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Abstract

There has been a lot of interest regarding the possibilities that the motion sensing technology in the Wii Remote can offer. This study investigates the feasibility of using the Wii Remote for 3D interaction in immersive Head-Mounted Display (HMD) virtual reality. Normal usage of the Wii Remote requires that the controller to be pointed in a certain direction, typically towards the display. The requirements of an input device for interaction in immersive HMD virtual reality differ from that of normal display systems, in that the user should ideally be able to turn around in the virtual environment. A number of design considerations are discussed, followed by a description of how the Wii Remote can be used in a space around the user. This paper also presents results of an experiment that was conducted to ascertain the accuracy of the device when used in a particular configuration.

Keywords

Wii, Remote, input, device, for, interaction, immersive, head, mounted, display, virtual, reality

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THE WII REMOTE AS AN INPUT DEVICE FOR 3D INTERACTION IN IMMERSIVE HEAD-MOUNTED DISPLAY VIRTUAL REALITY

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ABSTRACT

There has been a lot of interest regarding the possibilities that the motion sensing technology in the Wii Remote can offer to games as well as to other interactive applications. This study investigates the feasibility of using the Wii Remote for 3D interaction in immersive Head-Mounted Display (HMD) virtual reality. Normal usage of the Wii Remote requires that the controller to be pointed in a certain direction, typically towards the display. The requirements of an input device for interaction in immersive HMD virtual reality differ from that of normal display systems, in that the user should ideally be able to turn around in the virtual environment. A number of design considerations are discussed, followed by a description of how the Wii Remote can be used in a space around the user. This paper also presents results of an experiment that was conducted to ascertain the accuracy of the device when used in a particular configuration.

KEYWORDS

3D interaction, head-mounted display, immersive, virtual reality, Wii

1. INTRODUCTION

The motion sensing technology incorporated in Nintendo Wii's video game controller, the Wii Remote (informally known as the 'Wiimote'), is recognized by many as the next evolution in game technology. It has revolutionized the way games will be developed and played, and has opened up gaming to people of all ages and abilities [Nintendo]. In addition, it has also given rise to many interesting possibilities in terms of motion sensing for other applications.

While to date Nintendo has not released any official documentation about the specifics of the motion sensing technology contained within the Wii Remote to the public, there have been a lot of interested parties among the general public that have tried to reveal and share information about how this game controller operates. With this abundance of information combined with the fact that the Wii Remote can easily be connected to a computer via a Bluetooth connection, many people have applied the Wii Remote to a variety of applications that do not make use of the Wii game console.

There has also been much interest regarding the possibilities that the Wii Remote can offer among researchers alike. Researchers have used the Wii Remote for a variety of purposes, such as for gesture recognition based applications [Castellucci and MacKenzie 2008; Schlömer et al. 2008; Seedharam et al. 2007], robot control [Lapping-Carr et al. 2008], and others [Bruegge et al. 2007; Lee et al. 2008; Shirai, A. et al., 2007]. While a variety of motion sensing devices have surfaced over the years, the advantage of the Wii Remote is that it is a low-cost wireless device that combines an infrared sensor with accelerometers, vibration feedback, a speaker and a variety of buttons all within a single device. Furthermore, it can also be connected to a number of other low-cost extensions, like the 'Nunchuk' extension, which in addition to 2 buttons and a control stick also has similar motion-sensing technology [Nintendo]. In addition, given its widespread popularity, it is a device that is familiar to many people.

This study investigates the possibility of using the Wii Remote as an input device for immersive Head-Mounted Display (HMD) virtual reality. There are a number of existing endeavours by others who have used the Wii Remote in other virtual reality applications. Of particular significance and relevance is Johnny Chung Lee's popular head-tracking for desktop virtual reality display using the Wii Remote application [Lee], as well as using the Wii Remote as an input device for a virtual reality theatre [Schou and Gardner 2007] and for an immersive dome display [Bourke]. Due to various limitations of the Wii Remote (discussed in section 2), it is impractical to use it for user head-tracking in immersive HMD virtual reality. This is because head-tracking speed and accuracy is vital in such systems otherwise the user may suffer from a variety of adverse side effects known as simulator sickness [LaViola 2000]. However, the Wii Remote may adequately serve as an input device for interaction in immersive virtual environments.

The requirements of an input device for 3D interaction in immersive HMD virtual reality differ from that of normal display systems. This is due to the fact that unlike normal display systems where the user simply faces the screen, immersive HMD virtual reality systems are head-tracked systems where the display of the virtual environment is updated based on the user's head position and orientation, and the user can typically turn 360 degrees around the horizontal plane. Therefore, in order to interact adequately with objects in the virtual environment, these systems typically require a larger interaction space around the user. Normal usage of the Wii Remote requires the user to point it in the direction of the display screen. This is too restrictive for the purposes of immersive HMD virtual reality. The goal of this study was to design a method whereby the Wii Remote can be used in a 360 degree space in the horizontal plane around the user, rather than having to confine usage to a limited direction.

Even though there are a large number of technologies and approaches that are used for motion sensing and tracking, it has been pointed out that each approach available today has their respective advantages and limitations, and that there is no single technique likely to emerge to solve the problems of every technology and application [Welch and Foxlin 2002]. In that sense, if it is possible to work around the limitations of the Wii Remote, it would present a motion sensing input device that is a lot cheaper than other commercially available 3D input devices that are commonly used for immersive head-tracked HMD virtual reality systems. This could potentially be useful for applications such as virtual reality games. This paper discusses some of the design issues that had to be considered, presents a method of using the Wii Remote with such a system and evaluates its accuracy.

2. DESIGN ISSUES

This section discusses some factors that were considered when attempting to use the Wii Remote as an input device in a space around the user.

2.1 Limitations

Shirai et al. [2007] highlight the fact that there are a lot of problems with using the Wii Remote for motion detection. Unlike fully self-contained inertial sensing devices which require 3 accelerometers and 3 gyroscopes, the Wii Remote only has 3 linear accelerometers but does not use gyroscopes. Instead, these 3 accelerometers are combined with optical sensing. Optical systems require light sources and optical sensors, the main disadvantage of such systems is that there must be clear line-of-sight between the source and the sensor [Welch and Foxlin 2002]. In this regard the Wii Remote is no different.

The linear accelerometers in the Wii Remote are oriented along 3 orthogonal axes and the readings from these accelerometers can be used for tilt sensing, to estimate pitch and roll orientation of the controller with respect to gravity. This can be done directly as long as the acceleration is not due to hand movement. However this orientation information can only be obtained from the accelerometers that are not inclined in parallel to the direction of gravity [Tuck 2007; WiiLi.org]. Therefore, some other method is required in order to determine the controller's yaw. Note that designation of the controller's yaw, pitch and roll may vary depending on how the Wii Remote is used, whether vertically or horizontally.

In addition to the accelerometers the Wii Remote uses a 2D infrared sensor, mounted in front of the controller, and a 'sensor bar' for relative positioning. The infrared sensor can detect up to 4 infrared light sources and reports these as relative 2D coordinates. Nintendo's official sensor bar basically consists of two groups of infrared LEDs, with wavelengths of around 900 nm without modulation, located at either end of the bar. Since the infrared sensor can detect any infrared light source, care must be taken to minimize the likelihood of the sensor detecting any unintended infrared light sources (e.g. sunlight). However this also means that one can arrange up to 4 infrared light sources in any configuration to suit a particular application as long as they are within the sensor's limited field-of-view. While different sources have reported different field-of-view measurements, the general consensus is that it is rather limited [Schou and Gardner 2007; Shirai et al. 2007]. For the purpose of this study, it was essential to find a solution to overcome this field-of-view limitation, other than the obvious but rather impractical solution of surrounding the user with infrared light sources.

2.2 Optical Sensing

There are two design alternatives when using optical systems [Welch et al. 2001]. The first is the *outside-looking-in* approach, in which an optical sensor(s) is placed at a fixed location and landmarks (e.g. the infrared LEDs) are mounted on the user. This was the approach adopted thus far in Johnny Chung Lee's Wii Remote projects [Lee]. The other alternative is the *inside-looking-out* approach where the sensor is moving whereas the landmarks are placed at fixed locations in the interaction space. Normal usage of the Wii Remote uses this method, where the sensor bar is placed at a fixed position, either above or below the TV, and the user moves the controller. This method was used very effectively in UNC's HiBall tracking system, where infrared LEDs are fitted into the ceiling, to develop an extendable wide-area optical tracking system [Welch et al. 2001].

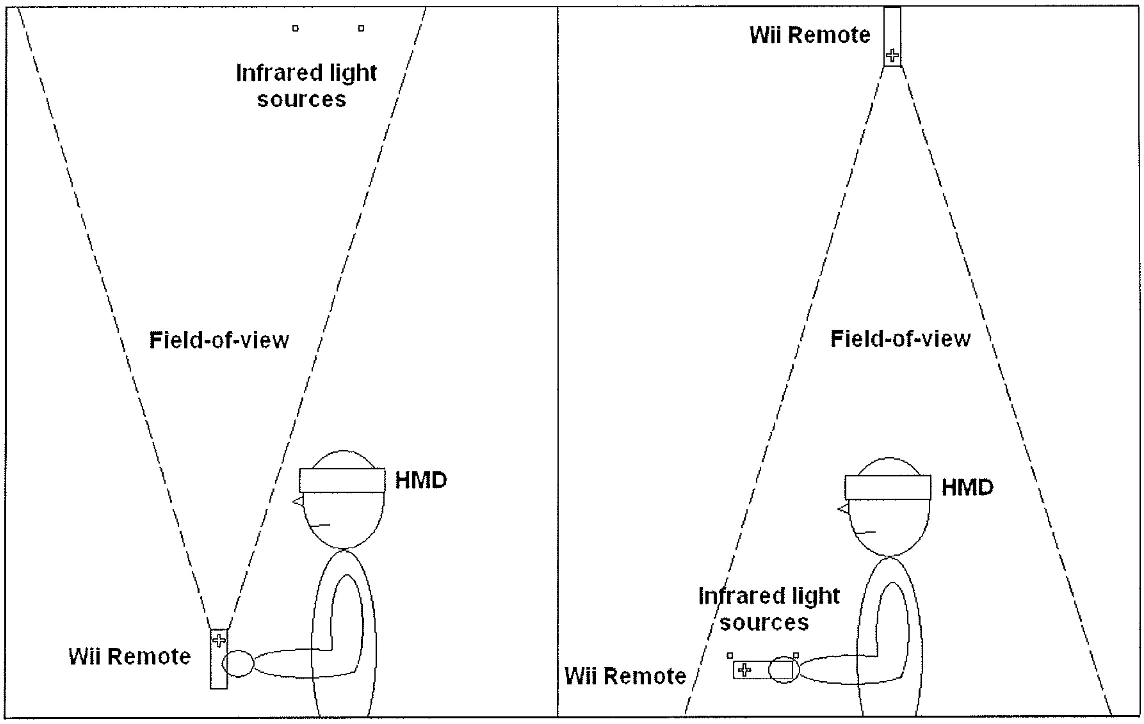

Figure 1. Configurations for (a) Inside-looking-out approach (b) Outside-looking-in approach

Both outside-looking-in and inside-looking-out techniques were considered for this study. Figure 1 shows two configurations whereby the Wii Remote can be used in the space around the user. The advantage of the inside-looking-out approach depicted in figure 1a is that like the design of UNC's HiBall tracking system, this system can be extended to a wide-area with ease by fitting many infrared light sources at multiple locations above the user. This approach is non-intrusive and is also less likely to be affected by other sources of infrared light, so long as the lights in the room do not emit light in the infrared domain. Furthermore, by using this arrangement multiple Wii Remotes can be used in the same environment, which would be useful for tracking multiple targets or multiple users. However, in order to maintain line-of-sight the controller always has to be directed upward and if used as a pointing device, users intuitively tend to point the controller lengthwise.

In the outside-looking-in approach illustrated in figure 1b, two Wii Remotes have to be used. The Wii Remote that the user holds is used to estimate pitch and roll information using the accelerometers readings, whereas the controller mounted above the user is used to estimate the controller's yaw as well as position in 3 dimensions using the 2nd controller's infrared sensor. For this approach, in order to maintain line-of-sight and to create an adequate interaction space around the user, the 2nd controller cannot be mounted too close to the user. In principle, instead of using the 2nd Wii Remote any infrared camera will do. Nevertheless, the Wii Remote's infrared sensor is convenient to use and has a higher update rate compared to most low-cost web cameras. While both of these arrangements provided a 6 Degree-of-Freedom (DOF) interaction space around the user, the later approach was the one used in the experiments.

One of the other issues with the Wii Remote is that the raw readings from the controller are not particularly stable. Even if the controller is placed on a flat motionless surface, the readings constantly fluctuate. Therefore experiments had to be conducted to determine the accuracy of the system.

3. METHOD

This section describes how the Wii Remote was used as an input device for 3D interaction in a virtual environment, and how the environment was designed to obtain some accuracy measurements.

3.1 Virtual Environment Interaction

Input devices are physical tools that are used to implement various interaction techniques in virtual environments. The challenge is how to naturally and efficiently map an interaction technique onto a given input device [Bowman et al. 2001].

The majority of interactions that arise from common tasks in immersive virtual environments fall into a small number of general categories. These may include travel or navigation of the user's viewpoint within the virtual environment, as well as virtual object selection and manipulation [Bowman 1999]. In selection tasks, a user singles out a specific object or point in a virtual environment [Wingrave et al. 2002]. There are a number of different approaches that have been used for selection tasks, this study uses the ray-casting selection and occlusion selection approaches.

In the ray-casting approach, a ray is projected from a 'virtual' 3D interaction entity (often shaped like a virtual human hand) into the virtual environment. When the ray intersects an object, the user can usually select this object through a button press on the input device. The occlusion approach is similar to the ray casting method in that a ray is projected into the environment; however in this case the ray emanates from the user's eye, through a point (typically the tip of a virtual 'wand' or virtual hand is used as the 3D cursor), then into the environment. So in this case, the user does not actually see the ray. The object that the user selects is the object that is occluded by the 3D cursor. Both of these techniques have been shown to have similar performance times, but occlusion selection is believed to be more accurate albeit more fatiguing for the users [Bowman et al. 2001; Wingrave et al. 2002].

Screenshots depicting a portion of the virtual environment are shown in figure 2; figure 2a shows the ray-casting selection method, where the ray emanated from the tip of the virtual gun, and figure 2b shows the occlusion selection technique, where the ray passed through the tip of the virtual wand and into the environment in the direction of the camera's viewpoint. The user selected an object by pressing a button on the Wii Remote.

3.2 Experimental Setup

For the experiments, a Nintendo Wii Zapper gun mount was used with a sensor bar attached to the mount. This minimized the chances of obstructing line-of-sight between the light sources and the sensor, because when holding the gun the user's hands would always be below the infrared light sources. Pitch and roll information were obtained from the accelerometer readings of the Wii Remote that was inserted in the gun mount, whereas yaw and position were estimated from the infrared sensor on the 2nd controller above the user. Height was estimated using the separation between the 2 infrared sensor readings and the controller's pitch. While this study only used 2 infrared light sources, it is possible to attach 4 infrared light sources on the input device in a non-planar arrangement to obtain more accurate yaw and position readings [Kreylos]. This was left for future work.

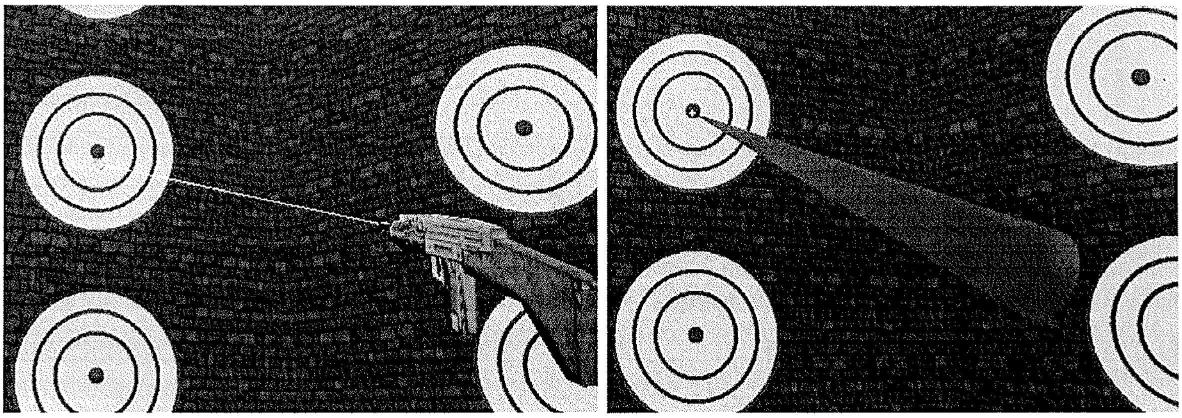

Figure 2. Interaction techniques for selection tasks (a) Ray-casting selection (b) Occlusion selection

This arrangement allowed limited 6-DOF; 360 degrees yaw but approximately +/- 45 degrees pitch and roll, as anything above greatly increased the likelihood of loosing line-of-sight. This can be improved by increasing the number of infrared LEDs in a group and aligning their directions to give a wider angle. The 3D positional estimates were confined to be within the sensor's field-of-view. Navigation in the virtual environment was implemented using the Wii Remote's Nunchuk extension, which was attached to the gun mount. The user could control viewport translation by manipulating the Nunchuk's control stick. This setup was adequate as an input device in an application where the user donned a head-tracked HMD and sat on a swivel chair, as this limited the user's translational movement while at the same time allowed the user to rotate around. An eMagin Z800 HMD was used to display the virtual environment and a Polhemus Patriot 6-DOF magnetic tracker was used to track user head position and orientation.

Using raw unfiltered readings from the Wii Remotes, gave very poor position and orientation estimates as the readings were not steady and jittered significantly. Therefore an experiment was designed to ascertain and to compare the accuracy of the setup, using the ray-casting selection and occlusion selection techniques described above, in relation to pitch and yaw angles, distance of the targets from the user as well as how much a simple smoothening factor (for small movements: $0.9 \times$ old value + $0.1 \times$ new value) would increase the accuracy.

The virtual environment used in the experiment consisted of targets located at yaw angles of 0, 30, 60 and 90 degrees and pitch angles of 0, 15, 30 and 45 degrees, giving a total of 16 targets (refer to figure 2 for some screenshots). Angles in other quadrants would merely mirror these. With the base of the gun placed on a stable surface, the user had to try to hold the ray steady within the target's bull-eye. Accuracy was determined by how much the ray missed the target's bull's-eye by. 1000 readings for each target were taken at 60Hz, which meant that the user had to direct the ray at each target for around 16 seconds. This was repeated for target distances of approximately 5 metres and 10 metres away from the user, repeated using the different selection techniques and for the cases with and without smoothening.

4. RESULTS AND EVALUATION

Figure 3 shows the average of how much the ray missed the target's bull-eye for ray-casting selection, and figure 4 shows the standard deviation of the accuracy measurements. It is not surprising that the results indicate that accuracy decreases with distance from the user. Of particular significance is the fact that accuracy decreases at higher pitch values. This is probably because when the gun is tilted at steeper angles the distance between the 2 points that are detected by infrared sensor's decreases, making position estimates more susceptible to jitters in the readings. The simple smoothening factor increased accuracy for high pitch

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values, but did not seem to significantly increase accuracy for low pitch values. Moreover even with the smoothening factor, it can be seen that the ray still considerably missed the target's bull's-eye. Not much can be inferred about whether the yaw readings affected accuracy.

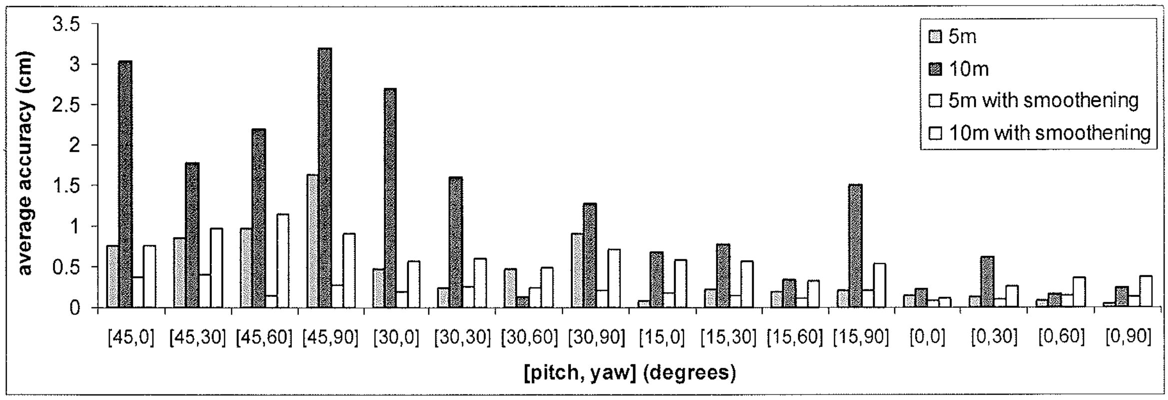

Figure 3. Average accuracy for ray-casting selection

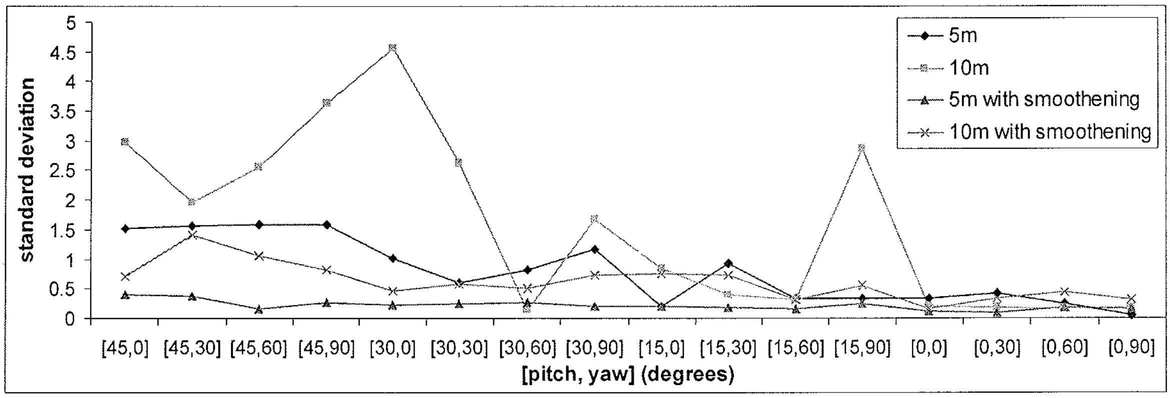

Figure 4. Standard deviation of ray-casting selection's accuracy

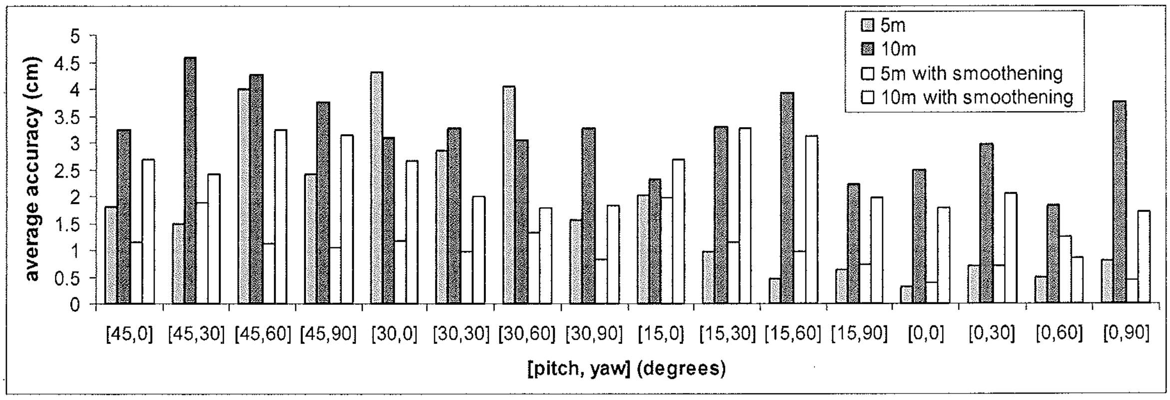

Figure 5. Average accuracy for occlusion selection

Figure 5 shows how much the ray missed the target's bull-eye for occlusion selection, and figure 6 shows the standard deviation of these accuracy measurements. These results also suggest similar conclusions, in that accuracy deteriorates with distance as well as at higher pitch angles. It is noteworthy that the results for occlusion selection are worse than that of ray-casting selection. This is possibly because in the ray-casting approach the orientation information from the input device plays a greater role, whereas in the occlusion approach the position of the input device is of greater importance. This in turn indicates that the orientation estimates of this application are more accurate than the position estimates.

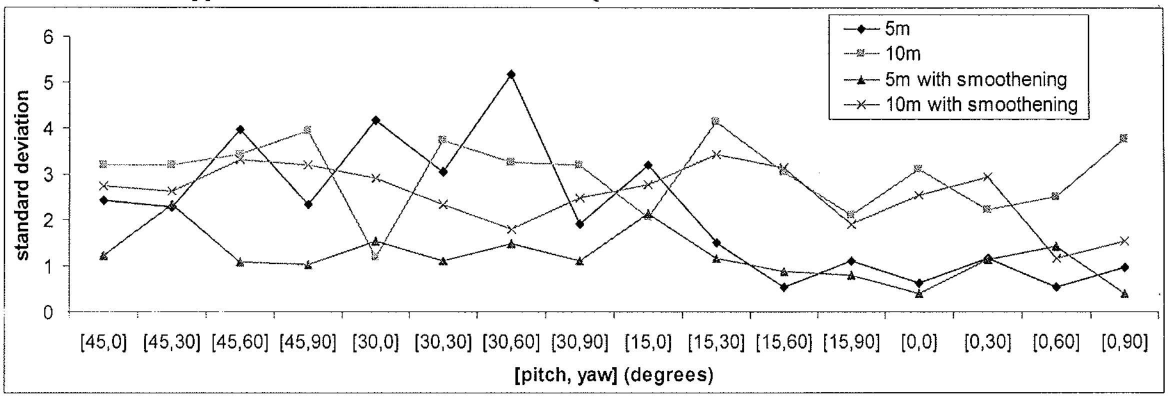

Figure 6. Standard deviation of occlusion selection's accuracy

From the results of the experiment, it can be seen that some kind of filter is required in order to improve the position and orientation estimates of the system, before it can be used adequately for more accurate 3D interaction.

5. CONCLUSION AND FUTURE WORK

This paper shows how it is possible for the Wii Remote to be used in an interaction space around the user for immersive HMD virtual reality. This presents a low-cost, albeit inaccurate, input device for 3D interaction in immersive virtual environments, which can be used for applications such as virtual reality games. Future work will focus on improving the accuracy of the system by increasing the number of infrared light sources and by finding an appropriate filter to smoothen the position and orientation sensing. Usability studies will also be conducted to assess user performance and satisfaction in conjunction with the system.

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