Smartphone-Based 3D Navigation Technique for Use in a Museum Exhibit

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***Abstract*—3D Virtual Environment (3DVE) comes up as a good solution for transmitting knowledge in a museum exhibit. However, interaction techniques involved in such settings are mostly based on traditional devices such as keyboard and mouse. Recently, the popular use of smartphone as a personal handled computer lets us envision the use of mobile device as an interaction support with these 3DVE. In this paper, we focus on the navigation task inside a 3DVE and we propose to use the smartphone as a tangible object. Physical actions on the smartphone trigger translations and rotations in the 3DVE. In order to prove the interest in the use of the smartphone, we compare our solution with available solutions: keyboard-mouse and 3D mouse. User experiments confirmed our hypothesis and particularly emphasizes that visitors find our solution more attractive and stimulating.**

Keywords-interaction with smarpthone, 3D navigation, museum exhibit, experiment.

I. INTRODUCTION

With the evolution of technology, computing capabilities and rendering techniques, the use of 3D Virtual Environments (3DVE) is becoming a standard. They are no longer restricted to industrial use and they are now available to the mass-market in various situations: for leisure in video games, to explore a city in Google Earth or in public displays [1], to design a kitchen on a store website or to observe rare or fragile objects in a museum. However, in these mass market contexts, the visitor’s attention must be focused on the content of the message and not distracted by any difficulties caused by the use of a complex interaction technique. This is especially true in a museum where the maximization of the knowledge transfer is the primary goal of an interactive 3D experience. Common devices, such as keyboard and mouse [2] or joystick [3] are therefore widely used in museums. To increase the immersion of the user, solutions combining multiple screens or cave-like devices [4] also exist. However, these solutions are cumbersome, expensive and not widespread.

Alternatively the use of smartphone, as a personal handheld computer, is commonly and largely accepted. Smartphones provide a rich set of features and sensors that can be useful to interact, especially with 3DVE and with remote, shared and large displays. Smartphones also create the opportunity for the simultaneous presence of a private space of interaction and a private space of viewing coupled with a public viewing on another screen. Furthermore, many researches have already been performed with smartphone to study their use for interacting with a computer. They explore multiple aspects such as technological capabilities [5], tactile interaction techniques [6], near or around interaction techniques [7]. Given the potential in terms of interaction support and the availability of smartphones in anyone's pocket, we explore in this paper benefits and limitations of the use of a smartphone for interacting with a 3DVE displayed in a museum context.

This paper is focusing on one task: the navigation inside a 3DVE. This is the most predominant task a user will have to perform in order to discover and understand the virtual space. Concretely our technique translates motions of the smartphone into motions of the point of view in the 3DVE. We thus propose 1) to consider a smartphone as a tangible object, in order to smoothly integrate it in a museum environment and because it has been proven to be easier to apprehend by newcomers [8], 2) to display feedback and/or personalized information on the smartphone display, 3) to deport the display of the 3DVE on a large screen, in order to provide a display space visible by multiple users as required in museum contexts. As a result, our technique combines the use of a popular and personal portable device, the physical space surrounding the device and the user gestures and input for navigating inside a 3DVE.

We compared our designed solution to the use of more common and available technologies: the keyboard-mouse device and a 3D mouse device. We proposed a controlled evaluation focused on the interaction techniques: out of a specific museum context, the user will not be distracted by pedagogical content. We measure usability and attractiveness in conjunction with performance considerations. The results confirm the interest of considering the use of personal mobile devices for navigating inside a 3DVE: results are particularly significant in terms of user attractivity.

In the following sections, we first detail our interaction technique. Next, we present the settings of the user experiment. We finally discuss the results, the place of our solution in the related work and we conclude with perspectives for improving the technique.

II. OUR INTERACTION TECHNIQUE

As described above, our interaction technique is based on the manipulation and use of a smartphone, a familiar and personal object for most of the users. Three major characteristics define our interaction technique: tangible manipulation of the smartphone, personalized data displayed on the smartphone and 3DVE displayed on a remote screen.

 ISBN: 978-1-61208-325-4

We restricted the degrees of freedom of the navigation task in order to be close to human behavior and existing solutions in video game with standard device: two degrees of freedom (DOF) are used for translations (front/back and left/right) and two for rotations (up/down and left/right). We did not include the y-axis translation and the z-axis rotation since they are not commonly used for the navigation task. To identify how to map the tangible use of the smartphone to these DOF, we first performed a guessability study.

A. Guessability study

14 participants have been involved and they were all handling their own smartphone in the right hand. To facilitate the understanding, the guessability study dealt with only one translation and one rotation. A picture of a 3DVE was presented to participants on a vertical support. It included a door on the left of the 3D scene and participants were asked to perform any actions they wished with their smartphone in order to be able to look through the door. A second picture was then displayed: now facing the door, participants were instructed to pass through the door.

In this second question, 11 participants performed hand translations to translate the point of view. Interestingly none suggested using the tactile modality. Results are more contrasted with the first question, requiring a rotation: 5 participants used a heading rotation of the handled smartphone; 1 only used the roll technique; 3 proposed to touch the target with their smartphone; 5 participants placed the smartphone vertically (either in landscape or portrait orientation) and then rotated the smartphone according to the vertical axis (roll) thus preventing the view on the smartphone screen.

B. Design solution

From the guessability study, we retain that physical translations of the smartphone seem to be the most direct way to perform translations of the point of view in the 3DVE. It has been implemented in our technique as follow. Bringing the smartphone to the left / right / front or back of its initial position triggers a corresponding shifting movement of the point of view in the 3DVE (Figure 1-a). The position of the point of view is thus controlled through a rate control approach; the rate applied is always the same and constant. In addition, feedback is provided on the smartphone. A large circle represents the initial position of the smartphone and the physical area in which no action will be triggered: the neutral zone. A small circle represents the current position of the smartphone and arrows express the action triggered in the 3DVE. As long as the small circle is inside the large circle, the navigation in the 3DVE is not activated. In addition it is possible to combine front / back translation with right / left translation. The feedback provided during each of four possible motions is illustrated in Figure 1-b. Finally, the smartphone vibrates every time that the navigation action is changed.

Regarding rotations, we retain from the guessability study the most usable solution: rotations of the hand-wrist handling the smartphone are mapped to orientations of the point of view in the 3DVE. In our implementation, horizontal wrist rotations to the left/right of the arm are mapped to left/right rotations of the viewpoint (heading axis, rY) and wrist rotations above/below the arm are mapped to up/down rotations of the viewpoint (pitch axis, rX) (Figure 1-c). A position control approach has been adopted here that establishes a direct coupling of the wrist angle with the point of view orientation. A constant gain has been set for the wrist rotations: the limited range of 10° to left and right [9] can be used to cover the range of the rotation angle inside the 3DVE (180°). This solution does not support a U-turn: this was not required in the experiment but could be solved by transforming the position control into a rate control when the wrist reaches a certain angle. In addition, two "spirit levels" feedback are displayed on the smartphone to provide an estimation of the current orientations of the smartphone (Figure 1-d) with respect to the initial orientations used as a reference.

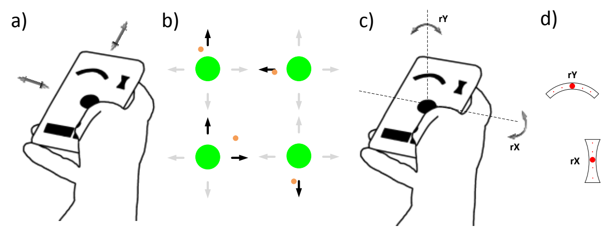

Figure 1: Our smartphone based interaction. (a) Physical action for translation. (b) Feedback of the translation: front, left, front and right, back translation. (c) Physical action for rotation. (d) Feedback of the rotation.

To avoid unintended motions of the virtual camera in the 3DVE, translations and rotations of the smartphone are applied to the 3DVE only when the user is pressing a button "navigate" displayed on the smartphone.

The smartphone also displays a "calibrate" button. This allows the user to recalibrate the smartphone at will, i.e., to reset the center of the neutral zone to the current position of the smartphone and the reference orientations.

III. Experiment

We conducted an experiment to compare our smartphone-based interaction technique with two other techniques using devices available in museums: a keyboard-mouse combination and a 3D mouse. In the museum context, the temporal performances are not predominant. In fact our goal was to assess and compare the usability and attractiveness of these three techniques. Our protocol does not include museum information in order to keep the participant focused on the interaction task.

A. Task

The task consisted in navigating inside a 3D tunnel composed by linear segments ending in a door (Figure 2-b). The task is similar to the one presented in [10] and sufficiently generic to correctly evaluate the interaction techniques. Participants had to go through the segments and go across the doors but could not get out of the tunnel. Black arrows on the wall allow finding easily the direction of the next door. The segments between the doors formed the tunnel, whose orientation was randomly generated in order to include all 25 possible directions to the next door. The center of each door is placed 0, 20 or 40 pixels to the left or right and to the top

 ISBN: 978-1-61208-325-4

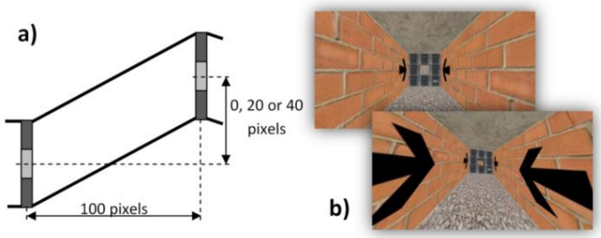

Figure 2. (a) Representation of one segment of the 3D tunnel. (b) Screenshots of the 3D environment of the experiment.

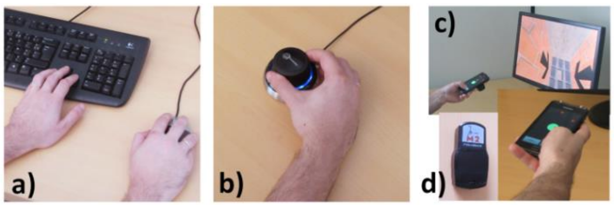

Figure 3. (a) The keyboard-mouse, (b) The 3D mouse and (c) the smartphone configuration. (d) The Polhemus sensor.

or bottom of the center of the previous door (Figure 2-a). The movement of the user is not subject to gravity. When the user looks up and starts a front translation movement, the resulting motion is a translation in the direction of point targeted.

B. *Interaction techniques*

We compared three techniques: keyboard-mouse, 3D mouse and our technique based on a smartphone. In keyboard-mouse, movements of the mouse control the 2 DOF point of view of the virtual camera (orientation). The four directional arrow of the keyboard control the 2 DOF of the translation of the virtual camera. In 3D mouse, the participant applies lateral forces onto the device to control translation (right/left, front/back), and rotational forces to control orientations of the virtual camera. The use of our technique, the smartphone, has been described in section II. For the three techniques, it appears that left/right translations are particularly useful when collision with doors occurs.

For each technique we determined the speed gain of the translation and rotation tasks through a pre-experiment with six subjects. We asked participants to navigate inside our 3D virtual environment with each technique and to freely adjust the gains to feel comfortable performing the task. We stopped the experiment and recorded the settings when the participant successfully went through 5 consecutive doors. Finally, for each technique, we averaged the values of gain between participants. We noticed that the gain of the translation of keyboard-mouse was higher than the 3D mouse or smartphone. This is probably due to the habit of subjects to manipulate this technique.

C. *Apparatus*

The experiment was done in full-screen mode on a 24″ monitor with a resolution of 1920 by 1080 pixels. We developed the environment with a 3D open source engine, Irrlicht, in C++. For the keyboard and mouse device, we used a conventional optical mouse and a standard keyboard with 180 keys (Figure 3-a). For the 3D mouse we used the Space-Navigator [11] (Figure 3-b), a commercial device with 6 DOF. For the smartphone, we implemented the technique on a Samsung Galaxy S2 running Android 4.1.2 (Figure 3-c). To avoid an overload of the smartphone computing capabilities with the processing of the internal sensors (accelerometers, gyroscope) we used an external 6D tracker: the Polhemus Patriot Wireless (Figure 3-d). We attached a sensor on the rear face of the smartphone. Via a driver written in C++, the marker returns the position and the orientation of the smart-phone. We filtered the data noise with the 1€ filter [12].

D. *Participants and procedure*

We recruited a group of 24 subjects (6 female), of 29.3 (SD=9) years old on average. All subjects were familiar with the keyboard and mouse, 17 of them had a smartphone and only 1 has used the 3D mouse.

Every participant performed the 3 techniques (smartphone, keyboard-mouse and 3D mouse). They started with the keyboard-mouse technique in order to be used as a reference. The order of smartphone and 3D mouse techniques was counterbalanced to limit the effect of learning, fatigue and concentration. For each technique, the subject navigated inside 6 different itineraries. We counterbalanced the itineraries associated with each technique across participants so that each technique was used repeatedly with each group of users.

Participants were sited during the experiment and were instructed to optimize the path, i.e., the distance travelled. They could train themselves on each technique through one itinerary. When the user passed through a door, a positive beep was played. When the user collided with an edge of the tunnel, a negative beep was played.

After having completed the six trials for one technique, the subject filled the SUS [13] and AttrakDiff [14] questionnaires and indicated three positive and negative aspects of the technique. The procedure is repeated for the two remaining technique. The experiment ended with a short interview to collect oral feedback. The overall duration of the experiment was about 1 hour and 30 minutes per participant.

E. *Collected data*

In addition to the SUS and AttrakDiff questionnaires filled after each technique to measure usability and attractiveness, we also asked for a ranking of the three interaction techniques in terms of preferences. From a quantitative point of view we measured the traveled distance and the number of collisions.

IV. RESULTS

We present in the following section quantitative and qualitative results obtained.

A. *Quantitative results*

First a Kruskal-Wallis test confirmed that none of the 18 randomly chosen itineraries had an influence on the collected results. On average we observed that the travelled distance is the smallest with the keyboard-mouse (2766*px*, SD = 79), followed by the 3D mouse (2881*px*, SD = 125) and the smartphone (2996*px*, SD = 225). According to a Wilcoxon test these differences are significant. The same conclusions

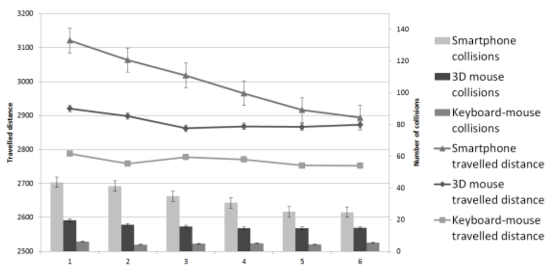

Figure 4: Evolution of the travelled distance and the amount of collisions according to 6 trials of the subjects

Figure 5: Portfolio generated on the AttrakDiff website

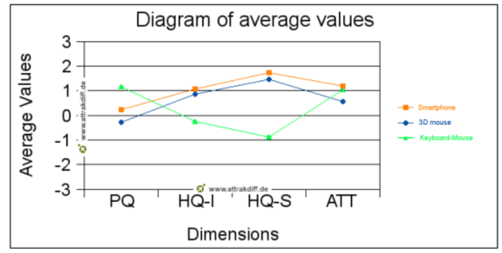

Figure 6: Average values for the four dimensions of the AttrakDiff questionnaire

can be drawn with regard to the amount of collisions (keyboard-mouse: 5.08, SD = 5.68; 3D mouse: 16.11, SD = 15.86; smartphone: 33.35, SD = 24.64).

Given the high dispersion of the distance and collision measures, we refined this analysis in distinguishing the results obtained for each of the six trials performed by the 24 participants (Figure 4). This refined analysis reveals a significant learning effect with the smartphone technique: between the first and sixth trial, the distance is 7.3% shorter (Wilcoxon test, $p = 6 \times 10^{-6}$) and collision are reduced of 43.3% (Wilcoxon test, $p = 2 \times 10^{-4}$). A significant learning effect is also observed with the 3D mouse, but only in terms of distance and with a smaller improvement (1.6% shorter, Wilcoxon test, $p = 0.049$).

The learning effect with the smartphone is so important that, at the last trial, the travelled distance for the smartphone (2893*px*) and the 3D mouse (2873*px*) is comparable (no significant difference, Wilcoxon test, $p = 0.49$).

B. Qualitative results

Three aspects have been considered in the qualitative evaluation: usability, attractiveness and user's preference.

Usability evaluation: the SUS questionnaire [13] gives an average score of 82.60 (SD=12.90) for the keyboard-mouse, 54.79 (SD=22.47) for the smartphone based interaction and 53.54 (SD=27.97) for the 3D mouse. A Wilcoxon test shows that the SUS difference is statistically significant between the keyboard-mouse and each of the two other techniques (3D mouse, smartphone). However, the SUS difference is not statically significant between the 3D mouse and the smartphone. Research conducted on the interpretation of the SUS score [15] permits to classify the usability of the keyboard-mouse as "excellent". According to this same interpretation scale, the usability of the smartphone and the 3D mouse is identified as "ok".

We also note a wide dispersion of the SUS score. We thus performed a more detailed analysis of the SUS score. First, according to [15] a system with a "good" usability must obtain a score above 70. In our experiment, 33% of participants scored the 3D mouse above 70 while 37% of participants scored the smartphone above 70. Second, 3D mouse and smartphone were two techniques unfamiliar to the participants. Results of the SUS questionnaire shows that when the smartphone is used after the 3D mouse, the average score for the smartphone is 65.62 whereas in the other order the average score is 43.96. The perceived usability of the two unfamiliar techniques is therefore lower than the perceived usability of the keyboard-mouse. However, once the participants have manipulated these two unfamiliar techniques, the perceived usability of the smartphone increases drastically.

Attractiveness: Data collected using AttrakDiff [16] give an idea of the attractiveness of the technique and how it is experienced. Attrakdiff supports the evaluation of a system according to four distinct dimensions: the pragmatic quality (PQ: product usability, indicates if the users could achieve their goals using it); the hedonic quality – stimulation (HQ-S: determine to which extent the product can support the need in terms of novel, interesting and stimulating functions, contents and interaction); the hedonic quality – identity (HQ-I: indicates to what extend the product allows the user to identity with it); the attractiveness (ATT: global values of the product based on the quality perception).

Figure 5 shows a portfolio of average value of the PQ and the HQ (HQ-S+HQ-I) for the three interaction techniques assessed in our user experiment.

The keyboard-mouse was rated as "fairly practice-oriented", i.e., one of the first levels in the category "task-oriented". According to the website report [16], the average value of PQ (above 1) indicates that there is *definite* room of improvement in terms of usability. The average value of HQ obtained (approx. -1) expresses that there is *clearly* room for improvement in terms of user's stimulation. The 3D mouse was rated as "fairly self-oriented", i.e., one of the first levels in the category "self- oriented". The average value of PQ (approx. 0) expresses that there is room for improvement in terms of usability. The average value of HQ obtained (approx. 1) expresses that room for improvement also *exists* in terms of user's stimulation. The smartphone was rated as "self-oriented". The average value of PQ (approx. 0) expresses that there is room for improvement in terms of usability. The average value of HQ obtained (above 1) expresses that the user identifies with the product and is motivated and stimulated by it.

Figure 6 summarizes the average values for the four AttrakDiff dimensions of the three interaction techniques. With regards to the four dimensions the smartphone is rated higher than the 3D mouse and the differences are statistically significant (T-test, $p<0.05$). For the PQ value the keyboard-mouse is better than the smartphone (statistically significant, $p<0.05$). For HQ-I and HQ-S values the smartphone is better than the keyboard-mouse (statistically significant, $p<0.05$).

In terms of ATT, smartphone is again rated higher than keyboard-mouse but the difference is however not statistically significant (p>0.05). Compared to the keyboard-mouse, the smartphone is considered as novel, innovative, inventive, stylish and creative. Improvements in term of simplicity, straightforwardness or predictability could increase the average value of PQ and probably increase even more the ATT value of the smartphone.

User preference: at the end of the experiment a short semi-guided interview was performed. Participants were first asked to rank the three techniques from 1 (best) to 3 (worst). Results are in line with the SUS scores: the keyboard-mouse technique is largely preferred and the 3D mouse is by far the least appreciated technique: only 2 participants out of 24 ranked it as the best, and 14 ranked it as the worst. The smartphone based-interaction is ranked uniformly in the three places (7, 9, 8).

Finally, three positive points and three negative points were asked for each technique. The most frequently mentioned positive points are “quick”, “easy” and “accurate” for the keyboard-mouse technique, “intuitive”, “novel” and “usable with on hand” for the 3D mouse and “immersive”, “funny”, and “accessible to everybody” for the smartphone. Participants are thus appreciating the conditions of use created by the smartphone while they particularly pinpoint the effectiveness of the mouse and provide general comments about the 3D mouse.

The most frequently mentioned negative aspects is a practical aspect for the keyboard-mouse (“requires the use of both hands”). They are related to the effectiveness of use of the 3D mouse (“difficulty to combine translation and rotation at the same time”, “lack of precision” and “high need for concentration”) and for the smartphone it focuses on one specific feature (“difficulty to translate to the left or right”) and the overall context of use (“the apparent time of learning” and “the fatigue caused in the arm”).

Technical issues for the 3D mouse and effectiveness of the keyboard-mouse are thus highlighted while benefits and limits related to the interactive experience are mentioned for the smartphone. This clear shift of interest between the three techniques reveals that the disappointing performances of the smartphone highlighted in the previous section are not totally overruling the interest of the participants for the smartphone-based technique. It is therefore a very interesting proof of interest for further exploring the use of smartphone in 3DVE.

V. DISCUSSION

Among the existing attempts for exploring the navigation of 3DVE with a smartphone, two different settings exist. A first set of solutions, as opposed to our setting, propose to display the 3DVE directly on the smartphone. Different techniques are explored to change the point of view inside the 3D scene: tactile screen like Navidget [17], integrated sensor [18], smartphone motions in the space around a reference, as Chameleon technique [19] and T(ether) [20] and manipulation of physical objects around the smartphone [21]. The second set of solutions avoids issues related to occlusion of the 3DVE with fingers by displaying the 3DVE on a distant screen. These solutions involved integrated sensor [22] to detect user’s motions, tactile screen [23] or a combination of both [24]. Although our technique is clearly in line with this second set of solutions, our use of the smartphone presents three major originalities. Firstly, the smartphone is not limited to a remote controller: it is also used to provide the user with feedback or personalized information. Secondly, using tactile interaction to support the navigation would occlude part of the screen and prevent its use for visualizing data, selecting objects or clicking on additional features. Instead, physical gesture are applied to the smartphone to control rotations like in [25] or [24] but also to control translations of the point of view in the 3DVE. Thirdly, the choice of the gestures to apply has been guided by the results of a guessability study that highlight the most probable gesture users would perform with a smartphone. We used this approach rather than a pre-experiment or results of existing experiment [24] because when getting familiar with the manipulation of smartphone, universal gestures will be adopted, and not necessarily those known as the most efficient. User’s prime intuition of use looked more important to us.

Beyond the interaction technique designed, the contribution includes a set of evaluation results. The user experiment revealed a significant learning effect with the smartphone. This is a very encouraging result because no learning effect was observed with keyboard-mouse and 3D mouse although the participants were unfamiliar with 3D mouse and smartphone: the use of smartphone thus significantly improves over the time. Results also revealed that the use of our smartphone based technique to navigate inside a 3DVE is more attractive and stimulating than more usual technique such as the keyboard-mouse and the 3D mouse. In terms of usability, user's preferences (interaction technique ranking) and quantitatively (travelled distance and amount of collisions) our smartphone technique appears to be weaker than the keyboard-mouse technique but similar to the 3D mouse. This tradeoff between attractivity and usability /performance emphasizes that compared to two manufactured devices, our technique is better accepted but weaker in performance and usability. This is particularly encouraging because technological improvements of our technique, such as mixing the use of integrated sensor with image processing to compute more robust and accurate smartphone position and orientation, will also increase the user's performance. In addition the use of smartphone is already widely spread and we believe that their use as an interaction support with remote application will develop as well and become a usual interaction form. Altogether this user experiment establishes that the use of smartphone to interact with 3DVE is very promising and need to be further explored.

Finally, to validate the interest of the approach in an operational context, the presented smartphone technique is currently running in an animated 3DVE representing a large telescope. The interactive installation (Figure 7) is used in a museum to explain the different parts of the telescope and how the telescope is operated. Visitors virtually navigate in the dome of the telescope to observe the different elements and perform complementary actions such as selecting a star or controlling the telescope. A large and varied audience,

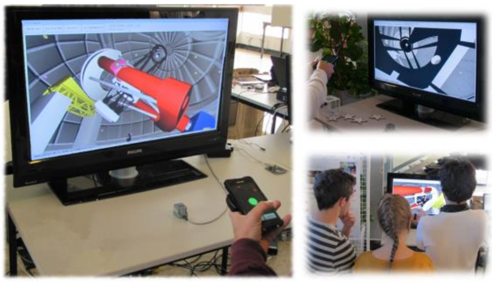

Figure 7: Interactive installation with our smartphone based interaction

ranging from scholar to retired persons, are using this interactive installation. An in-situ evaluation of the use of the technique in comparison to other will soon be performed.

VI. CONCLUSION

In this paper, we explored the feasibility of using a smartphone to navigate inside a 3DVE displayed in the context of a museum exhibit. Smartphones present the advantage to provide a private space for viewing and to constitute a personal device for navigating or controlling a 3D cultural or pedagogical content. Generalizing its use throughout a museum is also completely imaginable. With a QR code the visitor can easily download the mobile app in front of the exhibit and interact with the 3DVE. The originality of our technique relies on the fact that the smartphone is used as a tangible object. Physical actions on the smartphone trigger translation and rotation in the 3DVE. Very promising results have been highlighted in a user experiment comparing our solution to a keyboard-mouse technique and a 3D mouse, the most common devices found in museum nowadays. We measured that after a short learning time, the smartphone technique leads to performance results that are comparable to the 3D mouse. Through technical optimization we are also confident that it might become comparable to the keyboard-mouse technique. But more notably, we clearly established that visitors find such a solution more attractive and stimulating.

In this study, we have therefore established that the use of a smartphone as a tangible object for navigating inside a 3DVE is a good alternative to the keyboard-mouse and 3D mouse. A part from the technical improvements already mentioned we plan to investigate the causes and length of the learning effect. To complete our study, it could be interesting to measure the impact of the use of a smartphone on the museum visit and on the quality of the educational transfer. Finally, using a hand free interaction with the smartphone for navigating inside a 3DVE opens up perspectives for controlling additional features in the 3DVE with the smartphone that we will integrate.

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