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Pointing Task Evaluation of Leap Motion Controller in 3D Virtual Environment

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ABSTRACT

Performing tasks in virtual environments are to increasing extent becoming normal practice; such is possible due to the developments in graphic rendering systems and interaction techniques. Application areas from entertainment to medical industry benefit from gestural 3D interaction. With this in mind, we set out a study aiming to research the relevance of using determined 6DoF input devices in interacting with three-dimensional models in graphical interfaces. In this paper we present an evaluation of 3D pointing tasks using Leap Motion sensor to support 3D object manipulation. Three controlled experiments were performed in the study, exposing test subjects to pointing task evaluations and object deformation, measuring the time taken to perform mesh extrusion and object translation. Qualitative data was gathered using the System Usability Scale questionnaire. The data show a strong correlation between input device and performance time suggesting a dominance of the Leap Motion gestural interface over mouse interaction concerning single target three-dimensional pointing tasks. Multi-target tasks were performed better with mouse interaction due to issues of 3D input system accuracy. Performance time regarding shape deformation task demonstrated that mouse interaction outperformed 3D Input device.

Author Keywords

3D object manipulation; pointing task evaluation; 3D input device; leap motion.

ACM Classification Keywords

HCI, gesture interaction, 3D environment, user evaluation

INTRODUCTION

Despite of developments in 3D graphics rendering systems, we still face a lack of knowledge when it comes to interaction with three-dimensional environments. For the construction of this type of interaction it is important to consider a system that permits the user to manipulate the 3D objects in the most natural possible manner, as naturalness directly influences the system usability along with the engagement that the user might present during interaction [18].

Three-dimensional virtual objects and environments can be controlled in various manners, for example by making use of 2D or 3D input devices, providing the user with three, six or more degrees of freedom for translating and rotating objects [11]. Nowadays, the most common scenario for 3D virtual object manipulation are 3D graphics rendering systems on simple desktop setups; this makes the interaction possible, however not yet optimal [14]. More sophisticated Virtual Reality systems tend to use 6DoF sensors, which can be described as 3D input devices that enable translation and rotation (pitch, yaw and roll) in all three axes (cf. Figure 1). Such devices are used to measure position and orientation of limbs providing three-dimensional data regarding the user's movement.

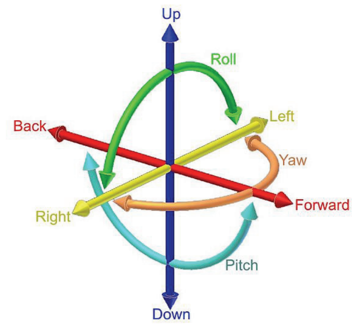

Figure1. Graphical description of movements addressed in 6DoF input devices

Even though we have observed a lot of technical development in the interaction field within the last two decades, 6DoF interaction is still challenging due to limitations of sensor technologies, not enough knowledge on how humans interact with computer generated 3D environments and the recurrent task-specific demands and constraints of each interaction device itself [7]. A few of the most well-known areas that benefit from three-dimensional interaction on virtual environments are: 3D modeling and scene composition, visual programming, medical visualization, prototyping, designing for engineering purposes, browsing large datasets, Technology Enhanced Learning and real-time 3D communication such as the Web3D [7]. Researching the aspects of 3D interaction is relevant as there are many appliances that might vary for every field. Nevertheless, the general goal of the casual user is usually related to browsing, manipulating or interacting with three-dimensional data. With the latter in mind, the purpose of this study is to compare user performance between interacting with a mouse and a Leap Motion

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device; subsequently, to find out whether or not the use of the Leap Motion device is beneficial for manipulation of virtual objects.

RELATED WORK

Although much work has been done in the field of 3D object manipulation, there are several aspects of interaction that still need to be further analyzed. Early research in the field was conducted with the aim of evaluating 3D input devices in the context of 3D interaction techniques and its relation to user performance [23]. Due to the constant development of interaction devices and rendering systems such research is still common practice.

To evaluate 3D input devices acting in virtual environments, researchers often use Fitts's Law to understand and predict user's reaction time in relation to pointing tasks. A study by Kouroupetroglou, G. et al. [10] reports on a pointing task evaluation comparing between mouse and Wii Remote Control input devices. The study was divided in 2D and 3D experiments in which both Wii Remote and mouse conditions were tested. The two-dimensional experiments were performed in a plane virtual environment counting with 16 circular targets equidistantly arranged from the starting point while, in the 3D case, 8 spherical targets were positioned on the vertices of a cube. The results gathered from both conditions showed that the Wii Remote was outperformed by the mouse in 2D and 3D pointing tasks. It is important to note, however, that the response of the Wii Remote, and thereby its interaction, was reported troublesome with certain light conditions.

Another study by Raynal et al. [16] defends the importance of unifying 3D pointing task evaluation, based on the ergonomic requirements stated in the ISO 9241-9 standard. In this study, researchers adapt the standard evaluation protocol of input devices for 2D pointing tasks, considering important variations that a 3D environment might imply. The devices used for the experiment are the 3D mouse *Space Navigator* and the *Polhemus Patriot* motion tracking input system. One of the most striking adaptations concerns to the validation of reached target in the context of pointing task. It is stated in the ISO 9241-9 that the validation is successful once the cursor is within the target's width. These authors proposed, however, that collision with the target already entails the validation of target reached. This results in a much more positive index of performance by the users and reinforces the necessity of occasional adjustments in pointing task evaluation on 3D-environments.

In [2], Bérard et al. conducted two experiments aiming to investigate the dominance of the mouse in desktop 3D interaction in relation to other 3D input devices. In this research, the *mouse*, *DepthSlider*, *SpaceNavigator* and *Wii Remote* are used as input devices. Evaluation was accomplished by measuring user-performance time when completing pointing tasks inside of a virtual cubic environment. In addition, in the attempt to analyze the bio-signals of the participants, researchers recorded data of galvanic skin response (GSR), heart rate (HR) and volume pulse amplitude (BVP). The experiment demonstrated that the mouse was more efficient than the other devices for accurate placement. In this research is was also concluded that the more degrees of freedom, the worse the performance time for task completion while the stress measured on the user tends to be higher. Nonetheless, it still remains unclear whether the interaction design of the experiment negatively influenced the results of the research in terms of 6DoF input devices.

NATURAL USER INTERFACES

Gestural interfaces are based on recognition and mathematical interpretation of gestures performed by the user, resulting in interactive scenarios that vary in relation to case-specific tasks depending on the goal of the interaction designer. Such interfaces are part of a group of input systems denominated Natural User Interfaces, or NUI. Natural User Interfaces can be classified in two main groups that can be ergonomically distinguished in relation to the physical contact with the body of the user: *wearable* and *touchless* interfaces. As the name suggests, wearable interfaces can be defined as input devices worn by users that contain sensors or markers in order to capture motion with the desirable precision. Systems such as the *Dataglove*, *MOVE* and *WiiMote* can be considered wearable Natural User Interfaces. Touchless interfaces, on the other hand, are characterized by the lack of physical contact with the human body, enabling the user to draw commands without having to touch any equipment. Devices under this category can be essential for determined 3D tasks such as sterile image-guided surgery, once again reinforcing the importance of researching the usability of such devices. Working examples of touchless NUI are the *Microsoft Kinect*, *ASUS Xtion Pro Live*, and the *Leap Motion* sensor.

In this research, we have chosen to use the *Leap Motion* sensor (cf. Figure 2) to perform the experiments with our test subjects. The Leap Motion device combines infrared LEDs and two cameras under a black glass, enabling the software to track finger movements as they are moved over the sensor. The decision to test this device in detriment of others was determined by its commercially announced qualities such as portability, purported accuracy and ease of use, suggesting its possible popularization in the context of domestic 3D environments and virtual object manipulation setups.

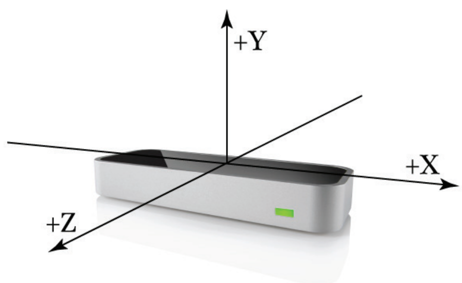

Figure 2. The Leap Motion sensor

3D OBJECT MANIPULATION

A few authors provide us with surveys and comparisons of distinct interaction techniques, describing the main functions that these input devices perform in their respective virtual environments. Chris Hand [7] reports three main operations that the application fields, which profit from 3D interaction, usually make use of, namely: *object manipulation, viewpoint manipulation and application control.* In this paper, we will focus on object manipulation, keeping in mind that, in future work, the other two main tasks should be investigated. According to Subramanian [18], the essential atomic actions within object manipulation can be described as selection, translation and deforming. In this study we will focus mainly on translation and deforming aspects, as we will further illustrate in our experiments.

Our aim is to draw conclusions about the system performance through measurements made during user interaction and therefore it is important to elucidate what variables to take into account for the analysis of the executed tasks. In his study about user performance in relation to input devices, Zhai [23] defines six usability aspects for a 6DoF input device; i.e., *speed*, *accuracy*, *ease of learning*, *fatigue*, *coordination* and *device persistence*. Among all these characteristics of three-dimensional input interaction we will quantitatively measure speed and ease of learning, while accuracy coordination and device persistence are known variables inherent to the given system. Fatigue will be measured qualitatively with the help of the System Usability Scale (SUS) [3].

METHOD

The variety of 3D input and interaction techniques has resulted in many different methods that are utilized to evaluate the performance of the user. Consequently, the novel characteristics of specific input devices might require the creation of ad-hoc approaches for 6DoF interaction evaluation techniques. From the literature, two major approaches are commonly observed as related to the field: structured approach and ad-hoc approaches. In brief, we can describe the structured approach as a composite of methods that aim to assess the pointing task data in a structured manner usually based on Fitts's model. The ad-hoc approaches may vary for case-specific tasks and devices. In this paper we preferred to make use of the structured approach along with inferential and descriptive data analysis in order to evaluate Leap Motion and Mouse input devices in relation to the proposed experiments. Qualitative measurements were performed using the System Usability Scale (SUS), which was filled in by the test subjects right after completion of all tasks.

Experiment Design

Test subjects were randomly divided into two groups that were exposed to different conditions related to the type of input device. The control group was exposed to the mouse condition while the experiment group performed its tasks with Leap Motion gestural interface. An optical mouse of 5V and 100mA wired to the computer via USB was used in the experiment. The sensitivity of the mouse was kept consistent during the whole experiment, not being specifically adjusted for every subject independently.

Subjects from control and experiment groups were exposed to the same virtual environment and target positions only differ on their input interaction method. Reaction time was measured in all the tasks and the initial pointing position of the user as well as target coordinates are known and equal for all test subjects. The experiment task environment was programmed in *Processing.js* supplemented by the *Onformative Library* in order to enable the gestural interaction. Overall, 35 subjects were tested, being 20 in the experimental group and 15 in the control group.

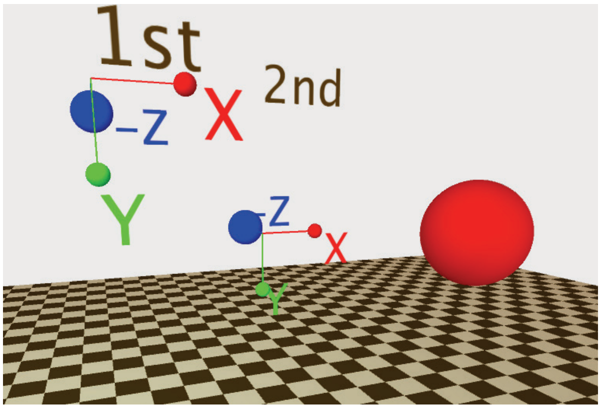

Figure 3. Experiment 1

In order to observe the correlation between input device and effectiveness of object translation we designed two 3D pointing tasks that were performed by the users in a given three-dimensional virtual environment (cf. Figure 3). It is important to notice, that in both cases, viewpoint or camera manipulation was not enabled, providing the test subject with a single angle of vision in order to make decisions with respect to their spatial movements. This decision was taken with the aim to isolate the distance and time variables, keeping in mind that *viewpoint manipulation* should be explored in future work. In the first pointing task, test subjects were instructed to reach a point in space by positioning a red colored sphere onto the first denominated target. The target was described to the user as the "intersection of all axis". The second task had two targets demanding the user to position the sphere on target 1 and subsequently on target 2. Please note that trigonometric and statistical analysis regarding the second pointing task is calculated considering the trajectory from point one to point two and not from the starting point. The validation of target selection is defined within a field of 60 voxels and once the sphere in positioned partially or completely within the field, a console message returns the time taken to reach the target, in milliseconds.

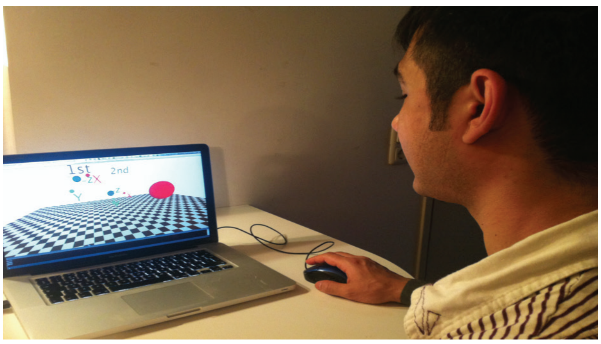

Figure 4. Mouse Interaction

Figure 5. Leap Motion Interaction

Both pointing tasks were analyzed according to variations of Fitts' Law in order to measure the *Index of Performance* (cf. Equation 1) of the given tasks in relation to their *Index of Difficulty* (cf. Equation 2).

$$IP = ID/MT \quad (1)$$

$$ID = \log2(D/W+1.0) \quad (2)$$

$$MT= a+b*\log2(D/W+1.0) \quad (3)$$

The first equation can be described as a formula used to calculate the *Index of Performance* or throughput of a pointing task. Equation 2 aims to calculate the index of difficulty of each pointing task where *D* is the distance between starting point to the center of the target and *W* is the width of the target. Since in our experiment all given targets had the same dimensions, the distinction between the two different given indexes of difficulty was determined by target distances. Equation 3 can be used to predict time measurements concerning the pointing task, where *a* and *b* represent empirical constants determined through linear regression

Although the conventional Fitts's Law is commonly used in research and multidimensional design tasks, the calculation applies only to one-dimensional movements, compromising the comprehension of three-dimensional data, when it comes to manipulation of virtual objects in 3D environments. Due to our different starting point, we adapted Fitt's law for work in a 3D environment, where *c* is an arbitrary constant to be determined through linear regression and θ is the angle between the starting point and target according to Figure 6. One can see in Equation 5 the adaptation we made considering the terms abovementioned in Equation 2. Therefore,

$$ID_3=\log_2(s/b+ 1.0)+c \sin \theta \quad (4)$$

thus changed to:

$$ID_3=\log_2(D/W+ 1.0)+c \sin \theta \quad (5)$$

Considering the referred adaptation of the Fitts's Law to three-dimensional tasks, indexes of difficulty were calculated considering several values of *c* as indicated in [15] and a constant target width.

After completing both calculations, we could understand that the three-dimensional version of Fitts's Law explains more clearly why the second target is harder to reach than the first one since this formula takes into account the angle expressed in a two-dimensional frontal plane from starting point in relation to the target, differentiating indexes of difficulty not only considering distance and width of target but also the referred angle.

Arbitrary constant	TASK 1			TASK 2		
c values	θ	D	ID	θ	D	ID
0	135°	19	3,45	315°	12	5,35
0.1	135°	19	3,52	315°	12	5,28
.0.2	135°	19	3,59	315°	12	5,21
0.3	135°	19	3,66	315°	12	5,14
0.4	135°	19	3,73	315°	12	5,07
0.5	135°	19	3,8	315°	12	5
0.6	135°	19	3,87	315°	12	4,93
0.7	135°	19	3,94	315°	12	4,86
0.8	135°	19	4,01	315°	12	4,79
0.9	135°	19	4,08	315°	12	4,72
1	135°	19	4,15	315°	12	4,65

Table 1. Variation of *c* value on adaptation of Fitts's Law for analysis of three-dimensional tasks

In addition to the first two pointing tasks, a third task concerning 3D object modeling was developed with the aim to evaluate the overall performance of the subjects from the two input conditions while deforming a 3D shape (cf. Figure 6), therefore calculating the average reaction time in both situations. This task consists of re-shaping a deformed cube by extruding one face of the object. The interaction was designed by moving the cursor or tracked hand on a specific axis.

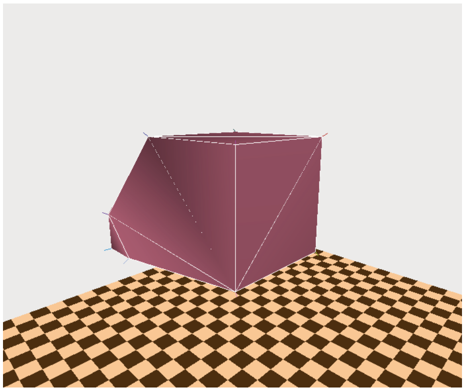

Figure 6. Experiment 2

Experiment Procedure

The mouse condition group was submitted to a brief instructional video, since a pilot study revealed that a few users did not comprehend how to perform the tasks. The 30 seconds of audiovisual demonstration were followed by the completion of the three tasks and data logging of the tasks.

Subjects in the experimental group were also exposed to a short video containing instructions on how to perform the pointing tasks. However, unlike test subjects exposed to mouse condition, the experimental group underwent a short training period that was performed individually. Each subject was introduced to the Leap Motion gestural interface by performing two minutes of interaction with a 3D environment specifically designed for learning purposes. In this environment, users did not have a pre-determined task, therefore interacting freely with a wired white sphere, being able to control the 3D position and rotation of the given shape. After getting acquainted with the gestural interface interaction in the context of a 3D virtual world, subjects were asked to perform two experiments concerning pointing tasks and object modeling experiment.

RESULTS

We tested with 15 participants for the mouse condition and 20 participants for the gestural interface condition. Between the 35 participants, we have 23 male and 12 female subjects from different ages and nationalities (cf. Figure 7). In Figure 8 you can observe the distribution of participants under both conditions by age groups.

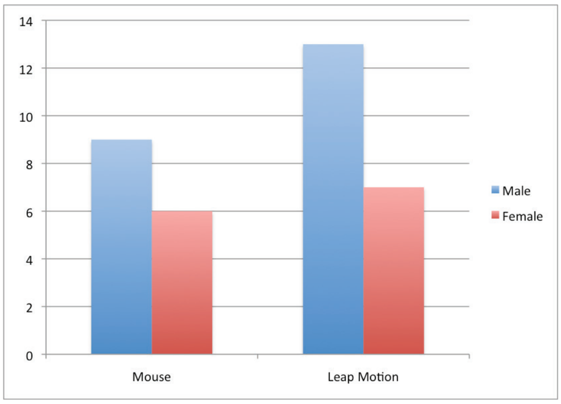

Figure 7. Number of participants in mouse and Leap Motion conditions by gender.

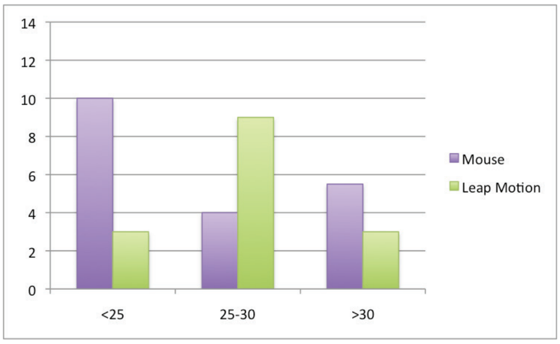

Figure 8. Number of participants in mouse and the Leap Motion conditions per age group.

The Mouse Condition

In Figure 9 the learning rate of the mouse condition is illustrated, showing that, at a second attempt, the user takes approximately 3 seconds less than the first time to reach the same target. The moderated learning curve is expected since we assumed that the mouse input interaction is (already) mastered by all users.

The Leap Motion Condition

The learning curve concerning the Leap Motion device is more accentuated since this is a practically unknown input device within our sample population. However, the interaction device is quite user-friendly, enabling performance time differences of even 8 seconds less in the second attempt to reach target than in the first.

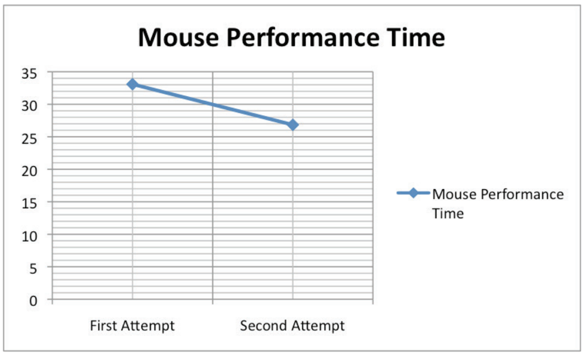

Figure 9. Learning progress on mouse condition

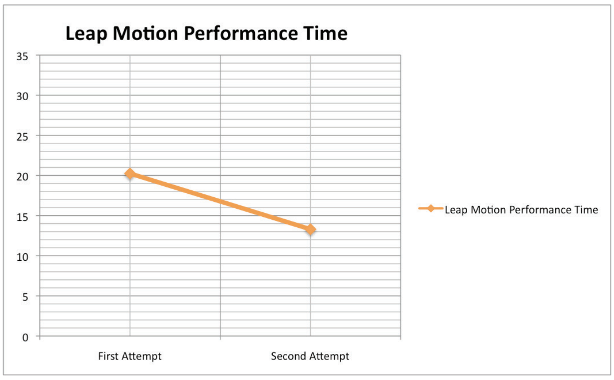

Figure 10. Learning progress on Leap Motion condition

Comparison between Conditions

To assure significance of the given values, a measure independent *t-test* was performed in both conditions for all three given tasks. In the first pointing task, we found significance in the performance time scores for Leap Motion (M=20.25, SD=8.96) and mouse (M=33.09, SD=16.99) conditions; t(30)=2.41, p = 0.05. The second pointing task showed the following t-test results regarding Leap Motion (M=4.88, SD=2.6) and mouse (M=2.46, SD=1.32) conditions; t(30)=3.59, p = 0.05. The third task, which involved mesh extrusion, did not achieve the minimum rate required by the t-test due to its high standard deviation: Leap Motion (M=19.45, SD=73.77) and mouse (M=33.09, SD=16.99); t(30)=0.4, p = 0.05.

Task 1

The first pointing task performed in this experiment has only one target describing a movement from starting point to target, meaning that there are no obstacles or other tasks within this trajectory. As we might observe, under the given constraints, 3D input interaction outperforms mouse interaction regarding the first pointing task (only one target).

After analyzing performance time means, correlation was found between gender and task completion time, showing that females outperformed males in the first pointing task in both conditions (cf. Figure 12).

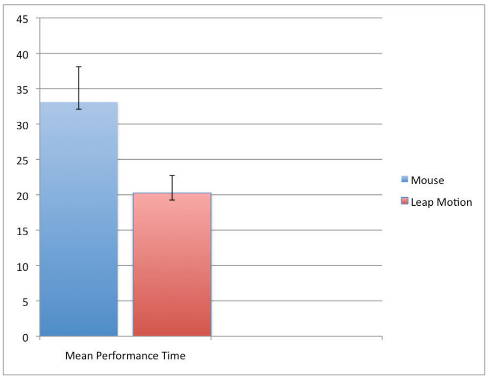

Figure 11. Comparing overall performance time means in both conditions (Task 1)

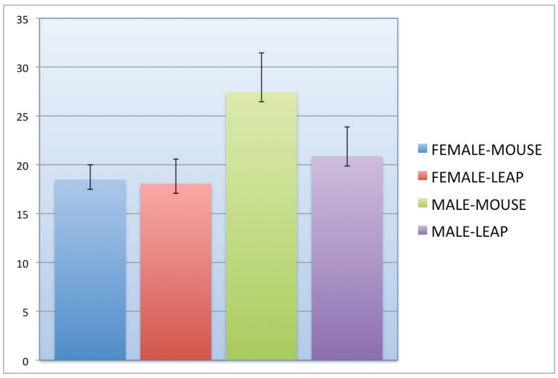

Figure 12. Comparison between performance time means in Task 1 for both conditions by gender

Below we can see a comparison between Leap Motion's and Mouse's learning curves concerning a single target task and considering performance time means regarding first and second attempt to reach the same target. Observing Figure 12 we can conclude that the mean performance time of the Leap Motion device shows much faster performance time compared to the mouse condition.

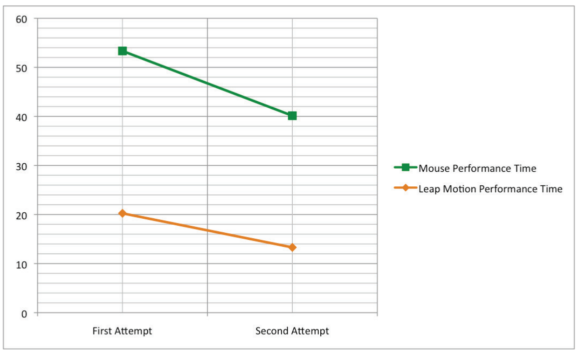

Figure 13. Comparing learning process of both devices

Task 2

The second pointing task contains two targets, assuming a trajectory described along starting point, 1st target and 2nd target. The value we considered in the data analysis and geometric calculations is equal to the spatial difference between target 2 and target 1. Unlike the first pointing task, Task 2 showed faster performance times in the mouse condition. In our case this might suggest that the additional degrees of freedom inherent to the gestural interface might be misleading when consecutively aiming at targets with different "z" coordinates rather than aiming at one single target. It is important to remember that viewpoint manipulation was disabled and that in mouse condition, the "z" axis could be assessed through the roll of the mouse while in the Leap Motion condition the third dimension is achieved by finger-tracking.

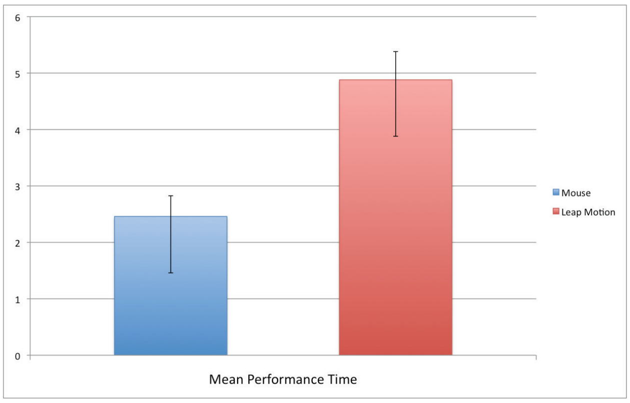

Figure 14. Comparing overall performance time means in both conditions (Task 2)

As we might observe, male and female subjects had a similar performance time in both conditions of Task 2. No significant difference was found between performance time and gender distinction.

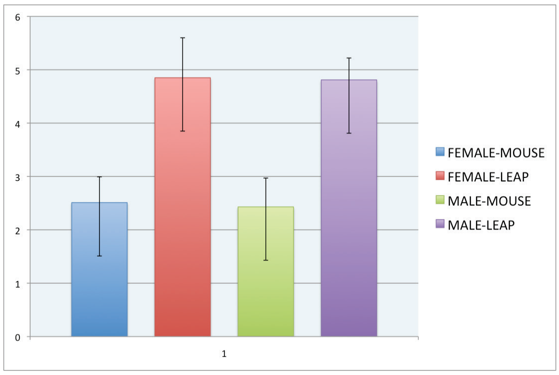

Figure 15. Comparison between performance time means in Task 2 for both conditions by gender

Comparison between qualitative measurement scores and performance time showed correlation between shorter task completion times and higher scores on the System Usability Scale, in which the Leap Motion condition scored higher, indicating a better satisfaction with the device. We must, however, consider that there might be a novelty effect caused by the unfamiliarity of the subject with the device, making subjects score higher on qualitative evaluations due to their interest in such new technology.

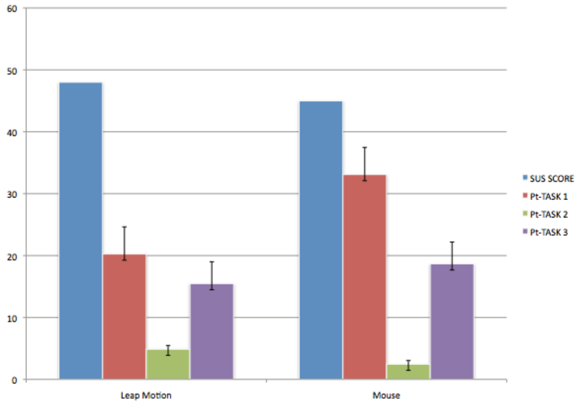

Figure 16. Relation between performance time means for each task and device compared to SUS score means

DISCUSSION

This study shows a comparative performance evaluation of pointing task interaction, showing that although 3D input interaction is qualitatively very well rated by the participants, accuracy is still an important issue that in more dynamic virtual environments can greatly compromise performance time.

From our sample population we could conclude that single target tasks were really simple to perform in the virtual environment with the gestural interface, but the same did not happen once multiple targets were arranged in the experiment. This can be explained by the fact that the second target was located behind the first target and the z-axis was accessed through mouse-roll interaction on the mouse condition, which is still much more accurate than the tracking performed by the Leap Motion, showing that inaccuracy of the tracking can dramatically compromise performance time.

Interestingly, gender correlations were found showing that the females outperformed males in the first pointing task regarding performance time.

CONCLUSIONS AND FUTURE WORK

Based on the results from the experiments, we can conclude that, within the constraints of the tasks developed in this research, the presented 3D input device outperformed mouse interaction only in single target situations, showing that 3D translation is less cumbersome when the "z" axis is provided as input based on real-life movement mappings. However, accuracy issues can prejudice performance time of more complex spatial movements (multiple targets).

Negative aspects of using the 3D input device for complex spatial interactions were reported in the development stage. Device accuracy issues are one of the biggest challenges for the popularization of those 3D input devices. Still concerning 3D tasks, expert users have shown in both quantitative and qualitative studies to be extremely biased towards mouse interaction, electing the mouse as the most reliable and practical device for manipulating 3D objects.

Further investigations and experimentations into *viewpoint manipulation* and *application control* is strongly recommended, since that would provide us with more clear guidelines on how to fully interact with a given 3D software by means of 3D input devices, including window and menu navigation, state changes and camera control.

In order to assess the performance of other available 3D input devices when modeling and manipulation 3D virtual objects, further research should be guided considering a broader selection of 6DoF input systems, enabling a more complete overview of the advantages of one technique over of a second, or third one. It is interesting to point out that making an assessment of the weak aspects from the evaluated 3D input systems could contribute with the development of existing or novel interaction devices.

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