Usability evaluation of input devices for navigation and interaction in 3D visualisation

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ABSTRACT
We present an assessment study of user experience and usability of different kinds of input devices for view manipulation in a 3D data visualisation application. Three input devices were compared: a computer mouse, a 3D mouse with six degrees of freedom, and the Leap Motion Controller - a device for touchless interaction. Assessment of these devices was conducted using the System Usability Scale (SUS) methodology, with addition of application specific questions. To gain further insight into users' behaviour, the users' performance and feedback on the given tasks was recorded and analysed. The best results were achieved by using the 3D mouse (SUS score 88.7), followed by the regular mouse (SUS score 72.4). The Leap Motion Controller (SUS score 56.5) was the least preferred mode of interaction, nevertheless it was described as *natural* and *intuitive*, showing great potential.

Author Keywords
user experience; usability evaluation, user study; 3D navigation; touchless interaction; 3D mouse

ACM Classification Keywords
H.5.2. Information interfaces and presentation: User Interfaces

INTRODUCTION
While the field of user experience and usability evaluations is not new, it has become very important in recent years due to the widespreadness of computer usage in everyday life. Many tasks that were once conducted only by the experts have nowadays migrated into the domain of users that are primarily trained and educated in different fields. One of such tasks examples is navigation in 3D space using different input devices. The majority of people today are familiar with the use of computer mouse and keyboard but not so many are faced with specialised input devices, such as 3D mouse or touchless interfaces (e.g. Microsoft Kinect or Leap Motion Controller).

Visualization of three-dimensional datasets is a good example of a task requiring users to navigate and interact with data in 3D space. The two-dimensional nature of the computer screen on which the 3D dataset is projected makes interaction and view manipulation essential for the user to grasp the presented data. Most of user interaction tasks can be divided into navigation, selection/manipulation and system control groups. Navigation furthermore consists of three aspects [5]: *exploration*, which describes navigation through space with no target goal, *search*, where the user must navigate to a certain goal with speed, and finally *maneuvering*, which describes slower movements but with higher precision. All of the above mentioned aspects are important while developing a highly usable interface for 3D navigation.

In our case we do not address a specific aspect of navigation listed in introduction (exploration, search or maneuvering), we are covering the user experience. Further research for addressing individual aspects are planned as part of future work.

Recently, we have developed a medical visualization platform NeckVeins [4] for displaying 3D vascular models of patients, captured with computed tomography (CT) or other volumetric methods (e.g. MRI or ultrasound). The main purpose of the application is displaying and exploring 3D data by object and camera view manipulation. Since the application was designed and developed for medical purposes, it is essential that navigation in 3D space is intuitive and simple to use, while still offering high precision. This led us to implement three different modes of interaction with three different input devices as well as comparing their usability in specific test scenarios:

Regular mouse and keyboard, the mouse is used for object rotation and zoom, the keyboard is used to manipulate the position and orientation of the camera. Zoom functionality is implemented in discrete steps due to the nature of most mouse wheel design. There are no additional adjustable parameters implemented in the application;

3D mouse (Connexion Space Navigator), a device with six degrees of freedom. Users can toggle between control of the object or control of the camera by pressing one of the buttons, thus manipulating both with one device. In our application we can adjust the sensitivity of interactions as well as toggle between using strongest action (rotation or movement along individual axis) or all of them;

The Leap Motion Controller, a touchless interaction device that tracks the position and orientation of hands and fingers in space above the device. We linked the position and orientation of hands to object rotation and zoom. We have not implemented camera movement functionality for the Leap Motion Controller due to the additional complexity of needed gestures. The interaction with the Leap Motion Controller is initialised by opening the palm and disabled by closing it. Scaling and rotations are binded to the hand movements. In our application we can adjust the sensitivity of movements detected by the controller.

In this paper we present a usability study of the above mentioned interaction options. The rest of the paper is organised as follows: in the following section we present related work, in section Methodology we are describing the methodology of our usability study, in section Experiments we describe the experiments, and finally in section Results the results. We conclude the paper with discussion and conclusions with future work.

RELATED WORK

User experience evaluation is becoming an integral part of software and hardware development processes. The first tools developed for assessing the usability of systems were presented in 1980's in form of questionnaires. One such tool that became widely used is the System Usability Scale (SUS) presented in 1986 by John Brooke [6]. The SUS questionnaire consists of 10 questions, half of them worded negatively and half positively towards the usability aspects of system under test. For each question the participants can rate how strongly they agree with the specific question on scale from 1-5. The final result of the SUS questionnaire is a score on a scale from 0-100, which can be converted to grades A-F. Studies such as [10] show that the scale was well designed and covers different aspects of usability. Brooke has also published a retrospective on his original paper several years later, after his work was used in numerous studies [8]. The ease of use and the popularity of the SUS method ensured its widespread of use and thus a large collection of results from various fields was obtained. This allows for easy comparison and evaluation of results. One can find more on using SUS as well as determining what each individual score means in [1].

Bhuiyan and Picking have presented a usability study [2], where they compared gesture based navigation systems with regular keyboard and mouse for controlling an application that supports everyday activities. They concluded that the technology offers some potential to improve the independence and quality of life of older and disabled users along with general users, although there remain significant challenges to be overcome. Evaluation of a touchless mouse interface, that is in a way similar to the Leap Motion Controller, is presented in [11]. Another study [3] presents application of the SUS methodology in a case of a biometric method for user identification on multitouch displays.

Touchless user interfaces were already tried in medical environments. The authors in [7] describe camera navigation in 3D space with the Kinect sensor and voice recognition commands in order to ensure additional control. They also conducted a test study, comparing their interface to regular mouse navigation with promising results. Participants were, however, still more used to the regular mouse and keyboard. Another study tried to tackle the challenge of non-contact navigation with the Leap Motion Controller [9]. They linked hand gestures from the Leap Motion Controller with application key bindings using the GameWave[1] application. They obtained good results and also tested the device in a real-life situation during surgery, however their method has not been tested from the usability standpoint.

METHODOLOGY

The main goal of this study is to identify which of the presented interaction methods is the most appropriate from the users' standpoint. Aspects, such as the usage in different environments, accuracy, efficiency, productivity and satisfaction while working with the device, are sought. We performed objective tests, comprising of measurement of accuracy and time spent while solving specific tasks, as well as subjective tests, mainly focused on observing the participants' reactions. The SUS method was used to assess the usability of each interaction modality.

Testing was performed in a dedicated room where participants were isolated from outside factors such as noise or interruptions, so the same conditions were ensured for all participants. The experiment was conducted on a computer preinstalled with the modified NeckVeins application which contained seven (7) different tasks that participants had to solve. All attempts were recorded. The testing phase involved three different roles:

The Participant

The participant follows the instructions of the moderator and tries to think aloud while solving tests. At the end of the testing he/she can give his/her opinion and suggestions on improvements of interaction with the tested devices. Their actions are monitored and written down by the observer, while they are guided through the test by the moderator.

The Moderator

The moderator explains to the participant the purpose of the study and defines the goals which the participant should achieve during the testing. He must first prepare the participant for the use of each device and explain the tasks, and then guide the participant through testing. It is essential that moderator does not force the participant to make actions and to maintain a pleasant environment. He is also in charge of making breaks when participant loses concentration and to help the participant, if needed.

The Observer

The observer takes notes of the participant's comments and suggestions. While the participant is solving tasks, he writes down everything he notices about participant's body language and interactions with the system. He also takes notes regarding the possible errors occurring in the test application.

[1]GameWave can be obtained in the Leap Motion Airspace store

The study was conducted in two parts. The first part was a preliminary study in which we tested 7 participants and evaluated the usability methodology test plan. We used results, comments and responses from the preliminary study to improve the test plan and questionnaire and finally the test application accordingly. The second part was a comprehensive study in which 29 people were participating and was completed in a time span of 1 month.

EXPERIMENTS

A moderator, using the usability methodology test plan guideline document, guided each experiment. First, the user was kindly requested to sign an agreement to participate in the experiment and to allow the video recording during the experiment. Next, the participant filled in the form with demographic information including a short questionnaire regarding the background knowledge on the NeckVeins the application and about the previous technology experience with the devices being used in the test. Finally, the moderator explained the purpose of the study, introduced the NeckVeins application itself and described the participant's tasks.

To balance the study, the order of tests with interaction controllers was different for each participant. This was done to assess how the participants would perform when using controllers in different situations. Nevertheless, for each controller the experiment was the same: the participant was given a description of the controller he/she would be using. For each controller a participant had 5 minutes to get acquainted with the use of specific controller within the application. During this time all other questions were answered and concepts explained. When the participant was ready the testing could began.

Tests were composed of seven individual tasks. The main goal of each individual task was to align, in terms of rotation and zoom, a teapot displayed on left-hand side of the screen with a teapot displayed on the right-hand side of the screen. Figure 1 shows a screenshot of the test application where one can see the desired position of the teapot on the right-hand side of the screen and the user controlled teapot in red on the left hand side of the screen. Individual tasks had differently oriented teapots, varying in desired orientation and scale. The teapot on the left side was a movable teapot, which the participant was able to rotate in all directions and translate along the Z axis thus effectively zooming in and out.

The moderator started each task by selecting one of the examples and starting the timer. The participant's goal was to rotate/zoom the teapot in order to position it in the same way as the reference teapot. The time needed to complete the task, as well as the rotation and translation errors of the positioned teapot with respect to the reference were saved. The choice of speed versus precision was left to the participant. After the participant had finished with all the tasks for individual controller, he was asked to fill in the SUS questionnaire.

The same procedure was then used for the other two input devices but with different - randomly selected - order of individual tasks. At the end of the experiment the participant was asked to answer some additional questions on comparison between individual interaction options. The experiment was completed with a short chat with the moderator and observer, expressing his/her opinion about the experiment and tests.

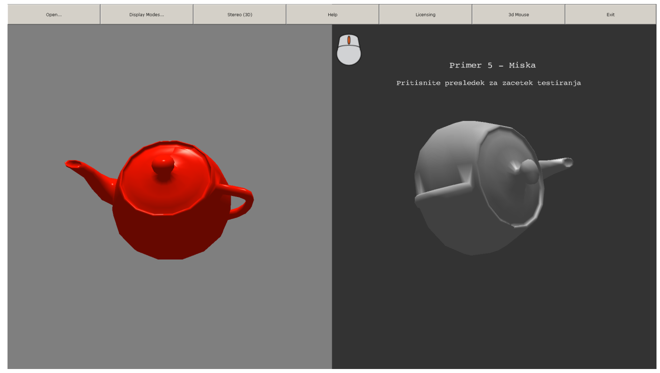

Figure 1. screenshot of the testing application is shown. On the left side is the participant controlled model of the teapot (red) is shown and on the right side of the screen there is a model of the teapot (grey) in the desired position.

RESULTS

29 participants took part in our study 55% men and 45% women. 14 between ages 18 and 24, 11 between ages 25 and 34, 3 between ages 35 and 44, and 1 between 45 and 54 years. Similar number was for their current employment status, 15 were students, 13 were employed and one unemployed.

The questionnaire participants filled before taking the tasks asked them to describe their experience in manipulation of 3D models, the NeckVeins application and using different input controllers. These questions were graded on a Likert scale from 1 to 5, "1" indicating no experience/knowledge and "5" indicating full experience/knowledge.

Results showed that most of the participants have not had experience with the NeckVeins application (average score of 2.5, more than 70% of answers marked with 1 or 2). Answers on understanding the concept of manipulating objects with regular mouse and usage of other controllers (such as gamepad or joystick), were evenly distributed. On the other hand, participants had little experience with the 3D mouse and 3D object manipulation (1.5 for knowing the 3D mouse and 2.3 for prior knowledge of object manipulation).

SUS results are listed in Table 1. They were calculated from questionnaires using the formula presented in [10]. After putting the results on a grading scale, the regular mouse and keyboard modality scores as B, the 3D mouse as A-, and the Leap Motion Controller as D. From these results we can conclude, that implementation of a regular mouse and 3D mouse is acceptable (on adjective scale [8] *good* and *excellent*), whereas the Leap Motion Controller has a low marginal score, but still scores an *OK* on the adjective scale. Participants really liked the implementation of the 3D mouse and according to [8] most of them would gladly recommend this controller to other people.

Controller	Average score	Standard deviation	Min score	Max score	SUS score
Mouse	72.4	18.4	45	97.5	**B**
3D mouse	**88.7**	11.4	50	100	**A-**
Leap Motion	56.5	19.0	20	95	**D**

Table 1. Results of SUS questionnaires showing controller performance in terms of usability. Higher score means better performance.

Results taken while performing individual tasks in the application showed that the average time of solving each task was 45 seconds. Solving tasks with regular mouse took 36 seconds on the average, with 3D mouse 35 seconds on the average and with the Leap Motion Controller 64 seconds on the average. The zoom error test showed that the best results were obtained with the regular mouse because of the discrete movement steps implemented. This gives the regular mouse the advantage in comparison with the other two input modalities. The participants were the most accurate, in terms of rotation and scale, with the 3D mouse and most inaccurate with the Leap Motion Controller.

DISCUSSION

Results show that the Leap Motion Controller's usability score is low. Analysis showed that the main reason for this is that participants experienced confusion when waving their hands above the device and not feeling any feedback. They also had problems remembering the correct gestures for individual actions (how to move the hands to rotate or zoom) and remembering to close the palm for disabling interaction and to open the palm for initialising it, thus unintentionally triggering interaction. They also reported some frustrations when trying to make very precise movements. On the other hand, some of the users felt that such touchless interaction presents a very natural way of interaction and said that the actions were intuitive.

The majority of the participants were thrilled with use of the 3D mouse for manipulating the teapot. That was mainly true because all of the movements of the 3D mouse directly reflected in the movements of the teapot. Therefore users did not need to remember certain gestures and motions so they could concentrate more on finishing the tasks and less on how to handle the controller itself.

Results, obtained from measuring the accuracy and time of individual tasks performed in the test application show that the participants quickly got hold of manipulating models with all the devices. This can be deducted from the fact that accuracies do not deviate a lot between different devices. On the other hand times are to some extend worse with the Leap Motion Controller. During experiments we also noticed that, while the users usually did not have problems handling the regular or the 3D mouse, several users had problems handling the Leap Motion Controller for the first time. After the initial problems were resolved the users were able to handle the Leap Motion Controller as well.

CONCLUSION AND FUTURE WORK

In this paper we presented a usability evaluation study of using different controllers for 3D navigation. Regular mouse, a 3D mouse and the Leap Motion Controller have been tested for 3D object manipulation where the user was timed and the accuracy of his/her actions was recorded. From the results obtained, we can conclude, that the 3D mouse is the most appropriate interface with an average SUS score of 88.7, followed by the regular mouse and keyboard, with an average SUS score of 72.4, while the Leap Motion performed worst with an average SUS score of 56.5, which is still at the acceptable level, but not any better.

Considering the results, we conclude that the Leap Motion Controller is not ready to be used in everyday environments, although it is a promising touchless navigational interface. Recently a new version of the Leap Motion SDK was released, which enables more precise tracking of the hand motions and provides the use of more pre-created gestures. The comments and opinions we gathered on manipulation of objects in 3D space with the Leap Motion Controller will be used in a new release of the NeckVeins application.

From user comments we have concluded that our implementation of 3D mouse is good and will therefore not be changed significantly in the future; while on the other hand we will make some changes to the implementation of the regular mouse by adding support for sensitivity and modifying the interaction area.

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