TABLETOP USER INTERFACE FOR NAVIGATION IN VIRTUAL ENVIRONMENTS

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ABSTRACT
In this paper, we present a multi-touch tabletop user interface for navigation in virtual environments and describe its preliminary evaluation. We have constructed a set-up where a multi-touch sensitive tabletop display is combined with a three-wall large-scale display system. In our set-up, the multi-wall large-scale display provides an immersive 3-D rendering of the virtual environment while the separate tabletop display provides a 2-D map view of the same data along with a user interface for controlling both views. We have developed three variations of navigation techniques for the display system and have conducted a user study to preliminary evaluate the overall usability of the set-up and to compare the three proposed navigation techniques. Qualitative and quantitative results of the study demonstrate the prospects and limitations of the navigation techniques and also provide input for further development of the multi-display systems. This work originates from the need to develop new tools for industrial process control, and we conclude this paper by discussing the implications of the user study for this application area.

KEYWORDS
Multi-touch tabletop and large-scale display interaction, virtual reality, navigation, multi-display environments.

1. INTRODUCTION
In most process control tasks adequate spatial and situational awareness are critical for effective operation of the system. Currently, there is an increasing use of digital technology in control room (CR) environments which have caused a number of challenges, both from the technical as well as users’ point of view. As a part of the digitalization process, the physical control panels and consoles used before are replaced by their digital counterparts i.e. a keyboard and mouse controlled displays on which a vast amount of process information can be graphically presented. In this digitalization process, CR operators’ secondary task demands have increased (e.g. navigation), and the development and maintenance of situation awareness has become more difficult because of the growing complexity of the control system and the large amount and variety of user interface elements (e.g. displays) required for carrying out the control operations.

Nowadays the development of screen technologies has made it possible to equip CRs with interactive and large sized displays. For example, many of today’s CR set-ups already make use of large-scale displays in the presentation of process information. New advanced visualization techniques have made it also possible to provide operators with a new kind of presentations and views to the controlled entity (e.g. 3D visualizations, simulations, virtual and augmented reality). These technologies could potentially support more immersive user experience in process control environments (e.g. looking deep into the process and operating the systems remotely). Lately, there has been a growing body of studies on multi-touch technology. Although, it is still not in use at operating plants, some of the more conceptually oriented studies have shown that multi-touch technology may be valuable also in these environments. By combining strengths of sophisticated interaction qualities and high-resolution graphical displays users are able to interact more efficiently and reliable with computer systems. Furthermore, the advances in display technologies can augment the artefacts of our physical and social environments, such as tables and walls, with digital technology. The future CR environment designs have been expected to take advantage of these technologies and leverage people’s natural abilities to act on and manipulate real-world objects.
The user study presented in this paper is an early step in our work in-progress aiming to draw a concept for future CR environments. As a part of this process we have developed a multi-touch tabletop called Affordance table. The development of the tabletop display started from the scratch by studying what kind of gestures people would prefer and what kind of associations they had on them when operating the multi-touch based interface. Based on the results of the first study, a set of appropriate interaction techniques for the tabletop were developed and the tabletop was integrated to work with the large-scale display system that provides a 3D view to a virtual environment. As its current state, the main aim of the present study was to conduct a preliminary evaluation of the overall suitability of a tabletop display and virtual reality (VR) system combination for data visualization and navigation tasks in CR environments.

2. RELATED RESEARCH

Several navigation methods and input devices used for navigation in VR have been described [3]. However, many of the methods and devices described suffer from usability drawbacks that have a negative impact on ease of learning, operation speed or vigilance. Use of tabletop display as a navigation tool in combination with VR system has been studied in various settings. Ajaj et al. compared usability of two tabletop user interface (UI) navigation techniques with one large-scale display [1]. Compared navigation techniques were based on egocentric and world reference maps similar to two of the navigation techniques (A and B) presented in this paper. In their approach tabletop UI detected only single touch events and additional hardware, i.e. joystick was used in combination with the tabletop. Examples of work where combination of 2D projection on a table with tangible objects has been used to control 3D visualization on a separate display have been described, e.g., in [5]. A general problem when using large-scale displays is how to get an access to all display elements, that is, how to navigate on a display and select items. There are several solutions to this problem: Navigation can be improved by providing a direct access to all screen locations, e.g., with a help of a laser pointer or of a gaze-based input device [12]. Novel UI elements such as, e.g., Vision Wand, Vacuum, and Frisbee have been developed (for a review, see [8]). Input methods that are based on visual hand tracking have also been designed [9].

One of the most promising features of the multi-touch display technology is its ability to provide hands-on computing experience for the user of the system. Since we are skilful in direct manipulation of objects by using actively our both hands, it seems reasonable to try to design tools and interfaces relying on these existing skills. Many studies that have investigated the use of two-handed interaction techniques with computers have shown their potential to improve both the directness and the degree of manipulation as compared to the traditional Graphical User Interfaces (GUIs) in the WIMP (Windows, Icons, Menu, Pointer) paradigm [4]. The foreseen advantages of multi-touch systems, such as encouraging two-handed interaction, allowing parallel input, making interface elements directly accessible, and affording collaborative use, are all the main drivers of the ongoing development. Especially, the utilization of hand gesture and multi-finger input for navigation and target acquisition are key features when interacting with these displays. One frequently mentioned challenge is the accuracy of the operation with touch based displays [2]. Many of today’s interfaces require and make possible the selection of very small targets, but with touch-based interfaces target selection and fine grained operation is restricted by the noise of underlying technology and lower tracking resolution as well as the relatively large touch area of a fingertip itself. The precision of touch-based interaction is further limited by the lack of tactile feedback and the occlusion problems. Due to these drawbacks, paying special attention to the design of navigation and target acquisition techniques is required in order to reach hands-on user experience. Many techniques have been suggested for increasing the accuracy of gesture and touch-controlled interfaces [5,11,13].

3. METHOD

The main aim of the study was to conduct a preliminary evaluation of the overall suitability of a tabletop display and VR system combination for data visualization and navigation tasks in control room environments. Our second aim was to investigate how the use of multi-touch tabletop impacts the use experience and users’ immersion into the virtual environment.
Three different navigation controls were compared in order to study how the variations in the interaction techniques affect the users’ experience and attentional focus during task performance. In the test scenario the users had to search for a target item and identify it. Both quantitative and qualitative information of their performance was gathered. During the test, the performances of the participants were video-recorded, and all the interviews were audio recorded. Two questionnaires were also completed, one measuring participants’ user experience on the three navigation methods, another one measuring their presence experiences [6].

3.1 Participants

Six volunteers participated in the study of which two were females and four males. Five of them were right-handed and one was left-handed. All the participants were either researchers or academic students. They had little or no experience on the use of touch screens, and none of them were an enthusiastic computer game player. Four of the participants were familiar with the building which 3D model was used as an environment for the search task whereas two of them had never visited the building before.

3.2 Technical Apparatus

User study was conducted on a prototype system which combines multi-touch display with an immersive three wall large-scale display system, as seen in Figure 1. The large-scale display consists of three rear-projected display walls, used in monoscopic viewing mode. The angle between display walls is 120 degrees, and as a whole display walls provide approximately 160 degrees’ field of view when operated from behind the tabletop display. The user is able to operate the multi-touch sensitive tabletop display in a standing position. The multi-touch display is composed of an off-the-shelf display (36” diameter) with 1360 x 768 resolution and a firewire camera array placed on top of the display frame. Multi-touch sensing is based on a proprietary camera-based touch tracking software.

![System Setup and Architecture](image)

Figure 1 & 2. Overview picture of the system set-up and architecture

The total system is composed of tracking software for touch detection, a client application running on computer attached to the multi-touch display, rendering servers that display the virtual environment to the large-scale display and communication interfaces between the above-mentioned components as seen in Figure 2.
Table 1. User Interfaces of navigation techniques A, B and C.

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<td>A</td>
<td></td>
<td>User controllable 2D map of the building</td>
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<td></td>
<td></td>
<td>Floor selection buttons</td>
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<td>User controllable camera object</td>
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<td>B</td>
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<td>Navigation target visualized on the map</td>
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<td>Static camera object located on the centre of the screen</td>
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<td>Floor selection buttons</td>
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<td></td>
<td>User controllable 2D map of the building</td>
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<td>C</td>
<td></td>
<td>2D map, camera location and target visualization</td>
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<td>Floor selection buttons</td>
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<td>Motion speed/direction control</td>
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<td>View direction control</td>
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### 3.3 User Interface

The UI of the test set-up is distributed between tabletop display and large-scale display system. In all test cases, the large-scale display provides a panoramic 3D view to the virtual building model. In addition to the 3D view, the large-scale display does not include additional UI elements. The UI layout and elements on the tabletop were changed according to the tested interaction technique.

Three different navigation techniques were implemented for the test. In the following, the three different interaction techniques are labeled as A, B and C. Two of the implemented navigation techniques (A and B) were based on the map metaphor and used a 2D floor plan of the virtual building model as a part of the UI. The third navigation technique (C) was based on the vehicle control metaphor and the UI provided two interactive control elements. The basic controls for the three interaction techniques were designed on the basis of the results of an earlier test on multi-touch gesture preferences and associations on them [9].

#### 3.3.1 Navigation Technique A

In the navigation technique A, the user can inspect a 2D floor plan displayed on the tabletop display and navigate through it by manipulating a graphical camera object, which represents a camera location relative to the 2D floor plan (Table1). The floor plan can be rotated, scaled and translated freely with multi-touch gestures. The camera object controls the viewpoint of the 3D rendering, so that the user can freely navigate the 3D model of the building by manipulating it. The camera object can be translated with a single touch manipulation and rotated with a multi-touch gesture where the user first selects the camera object by touching it and then defines the rotation angle with a second touch anywhere on the display area.

#### 3.3.2 Navigation Technique B

In the navigation technique B, the user can translate, rotate and scale the 2D floor plan displayed on the tabletop UI (Table1). The camera object is static and in a fixed position and orientation in the centre of the screen, and navigation is controlled by translating and rotating the 2D floor plan. 2D floor plan is translated with a single touch manipulation and rotation and scaling can be activated simultaneously to the translation
with a multi-touch gesture. As the floor plan is translated or rotated, the viewing position and orientation of the virtual environment on the large-scale displays is updated accordingly.

### 3.3.3 Navigation Technique C

The navigation technique C is based on a control metaphor often used in computer games. This third navigation technique was included in the comparison because people tend to have more experience on using such controls, i.e. playing games and using radio controlled vehicles, than on using the techniques A or B. In this navigation technique two control elements are provided, one for manipulating the view orientation in the virtual environment and other for defining direction and speed of the translation of the view in the virtual environment. Controls can be thought of as being a steering control and a thrust direction / speed control. Also in this navigation technique, a static 2D floor plan and a static camera object are being visualized to provide visual information to the user about the view location in the virtual environment.

### 3.4 Procedure

#### 3.4.1 Introduction and Training Phase

In the beginning of the test, participants were introduced with the main idea and purpose of the study followed by a short background interview. The training phase was divided into two sub-phases, training of the basic gestures and training of the navigation techniques. The first phase of the training focused on the use of multi-touch display and the basic multi-touch gestures. The goal of this phase was to introduce and evaluate the basic controls as well as capture the first reactions on the use of multi-touch tabletop. For this sub-phase the UI was modified so that each of the single multi-touch control was first used and trained individually (i.e. translation, rotation, and scale). More complex interactions allowing simultaneous combination of controls were introduced at the end of the training phase (Figure 3). The aim of this training approach was to allow users to learn the complete UI gradually but also to be able to evaluate each control type and associated gestures individually. During this phase the user’s experience on the basic gestures were evaluated by a three-item questionnaire measuring the pleasantness, easiness and accuracy. In the second part of the training, the participants were introduced with the integrated VR displays and multi-touch tabletop system. They were also given a possibility to test and practice the use of the three compared interaction techniques (A, B and C) separately.

![Figure 3. Training session on basic gestures.](image1.png) ![Figure 4. Search target visualized in immersive 3D environment.](image2.png)

#### 3.4.2 Main Test Phase

In the main test phase, the participants carried out twelve search tasks. The test included two kinds of search and identification tasks. In one task the location of the cue was shown in the floor plan, and the users had to navigate to the given location of the building. In another task, no cue was given, and the users had to search for it within the building. Within-subjects design was applied in the test. The order of the trials was counterbalanced.

The basic task for the test was to navigate within the virtual building and to search cubes that were hidden around the building. After finding the cubes the participants were asked to identify the numbers and letters on the sides of the cubes to complete individual reach tasks (Figure 4). After each test run, the participants also completed the user experience questionnaire. The presence questionnaire was completed after six test runs.
3.4.3 Debriefing Phase

After the main test phase a debriefing interview was carried out to gather user’s preferences on the integrated display system. The participants were also asked about the possible problems that they had encountered. The debriefing interview included questions around three different themes: 1) the potential usefulness of multi-touch technology; 2) user experience on the tested navigation techniques and the multi-touch display itself; and 3) the perception of the 3D virtual environment and the use of the integrated VR display and multi-touch tabletop system.

4. RESULTS

4.1 Quantitative Findings

The results of a one-way ANOVA showed that there was a significant difference between navigation methods in search time, F(2,33) = 4.1, p < 0.05. According to post hoc tests, Method A was significantly faster than Method C. There was, however, no significant difference in search times between Method A and B or between Method B and C.

According to the questionnaire results, there was a significant overall effect of navigation method on user experience (all ps < 0.01). According to post hoc tests, Method A was considered easier and more pleasant and accurate than Method C. Method A was also thought to be in overall better suited for navigation than Method C. The participants also thought that Method B was easier than Method C: it was also considered in overall better than Method C. Interestingly, Method A was considered easier than Method B: it was also thought to be in overall better suited for navigation than Method B. In sum, these results suggest that the method in which the camera object is moved around relative to the map view is the best alternative of the three navigation methods that were tested.

According to the presence questionnaire, there was a significant overall effect of navigation methods on experienced action possibilities in the virtual environment, F(2,15) = p < 0.05. According to post hoc tests, the participants focused more intensively on the action possibilities within the 3D model of the building when using Method A than Method C. This finding suggests that when the camera itself is moved around by touch, the user has the best opportunity to focus his/her attention in the virtual environment.

4.2 Qualitative Findings

4.2.1 User Experience on Basic Gestures, Multi-Touch Tabletop and the Navigation Methods

As mentioned above, the basic controls for the three interaction techniques were designed on the basis of the initial user study that were organized for assessing the preferred multi-touch gestures and associations on them. Generally, the participants agreed that the basic gestures that were used for the manipulation of the multi-touch display were intuitive and easy to learn, that is, the movements were immediately associated with the functions that they were designed for. From the basic gestures, the one serving the “moving the floor plan” function was preferred most. Also, the gesture for zooming functioned as the users expected. The participants had problems most often when they were asked to perform accurate operations (e.g. zooming objects to some given size).

According to debriefing interviews, method A was thought to be best suited for the navigational search task at hand. It was thought to be the most intuitive, and it was also considered to be the easiest technique to navigate through the building. According to the debriefings, the use of the other two techniques (B and C) caused some confusion among the participants as they did not always work as expected. Overall, there were more difficulties experienced in navigation when using methods B and C. However, the participants thought that also methods B and C had some useful properties; for example one participant mentioned that method C seemed to be potential for “steering” purposes as the way of using the control elements and 3D view reminded the way how the steering wheel and view out from the car’s windscreen is used. But because of the
lack of the tactile feedback, attention had to be paid on the use of control elements, and the participants were therefore not able to fully utilize the 3D view when using method C.

The participants were also asked to evaluate the potential usefulness of multi-touch tabletop and the three introduced navigation techniques. They thought that the multi-touch technology would be the most suitable for navigation and browsing purposes. The system was also considered useful for design and problem solving tasks (e.g. viewing larger pictures/drawings). Particularly the manipulation (rotating, moving, scaling) capabilities were thought to be promising for these purposes.

### 4.2.2 Sources and Types of Operating Problems

Video recordings from the main test phase were also used for analyzing the magnitude and type of operating errors (technical or human originating). The number of errors was the lowest with method A. Generally, rotating the camera around the cube (operating the close-up view) caused most problems. It was typical that while trying to change the viewing angle of the camera (with method A) the camera accidentally drifted out of the building. In most cases this failure did not have dramatic consequences for the operation, but it came evident that when using the method A a lot of room was needed for executing the rotating action. Another typical error with the method A was that the participants accidentally manipulated the floor plan instead of the camera object.

The main difficulty with the interaction method B, in which 2D floor plan view at the bottom was moved relative to the static camera object, was that while trying to move and turn the floor plan picture the participants accidentally also zoomed it (usually it was zoomed out so that the 2D floor plan shrank). This action hampered the manipulation of the 2D floor plan view. Furthermore, because of this unexpected zooming effect and the other difficulties with the parallel manipulations (moving and rotating) the participants reported that they had got lost out of the map for short periods of time.

The number of mistakes was the highest when using interaction method C. Errors related to coordination were typical for this method. For example, the camera was accidentally moved or rotated to the wrong direction causing confusion. One reason for these mistakes might be the conflicting orientation of the 2D floor plan view on the tabletop and the 3D view on the large-scale display. Furthermore, also the manipulation of the control elements caused problems. It seemed that the controls did not react in the way the participants expected. Especially, the control for turning the camera was shown to be slow and inaccurate.

### 4.2.3 User Experience on the integrated 3D Large Screen View and Multi-Touch Display System

The participants thought that since the navigation task was quite easy and they had not attended to the 3D environment very intensively, the navigation experience was not very immersive. Participants were also asked to evaluate the potential usefulness of the combined multi-touch tabletop and the wall display system. They thought that in an industrial process control context, the multi-touch tabletop and the large-scale displays could complement each other, and the combined interactive display system could potentially provide an overall medium for the navigation and information presentation. The kind of presentation format (virtual environment) and way of interacting (multi-touch) was thought to be useful in situations in which there is a need for monitoring places and objects that are not approachable and easily viewable. The combined display system was also considered to be useful for remote operations.

### 5. CONCLUSION AND FUTURE WORK

Overall, our test suggests that a multi-touch screen can be used as a remote control device for controlling movements of an object in a virtual environment. It was also found that some interaction methods are better suited for navigation in a virtual world than others. More research is however needed on determining the appropriate methods for multi-touch screen based navigation. The results of the test provide design implications for the further development of each navigation technique.

We are aiming to develop an interaction concept and a prototype for more efficient and integrated operation of industrial process (Figure 5). We expect that interactive surfaces are central media for the future CR environments and that this kind of integrated display systems can be designed to support collaborative management of the process. The future CR environments equipped with the combined multi-touch tabletop
and wall mounted large-scale displays should help operators to manage different types of situations as well as help them to maintaining the global overview and awareness of the process. In these environments digital information would be distributed over the whole physical CR space and its objects. New interface technologies enabling more concrete representation of complex phenomena and based on existing human manipulation skills can be expected to promote better awareness and sense of control. These technologies may also support more efficient and effective navigation within the complex system.

Figure 5. Concept images of the future control room settings.

REFERENCES


