In-Place Natural and Effortless Navigation for Large Industrial Scenarios

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Abstract. Here we address the problem of navigating in virtual environments with fixed display visualizations (e.g. projections and tvs) by using natural gestures. Gesture metaphors have proven to be a powerful tool for human computer interaction. Examples arise from smartphones to state of the art projects like the Holodesk (from Microsoft Research). However, regarding the use of gestures for navigation in virtual environments, a specific limitation arises in respect to the user movimentation in the real space. The gestures should provide the user a way of turning the virtual camera direction without losing the view of the screen. Moreover, the user must be able to move long distances in the virtual environment without trespassing real world boundaries and without becoming fatigued.

Keywords: natural interaction, in-place navigation, body gestures.

1 Introduction

Navigation is a common task related to 3D content in which the user is able to move and rotate the virtual camera in order to explore a virtual environment. In most scenarios the navigation interaction occurs through regular devices such as keyboard, mouse and joysticks. Alternatively, considering the system is able to interpret body and hand gestures, the interaction can be designed to be more natural and user friendly.

Navigating through a virtual scenario is an important task in industry. It can be used in training for critical situations where manipulation errors can be fatal while performing visualization tasks in remote areas such as an oil reserve in deep sea, or even to explore possible dangerous areas in electrical substations. This work focused on the domain of electrical substations and proposing a simple path following task in order to make the user perform the correct use of the substation space, without trespassing dangerous areas. The case study definition aims to start an investigation directed to the specific domain of training activities

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on electrical substations. Moreover, the chosen substation scenario provides a controlled static and planar environment, with no stairs, lifts or other vertical navigation possibility. This way, the case study is more controlled and focus specifically on the tasks of moving and rotating the virtual camera horizontally.

Navigation can be done from a computer using a mouse and keyboard, but those devices provides a limited experience. The use of more immersive environments as projectors or a CAVE along with gesture recognition for interaction can improve this experience, increasing the degrees of freedom in manipulation tasks and giving new capabilities as speed, zoom in & out and visualisation. But each new capability given to the user implies the problem of informing the user on how to command the system and trigger the features. Gestural solutions based on computer vision devices are an attractive solution for capturing user commands and propose natural ways for the users to understand and acquire experience on the use of an interface. Gloves and wearable devices gives place to depth sensors as the Microsoft Kinect, helping users to perform commands in 3D immersive environments using body gestures. Regardless the available tracking and recognition solutions, there is a challenge on searching and understanding the relevant gesture aspects for the user in order to interact with a given scenario in specifics domains.

Although the use of natural gestures to interact appears to be a good alternative, since we do it all the time when manipulating objects and even when speaking, it may be tiresome if the gesture is used long enough. Furthermore, besides the physical tiredness, there is also the cognitive effort, elevadori.e., the gesture may be hard to associate to the command and so it requires the users to keep trying to remember what they should do instead of just doing it. These problems have also to be taken into account when proposing navigation gestures.

1.1 Navigation Design

We have generated, elected and prototyped several navigation metaphors, based essentially on travel, maneuvering and wayfinding legacy techniques [3]. Brainstorm sessions were conducted for the development of virtual environments and the proposed gestures. The main goal of the proposed work, rather than create a specific gesture set, is to gather insight about the navigation experience regarding the naturalness and effort cost. Additionally, we also prototyped state of the art navigation techniques for later performance and experience comparisons. Moreover, we give users the chance to develop their own gesture metaphors to create opportunity for new ideas as well as understand which aspects are preferred and reproduced by the users.

1.2 Wizard of Oz and Gesture Interaction

The navigation design proposed in this work is concerned but not limited to nowadays available tracking and gesture recognition technologies. The main goal of this research is to deeply study the naturalness and effort impact on navigation. During the conceptuation of the targeted gestures some showed to be not

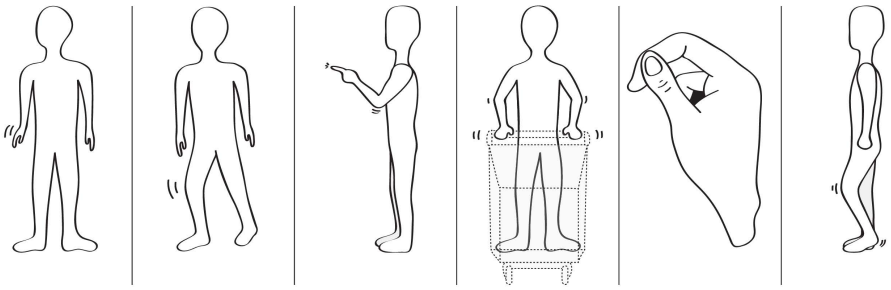

Fig. 1. Examples of the prototyped gestures: Hand as Joystick, Equilibrium, Taxi Driver, Supermarket Cart, Thumb-based, Tapping-in-Place, respectively, from left to right

recognizable by accessible devices and algorithms. And despite of good performance on recognizing users movements, the computer vision systems available cant capture discrete and fine gestures that could enrich the user interaction propositions. In these cases, the prototyping was performed using the Wizard of Oz.

The Wizard of Oz technique is well-known for its power in replacing not implemented features of the system by human actuators. Although it is usually used for more turn-based interactions such as voice interfaces [10], some recent works showed its application for gesture-based interfaces [7] and we intend to apply it in a more continuous action/reaction interaction. The Wizard technique assists the participatory design strategy that allows the user to create and perform travel commands in real-time thanks to trained operators.

As a prior step, an iterative process of wizards training and evaluation was conducted. The evaluation concerned about response time and false-positive and false-negative errors. Additionally the wizard performance was compared to common gesture recognition solutions such as the Microsoft Kinect. Once we validated the Wizard of Oz prototyping, the user experiment was conducted.

This work is structured as follows. Section two discusses the main related works. Section three defines the proposed experiment. Section four explains the used gestures and which aspects are analyzed. Section five presents the experiment results and finally section six exposes the main conclusions and future worlds.

2 Related Work

2.1 Gesture Navigation

Several VE locomotion metaphors do not require the user to walk [2], such as Drag'n Go [11], Tapping-in-Place [12] and Walking in a cube [5]. In the Drag'n Go metaphor, users select a target and move along a path from themselves to the target position. After choosing the target point, navigation is performed by

simply moving a slider. This technique extends the Point of Interest (POI) approach by controlling both targets position and velocity with the slider. Walking in Place (WIP) mimics the act of walking without leaving the current position [5]. Tapping-in-Place extends WIP by reducing effort and improving the naturalness of performing the act of marching. With this technique, the user can navigate by alternately lifting his/her heel without losing contact to the ground, rather than moving the entire leg.

Usually, the real space available for performing the interaction limits the amount of walking that can be done: after performing a few steps the user finds a nearby obstacle [5]. Walking in a Cube proposed three techniques for real obstacle collision avoidance, since this is a common problem related to CAVE-like environments. The basis for the proposed techniques was the Magic Barrier Tape (MBT) combined to WIP. The first one, the Constrained Wand metaphor, uses alert signals to indicate whether the user is too close to a real obstacle and allows navigation with a physical wand. Using the second technique, the Extended Magic Barrier, whenever the user is too close to an obstacle, he/she pushes a virtual barrier that moves along the direction of users head and hands (pulling back the hands maps rotations). The third one, Virtual Companion, lets the user guide a bird through a rein. The bird animations alerts the proximity to real world boundaries. The navigation is then performed by mimicking gestures such as the ones used to for riding a horse.

2.2 Participatory Design

To explore natural manners on how users interact with the 3D virtual environment and to encourage them to interact naturally with the system, we choose an empirical design strategy based on user-defined gestures and participatory design. These iterative design processes were adopted in many researches in HCI [4] [7] in which the user is free to propose gestures for a given set of tasks. This method is used to elicit tacit knowledge and to investigate interaction on novel technology collecting relevant gestures from the participants in the real context of use. Participatory strategies are a direct consequence of user involvement in design processes such as user-centered design in which the the user takes part in the project steps in an iterative development from ideation to prototyping.

The User-defined gesture method is described in [15], who presents ways to evoke natural gestures in tabletop devices applications. The user-defined gestures process is also defined in [8], where the authors measure the memorization of gestures created by users for 3D interfaces. [13] proposes the use of this eliciting method to search natural gestures for commands that uses the motion sensors of mobile phones. Finally [1] describe the use of Wizards associated with the collecting of gesture proposed by users for the selection of neuronal pathways in 3D brain representations. We have adapted the process in an hybrid task analysis method where the user is initially free to propose the gestures for navigation commands in the 3D scenes and then is asked to perform the tasks with the gestures that are domain-specific to the context previously chosen. He is helped and oriented by the wizards who are trained operators that reacts in real time to

the gestures proposed and accomplished by the participant of the evaluation. At the end of the experiment the user is asked to create or review his/her gesture proposals from the beginning of the experiment and the changes are recorded for further analysis.

2.3 Tracking and Gesture Recognition

An option to improve the recognition of the gestures and therefore the accuracy of the interaction response is to use the tracking technologies such as the one presented on [9]. This research does not present new navigation techniques, however, the resulting device is able to track hands configuration with a good time response and precision. Navigation tests to evaluate accuracy and function were performed using gestures such as pinch-to-zoom.

Wei et at. [14] developed a full body motion tracking system based solely on monocular depth images. By combining 3D tracking with 3D pose detection, they managed to automate the entire process of body tracking. Their results are not only more reliable, but also less susceptible to errors than the ones from Microsoft Kinect SDK.

In order to push further body tracking accuracy, Helten et al. [6] makes use of a sensor fusion approach that succeeds when the monocular depth camera provides insufficient information. The framework developed uses information from six IMUs (inertial measurement units) attached to the user (head, trunk, forearms and lower legs) along with the depth data from Kinect.

3 Experiment

The primary purpose of this study was to understand which aspects of a could contribute to propose guidelines more natural and effortless navigation on virtual scenarios. For this we conducted an experiment aiming to stimulate people to interact with a virtual environment using body gestures. Thereunto, a creative session was conducted, in which the participants were encouraged to generate their own gestures. In the following session users experienced predetermined gestures. After the users had experienced these steps, they could suggest another set of gestures based on their experience. The goal of this task was to allow the participants to create final gestures after they used the set of movements previously generated. The premise was that the participants could have their cognitive repertoire augmented after the second session, increasing their creativity.

We have collected quantitative data from a Likert questionnaire performed after each task. The users scored statements about some usability aspects. The qualitative questions regarding user experience were collected using a semi-structured interview. Through our analysis, we could also observe which body parts were involved in each type of movement performed by the participants. Such information allowed us to associate which movements could be considered more natural and effortless for each situation. The followed path and the time consumed by each one were analysed, in order to compare the proposed gestures.

3.1 Participants

Ten participants (nine males and one female) aged from 21 to 40, all from the Informatics Center of UFPE, took part in this experiment and were rewarded with sweets after completion. Two of them were left-handed. None had motor disabilities. Only one subject had no experience with virtual reality, eight had some and one was high experienced. Five subjects had a lot of experience with 3D games while five had some. Four of them were very familiar to gesture controlled games, the other six of them were not that familiar but have used it at least once.The mean experiment time per subject was one hour, this includes going through introduction to the experiment, pre-questionnaire, warm up, instructions and the six experiments while attending to a questionnaire after each performed gesture.

3.2 Setup

The experiments were conducted in a room that had space for the users to perform their gestures freely without hitting any walls or equipment. There was a projector for a more immersive experience, a webcam that recorded the user for further analysis, and a notebook equipped with a Intel i7 2.3GHz processor, 8GB of RAM and a GeForce GTX 670M graphics card. Also, three people were conducting the experiments, two of them (the wizards) responsible for simulating the gestures recognition and one to guide the experiment and explain the gestures to the user. The wizards were looking to the user through a mirror; this way it was easier to correlate the gestures and do not make mistakes as pressing the right key whenever it was supposed to be left, and also, that way, the user did not feel like someone was staring at him / her all the time.

3.3 Scenario

The experiment focused on the engineering training process of electrical substations. A 3D model was used and a path of colored balls was inserted to guide navigation. In such scenarios the user must navigate long distances from one point to another. There are path restrictions due to electrical properties of the equipments, which require precision during navigation. Additionally, real-world electrical substations are a dangerous environment for employees without experience. This way virtual navigation can help the training process.

3.4 Procedure

Before initiating the experiment, the participants filled an initial profile questionnaire. Second, an overview of the study was presented. After that, we stimulated them to warm up themselves to avoid fatigue and muscle strains.

After each navigation task the users answered a Likert questionnaire to evaluate it. They applied a score between 1 and 5 (1 = "I completely disagree" and 5 "I completely agree") to 8 statements about some criteria, which were:

Accuracy; Velocity; Ease of Use; Sensation of Walking; Tiredness; Enjoyable Interaction; Security in Physical Space and Screen View Obstruction. Being the first two related to the response of the Wizards.

The first task was to idealize and test three sets of gestures for navigation in the virtual environment (walk forward / backward / left / right and rotate left / right or a subset of these that they judged necessary for navigation). At first, they were stimulated to interact with the virtual scenario using the gestures they created as it was more natural for them. Next, we asked them how they could make the navigation more effortless. Finally, they could use a swivel chair, and they were also allowed use the chair as a tool (e.g. using its rotation properties). We had hence three sets of gestures, generated by the users themselves, that helped us to understand which parts of the body are commonly used when they were requested to perform navigation.

In the second task we asked the participants to use three sets of predetermined gestures. These three gestures were chosen between a set of six defined by us. The proposed gestures were demonstrated to the user and it was shown how the system should respond to it. Also, it was explained that now there was a path to be followed, composed of blue and red balls to guide through the electrical substation. By gathering information about the time taken to complete the given task and the path the user traced through the scenario, it was possible to extract quantitative data to analyse the performance of each set of gestures.

After these steps, the participants answered which gestures were better to perform each action (forward, back, left and right sides), and hence, they could suggest a final set of gestures that was also evaluated by the questionnaire. Finally, the users took part in a semi-structured interview that allowed us to collect qualitative data about the user experience.

4 Gestures Sets

After reviewing previously proposed methods for enabling intuitive, effortless and natural locomotion through virtual environments, we had two brainstorming sessions for inspiring us to create novel metaphors using different parts of the body. Each session took about one hour and was performed by 6 people. As a result, 54 alternatives were generated, and hence, 6 novel gestures were selected and will be further detailed as follows.

The first metaphor, named Hand as Joystick, was inspired by the use of an ordinary Joystick where the user could navigate forward, backward and rotate to the left and right using a single digital directional part of the joystick. In the metaphor, with one of the hands, the user signalled ahead to move forward and signalled sideways to rotate. For continuous interaction, the user should maintain the gesture for the duration of the desired action.

The second set of gestures, called Equilibrium, benefits from users gravity center for indicating the direction, forward or backward, along with the rotation movement of shoulders to indicate the rotation side. As the previous one, the user should maintain the gestures for keep moving.

In order to mimic real-world gestures, the third metaphor was based on the way instructions are given to a Taxi Driver, which also gives the metaphor name. By pointing forward just once the user moves ahead; by showing an open hand, the movement stops. Pointing while maintaining to the right or left rotates the virtual camera. This gesture employs a trigger based interaction, minimizing the effort on the continued walking forward activity.

Still metaphorizing real-world gestures, the next set imitates the activity of guiding a supermarket cart. By slightly stretching arms forward, the user pulls the invisible cart and then walks forward; to keep walking and turning to one of the sides, must retract one arm a bit, and by retracting the entire arm until touching the body, the user just rotates without walking forward. Therefore, this was one of the gestures that gave the user the possibility to chose if he continues walking when rotating or if he stays still while turning to the right or to the left.

The last set designed by us is called Thumb-based gesture set and uses only the thumb and forefinger of one hand. With the thumb the user touches one of the phalanges of the index finger to navigate. The middle phalange indicates walking forward, the right one would turn to the right side, and the left one would turn to the left side. This gesture was chosen due to its minimization of the required effort.

For comparison reasons, a set of gestures from the state of art Tapping-in-Place [12] was included in the experiment. The movement of going forward is generated by tapping each heel against the ground. The user lifts alternatively one heel off the floor without breaking contact with the toes and continue with the gesture for keep walking. For rotating to one of the sides, he/she simply needs to turn the head right or left.

5 Results

As prior result we validated the use of the Wizard of Oz technique for real-time gesture interaction prototyping, specially regarding the emergence of natural gestures defined by users and the capture of fine and discrete body commands. At the end of the wizards training the mean delay between recognizing the gesture and performing the correct input to the system was 0.086 seconds if compared with the same gesture being tracked by a Kinect device. The releasing delay was about 0.101 seconds when releasing the button. The rate of false positives was nearly zero (0.007) and zero false negatives occurred. In the overall, the wizard technique fulfilled this research needs and objectives. Although, we observed the limitations of this prototyping technique for rapid or precise movements from the user.

Moreover, we have found insight about the user experience on each type of navigation in respect to concepts related to the naturalness and effectiveness of the interaction. The data collected in the first step revealed that the use of the hand is a consensus among users. When they were stimulated to generate less strenuous gestures, the use of entire arms is commonly reduced to use smaller movements. The use of the lower body parts was almost inexistent.

Also, pointing the direction forward was very often proposed as a command to advance and when this gesture is requested the Taxi Driver usually replaces the users chosen gestures as the best and most ergonomic solution. The usage of the whole body as a navigation command also was very claimed but at the end of the experiment it revealed a strong fatigue and lack of precision.

Figure 2 shows the paths the users walked through using each of the predetermined movements, different colors are used for each user per gesture. It is also shown the blue and red balls, which were used to guide the navigation through the scenario. It can be seen from this figure that the Equilibrium and Thumb-based metaphors gave more control to the user as all the users walked almost the same path, they did not made a lot of zigzags and passed near almost all balls. It is important to notice that on Thumb-based, one user ignored some balls and jumped to the next, but that was the user decision and not a control problem. On the other hand, Supermarket Cart and Tapping-in-Place demonstrated to give less control as the users deviated more from the balls and seem to be going from right to left all the time, trying to line up their course.

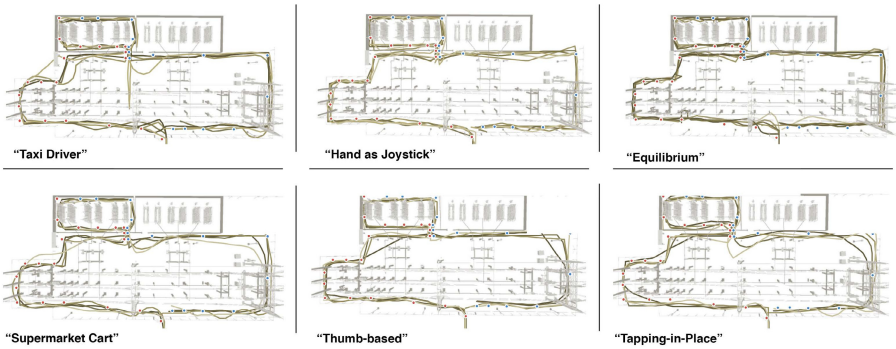

Fig. 2. Paths performed by all tested users while trying the six different metaphors

Another observation is that in gestures which allowed multiple inputs, i.e., walk forward and rotate, (except the Equilibrium) the users tend to make curves while still going forward. Although that seems to be bad while looking for the path traced as it sometimes does not pass near the balls, it makes a more continuous movement and thus, the path can be completed earlier since the user does not have to stop, rotate and then walk again to make a curve.

Regarding the time taken to complete the given circuit, Hand as Joystick had the worst performance with an average of 290 seconds, followed by Equilibrium and the Taxi Driver that had 277 and 260 seconds, respectively. On the other side, Tapping-in-Place provided the fastest way to navigate having an average of 192 seconds, followed closely by Supermarket Cart and Thumb-based where it took 199 and 211 seconds, respectively, to complete the same task.

5.1 Naturalness

The experienced degree of Naturalness was assessed by two questionnaire items requiring the participants to rate their level of agreement as it was explained in the Procedure Subsection. The two items measured the Cognitive Effort and the Walking Sensation. It was noticed that, except for the Supermarket Cart gesture, all the others were considered to have low cognitive effort and two of them, Equilibrium and Tapping-in-Place, were considered to have high Walking Sensation because of the use of the legs or foot for moving forward. The Thumb-based gesture was considered the most comfortable because of the reduced quantity of movements but it did not provide a good Walking Sensation, as shown in Figure 3.

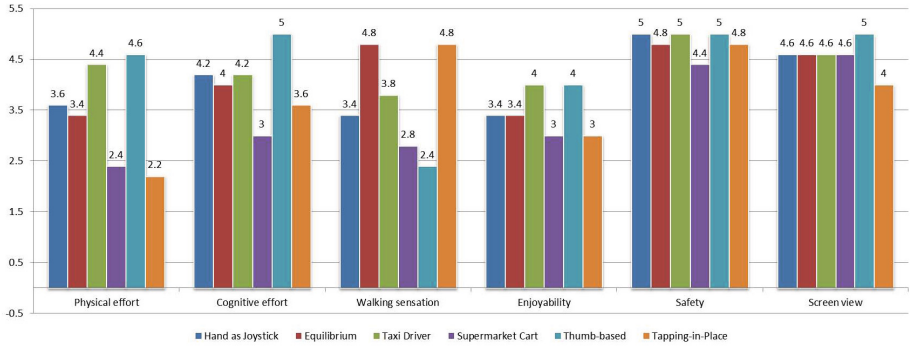

Fig. 3. Comparison between all tested metaphors regarding the six parameters evaluated

5.2 Physical Effort

The results obtained from the questionnaire item related to Physical Effort are shown in Figure 3. Significant differences were found regarding the techniques that used more than one body part: Hand as Joystick, Equilibrium, Supermarket Cart and Tapping-in-Place. These ones were considered more strenuous and had a mean of 2.9 on a range from 0 to 5. In qualitative data, the users said the Thumb-based was the less tiring but Taxi Driver was most intuitive and let them free to do other movements since it works as a trigger in the act of moving forward, and thus, being more comfortable when navigating long distances.

5.3 Semi-structured Interview

After all gesture were performed, the users answered a semi-structured interview. When we asked them which gesture was more interesting to be executed, the most frequently cited were Taxi Driver and Thumb-based. It occurs because the users had less effort to execute them and considered these gesture as more natural, as well. All participants answered that they wouldn't have any restriction to perform the gestures with other people around.

6 Conclusion and Future Work

In this article we have proposed and evaluated, using the Wizard of Oz technique, five novel gestures for navigation in a 3D virtual environment of an electrical substation, plus one gesture from the state of art for reference purposes. Also, each user had the opportunity to create his own set of gestures, and all these gestures were analyzed in order to extract what aspects are important to the user regarding a navigation task in a virtual environment.

From the analysis it was possible to conclude that the Thumb-Finger and Taxi Driver were the most accepted by the users and some gestures that at the beginning seemed effortless showed to be strenuous. Also, the fingers (or the whole hand) were often used in the gestures, specially when the user was asked to decrease the physical effort. Besides, it is important to notice that the sense of direction has a big influence in the conception of the gesture, i.e., when looking for a gesture to assign the task of walking ahead, the user tries to associate the gesture with the direction of the movement.

For future work, we intend to gather the acquired insights to improve the proposed metaphors and create new ones in order to apply our results in a real industry application. Also, this study can be expanded and the gestures can be used for other kinds of applications.

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