WiiRtrack - an evaluation of a low cost head tracking based on the Wiimote

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Abstract

This paper presents the quality evaluation of a low cost head tracking system based on Nintendo Wii. WiiRtrack was implemented with the use of one Wiimote [1] infrared (IR) camera and a custom built LED transmitter. For evaluation purposes it was compared with a high end commercial two camera tracking system. Our system creates a platform that enables everyone to build a low cost head tracking system. The results indicate that the system is suitable for confined work spaces and is also as stable and accurate as the commercially available system.

CR Categories and Subject Descriptors: I.3.7 [Computer Graphics]: Virtual Reality H.5.2 [Information Interfaces and Representation]: Input Devices and Strategies

Additional Keywords: low cost head tracking, Wiimote, wiiuse, evaluation of tracking systems

1. Introduction

Within the Virtual Reality (VR) community is still a need for stable, low cost and easy to handle tracking systems. Often the first step into immersion requires tracking of the user's head and a correctly rendered perspective for the user. These head tracking systems are available nowadays, but they still have a long way to go to achieve a mass consumer acceptance.

This paper presents our current work on the low cost tracking solution WiiRtrack that uses the Wiimote IR camera. Section 1 and 2 are introduction and previous related work on this topic. In section 3 the integration process of the Wiimote as a translational tracking device with the use of the Wiiuse-0.12 [3] library is presented. The theoretical accuracy and work space of the WiiRtrack system are determined in section 4. In section 5 the setup for measuring is described, while in section 6 the actual measurements and the comparison of our system and the well known A.R.T [5] marker based video tracking are presented. Finally section 7 will conclude our results and give an overview on our plans for the future.

The main contribution of this work is the preliminary positional evaluation of our system including the theoretical considerations, the comparison of WiiRtrack with an A.R.T. system and the error discussion. The theoretical consideration will describe the physical limitations of our solution concerning tracking volume and accuracy. The comparison will point out the differences and similarities of the two systems, and the error discussion in section 5 focuses on the main error sources of our experiment and their severity in our computations.

2. Related Work

The development of tracking systems for immersive virtual environments has a long history. In the early phase electromagnetic systems have been widely used as e.g. Polhemus FasTrack [7] or Ascension Flock of Birds [8]. They are now superseeded mainly by the more accurate and often more robust video based systems as Vicon [13], A.R.T [5], etc. or hybrid systems as Intersense [2]. Many Publications have been on systems and its algorithms itself as e.g. [9][10][11] and on the calibration as described in [12]. The problem with the therein described performance is that there is to our knowledge no agreed measurement procedure for comparable results. For video-based tracking, there has been a proposal for a measurement framework by Smit [14] which seems to be suitable only for the evaluation of the actual algorithms.

This observation seems even true for low cost systems. This may be due to the fact that they are only commercially available for a short period of time or their performance is obviously so poor that there is no use in evaluating. Both reasons might not hold for the Nintendo Wii. It is maintained by a big company and a proof of concept with promising properties has been shown by Johnny Lee [4]. This was the starting point for our own investigations. Our contribution to the former is the comparison of the work Johnny Lee has started with an established video tracking system, which has, at least to our knowledge no one made publicly available yet.

3. Low cost tracking using the Wiimote

With the use of Wiiuse-0.12 library we were able to read data out of the Wiimote blue-tooth stack. The Wiimote delivers different data: the already calculated cursor position in x y z, the pixel coordinates of maximum 4 IR dots, the dot size and a distance of the target from the camera. Since we want to support custom built targets, we must implement a method that calculates a three dimensional position out of the 4 returned IR dots. We implemented a real world position calculation based on the mathematical theorem on intersecting lines. To be able to translate the pixel distances in real world coordinates we initialize the system using a fixed Z-distance between the Wiimote and the

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target which has fixed size. Our target uses two LED's with a marker distance of 17 cm. The initial Z-distance was 57 cm to the Wiimote (see figure 1).

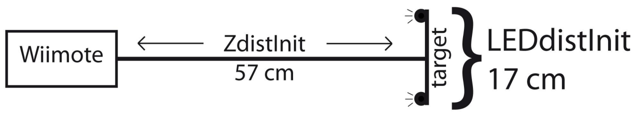

Figure 1. Initialization of the Wiimote

The initialization enables us to translate the pixel distance (pixDist) of the two target LED’s (markers) into real world coordinates. For this transition we used the following formulas. The orientation of the coordinate system is illustrated in figure 3.

Zconst = ZdistInit * TargetPixDistInit

ActualZPos = (Zconst / TargetPixDist)

cursorPos = (IRdot1 – IRdot2)

ActualXPos = (XcursorPos) / (pixDist / LEDdistInit)

ActualYPos = (YcursorPos) / (pixDist / LEDdistInit)

After the initialization phase more than two IR dots may appear on the camera due to noise. Therefore, we implemented a filter mechanism, which activates if there are more than two IR dots and compares all possible marker distances of all visible IR dots with the saved marker distance of the last simulation step. Then it chooses the two IR dots with the smallest difference to the marker distance of the last simulation step. We have decided not to follow the single dots position, because if the target is close to the camera the change of a single point could be much greater than the change in the distance of two.

4. Theoretical considerations

Before the practical evaluation of the two tracking systems a theoretical estimation of the maximum possible accuracy and the tracking volume of the Wiimote IR camera has been made. The measured marker distances in Wiimote pixel space are mapped to the physical reference frame. The theoretical accuracy of the Wiimote in Z (distance to the IR camera) depends on the marker distance of the two LED's. The maximum tracking volume in XY (left, right, up and down to the IR camera) depends on the Z-distance and size of the tracked target.

1.1. Accuracy of a Wiimote

The Wiimote has a field of view of 45 degrees and a range dependant to the power of the used LED in the target.

The resolution is interpolated for all pixels. This interpolation illustrates all possible Z-distances of the Wiimote for a specific target, where the difference of the last position and the current position represents the actual resolution. For example we have a target with 17 cm marker distance at a Z-distance of 66 cm from the Wiimote camera. If the target moves closer to the Wiimote such that the targets LED will be one pixel wider in the camera the calculated position will jump from 66 cm to 65.8 cm. We have a actual resolution of 0.2 cm that is calculated as follows.

Raster = (ActualZPos – LastZPos)

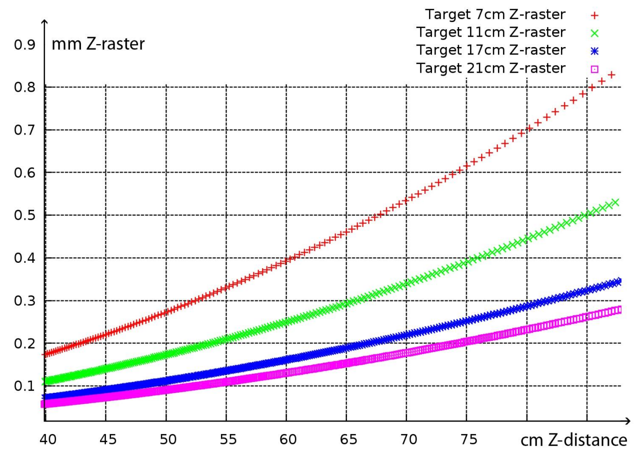

Figure 2. Z accuracy raster depending on target size

1.2. Tracking volume of a Wiimote

Corresponding to the marker distances we have determined the theoretical tracking volume in the XY-plane (see figure 3). This is based on the initial measurements with regard to an object that has one pixel size in the current X or Y direction.

Field of view = (CamRes) / (TargetPixDist / LEDdistInit)

For a tracker distance of 63cm from the camera the tracking volume of the Wii is 50x37cm.

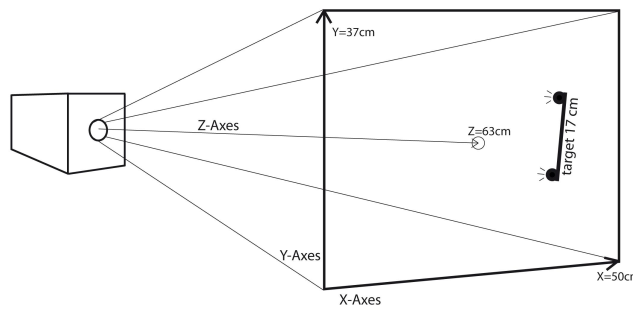

Figure 3. X-Y Tracking plane at specific Z-distance

1.3. Summary

The accuracy and the tracking volume are contrary since the resolution depends on the used target size that is the marker distance. The larger the targets size, the more precise is the resolution, but it obviously reduces the tracking volume. Therefore the optimum depends on the application and is a trade off between needed workspace volume and accuracy.

5. Setup for measurement

For the measurements we built an experimental setup (see figure 4) combining the WiiRtrack with the A.R.T. tracking system. The A.R.T. target was fixed together with our custom target in order to initialize both systems simultaneously. The target should be in a predefined distance to the camera.

Figure 4. Experimental setup for dynamic measurement

To be able to evaluate the accuracy of our measurements and to optimize our setup we made an error analysis. For the initial configuration we have used a water-level to keep the breadboard horizontally aligned, an optical laser measurement tool to measure distances with an accuracy of 1.5 mm, the A.R.T. tracking system with a mean accuracy of 0.9 mm [5] and an angular stop.

In order to position the breadboard precisely, the mounting of the targets and also the camera position have to be set up correctly. From all these sources the rotational deviations of the cameras with respect to the fixed breadboard were detected as the most critical source of error.

Our system can report wrong target positions if the following factors are not set accurately:

- Measured distance between the WII IR camera and the target,
- Mounting plate heading not being aligned to the cameras.

With our laser measuring tool we were able to align the breadboard's heading with accuracy below 1 degree. This still leaves a margin error of 3.5 mm at the maximum Z-distance 20 cm from the virtual origin. To reduce this error we additionally positioned the breadboard with the use of the A.R.T. system. This double checked setup should improve our margin of error below 1.0 mm at the maximum Z-distance. Since the source of error is linear and will affect both tracking systems we accepted this error.

6. Comparison

In our experiment we compare the custom built IR tracker with a commercially available system from A.R.T. We set up two categories of experiments: Firstly static measurements, where both targets were mounted on a static breadboard with predefined locations and secondly dynamic measurements, where both targets were moved simultaneously in order to confirm that the results of the static measurements could be transferred to a dynamic environment.

During the first set of experiments, the targets were measured in fixed, predefined positions. This time the targets were mounted on a breadboard with a fixed position to each other. The breadboard had drilled holes, where the targets could be placed (see figure 5). The holes had 10mm distance to each other with an accuracy of 1/100mm. Again, we initialized both tracking systems at the same frame of reference at 0,0,0. However, this time the movements made after the initialization had absolute differences with each other of 10mm. Therefore we were able to measure the positional accuracy of both systems.

During the second set of experiments, we measured the targets while moving. Our main consideration to identify the behaviour of the custom built system while it is in motion. Therefore, we mounted both targets on a plate, moved by step motors. Then we initialized both tracking systems at 0,0,0. Afterwards the experiment was conducted by moving the plate up and down along the Y direction. During this set of measurements no absolute values were recorded, but only the relative positions, reported by the two systems. This is a suitable method to show if our experimental low cost system can deliver comparable measurements like the commercial A.R.T. system whose measuring accuracy should be within 1mm [5]. The graphs in figure 6, 7 and 8 show the Z or Y distance to the initial origin.

Figure 5. Breadboard and mounting plate

1.4. Static measurement

The static measurements focused on the behaviour of the targets in Z and in X-direction and were made with a target size of 17 cm marker distance. The results in X-direction differ from those in Z-direction. It is evident, that we have some sort of quantization grid because the Wiimote is not delivering subpixel information. As mentioned in section 4.1 the outcome seems to be in line with the theoretical considerations. The expected quantization effects occur because the dot size is not considered. In figure 6 the Wiimote shows a resolution of 1.6 mm at a Z-distance of 61 cm. This is a coarse tracking quantization, but for low cost tracking system it seems to be sufficient and is comparable to the average error of electromagnetic tracking systems [6]. It can be seen that the A.R.T. has less quantization errors, but this is to be expected as they use 2 cameras a target with 5 markers and are able to include subpixels information for their calculations.

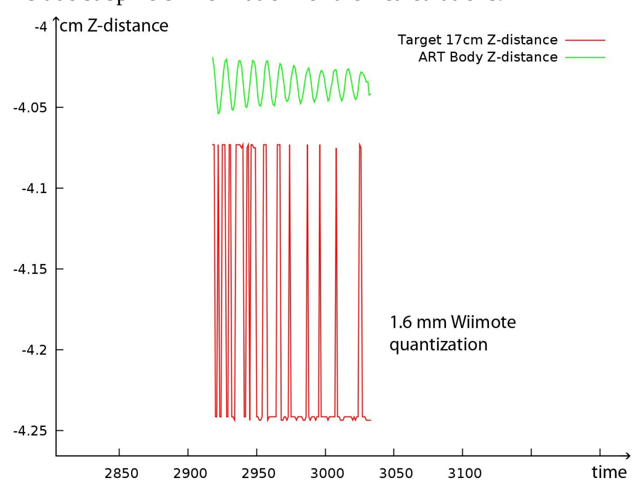

Figure 6. Quantization of the WiiRtrack compared to the A.R.T. system

For the Z-distance measurements the mount was moved backwards in 20 mm steps and 50 records of XZ position cycles were taken. The records show that the biggest problem for the Wiimote is the quantization jitter. The offset between the Wiimote and the A.R.T. system never exceeded two pixel steps (see figure 7). It follows that, the Wiimote accuracy is below 6 mm within Z-distances of 570 to 770 mm.

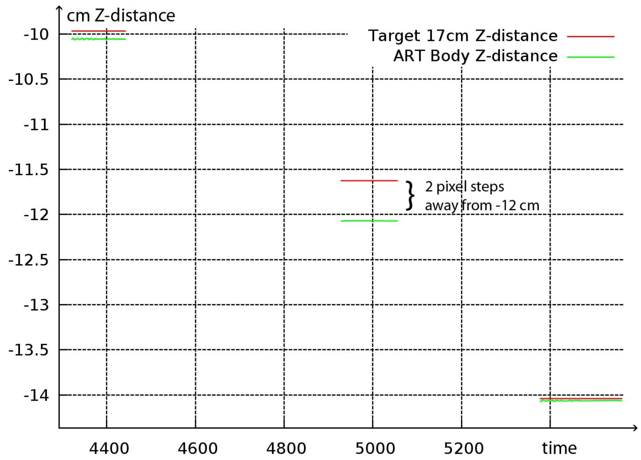

Figure 7. Absolute value for WiiRtrack and A.R.T

The results in X-direction showed no real difference between A.R.T. and our system. The difference of both targets lay below 1 mm and the Wiimote performed constant results in 70 cycles of measurements.

1.5. Dynamic measurement

The dynamic measurements recorded the relative performance of the Wiimote in comparison to the A.R.T. system and if there are any significant differences within the two records. Since head tracking is a dynamic process we used this method to confirm if our results of the static measurements can be transferred to moving targets. The dynamic measurements additionally focused on the approval of the hypothesis that the accuracy of a Wiimote in X-direction will be similar to that in Y-direction.

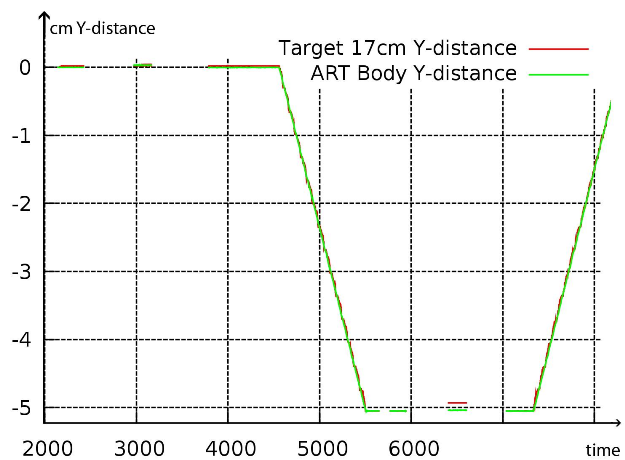

Figure 8. Dynamic measuring of the WiiRtrack and the A.R.T. system

To confirm this, 20 cycles of continuous up and down movements have been recorded. If no differences in the results of the XY-Axes occur, it is assumed that that there is no difference. Moreover, it was observed that the Wiimote offers the same speed in tracking as the A.R.T. Even at free hand movement, both systems report the same position at any given time.

7. Conclusion and future work

Our work with the Wiimote looks really promising and we will continue the development. Although it has its clear limitations with respect to range, number of targets being tracked and tracking volume, we think that for many purposes and setups this technology will be sufficient.

Our plans for future development are:

- Improvement of the tracking space by using more than one Wiimote
- Build a fixed setup where only a single calibration is needed.
- Use more than 2 LED's and other geometric configurations to increase accuracy and to be able to measure precise rotations.
- Improve filtering to suppress the quantization noise

The advent of low cost tracking devices in the consumer market is also an opportunity for industrial or research applications. The Wiimote is a perfect example of a capable yet affordable tracking system.

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