questionnaire. The eight (8) subjects have completed the questionnaire after the tests: this one is composed of eight (8) questions. Participants answer each question with a scale of 1 to 5 (5: strongly agree, 4: agree, 3: average 2: slightly disagree, 1: completely disagree). A "description" field is made available to the participants to give their comments after tests. The same devices have been used during the tests. According to the questionnaire, when answering the questions Q1, Q2 and Q3, the subjects are able to make the canonical 3D interaction tasks (positioning, rotation, selection, scaling) in mixed reality environment, as depicted in Figure 14.

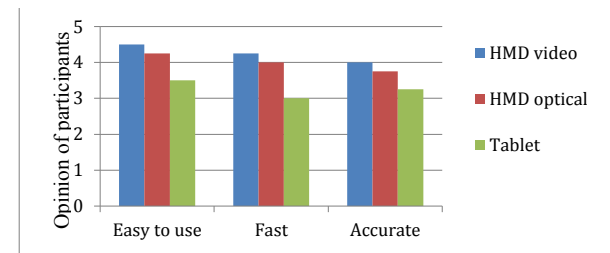


Fig. 14. User's average rating.

Analyzing the qualitative evaluation of ease-of-use, speed and accuracy, grouped by the user's experience, revealed significant better

ratings of 3D interaction in ease-of-use only of the experienced users and the HMD devices compared to Tablet. The participants found more difficulties to make manipulations in space using a tablet. Indeed, the manipulation is realized with one hand since the second one handle the tablet. We noted a difference between the two HMD devices and the Tablet in terms of ease of use. The same difference was deduced for fastness ($F = 5.741$, $p = 0.014$, $ci=95\%$).

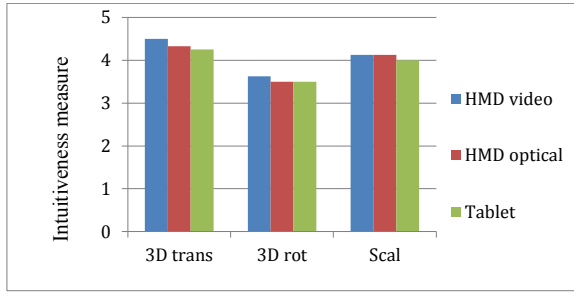


Fig. 15. Users' intuitiveness given in Q4.

In the other hand, it exists a relationship between the accuracy and the device used. Indeed, the accuracy is better when using wearable devices, especially the HMD video. The latter present slightly better performance than HMD optical (see Figure 14).

For question Q4, the participant's intuitiveness ranking of 3D canonical manipulations in terms of 3D translation, 3D rotation and scaling for first, second and third device is shown in Figure 15. When analyzing the intuitiveness of each manipulation, grouped by the users' experience, we observed the device does not influence the intuitiveness of 3D translation ($F = 0.04$, $p = 0.938$, $ci=95\%$), 3D rotation ($F = 0.600$, $p = 0.561$, $ci=95\%$) and scaling ($F = 0.394$, $p = 0.681$, $ci=95\%$).

E. Discussion

Results show that, no significant difference was found for overall mean task completion time, completion time for the positioning tasks, overall user preference or user preferences regarding the positioning tasks when using wearable devices for HMD video and optical. The difference was observed with Tablet that presented less performances using 3D Interaction technique. The intuitiveness is only the aspects not influenced by the type of devices used.

V. CONCLUSION

In this work, we have developed a low-cost 3D interaction technique for MR environments using mobile devices (wearable and handled). Therefore, we intended to reduce the number of devices and software used for designing 3D interaction. Our approach requires only one marker to achieve either 3D manipulations in physical space or application controlling.

The performance study clearly exposed the strengths of the 3D technique when using wearable devices. However, the interaction technique revealed limitations when using handled devices such as a Tablet, here, the users prefer performing 3D object manipulations with touch input approach.

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