Video-Based Measurement of Tracker Latency

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1. Introduction

This paper describes a simple-to-implement method for measuring end-to-end tracker latency in projection base virtual environments such as CAVE.

Three-dimensional trackers are key components of most Virtual Reality systems. In projection based systems, they are used to determine the current position of the head of a user and the position and orientation of input devices. In head-mounted display (HMD) based systems, head trackers are more critical because the scene needs to be changed according to the current orientation of the user head.

There are several different kinds of tracking systems presently available, including mechanical, electromagnetic, acoustic, inertial, and optical ones. They have their own pros and cons. Currently, the most common technology used in VR community including EVL is electromagnetic, which has many advantages such as good resolution, low latency, no line-of-sight problem, not cumbersome. But the insurmountable problem with electromagnetic trackers is that they are distorted by environmental ferromagnetic and metal objects. Although calibration methods are used to correct such static errors, the calibration procedure is time consuming and they cannot work at all when the magnetic field "fold back" on itself [1] [2]. A new tracker system IS-600 introduced from InterSense is being evaluated by EVL because it is advocated that the system has not distortion problem and has lower latency. The IS-600 system is a hybrid acousto-inertial 6-DOF position and orientation tracking system. It tracks changes in orientation and position by integrating the outputs of its gyros and accelerometers, and corrects drift using a room-referenced ultrasonic time-of-flight range measuring system [3].

The most important requirement of a tracker is that it can track head or hand as precise as possible, i.e., its error should be as small as possible. Error of trackers could have two kinds, static error and dynamic error. The error when the tracker is still is static error, while dynamic error is caused by system latency. In HMD based systems, end-to-end latency is defined as the time difference between the moment that the tracking system measures the position and orientation of the user's head to the moment when the generated images corresponding to that position and orientation appear in the HMD [4]. In projection based systems, we can define the latter as the moment when the data of the position and orientation takes effect in the generated image. For example, the cursor moves to the position where it should be. Some research has shown that latency has more significant impact on human performance in virtual environment than static distortion [5] [6]. In augmented reality, the system latency has even more important impact on the whole system. The latency will make the virtual objects appear to "swim around" and "lag behind" the real objects and make the whole augmented reality system cannot be accepted. [4]

Measuring and comparing the amount of end-to-end latency is important in evaluating the usefulness of different tracking systems, and of different possible configurations of the tracking and overall VR system. No common way of measuring tracker latency has been defined as yet. Jacobs, Livingston and State measured the end-to-end latency of whole system by adding the end-to-end latency of the video camera and the relative latency between the video camera and the tracker [7]. Their method can only be used in their special situation. Wu and Ouhyoung compare the latencies of four prediction methods by letting some subjects to trace the flying target as close as possible and recording the error distance between the center of viewport and the center of the flying target [8]. Their results are not objective and the actual end-to-end latency does not measured.

In this paper, we are developing a video camera based test of latency of the tracker. Our latency measurement system uses an ordinary video camera to record movements of the tracked wand in a CAVE or an ImmersaDesk. This makes the tests very simple, as no unusual equipment is required.

2. The method

Our system involves a simple application that draws a marker attached to the tracked wand. The user moves the wand back and forth at moderate speed, while video is recorded of this action (of both the wand and the image on screen) as Figure 1. The recorded video is analyzed to determine the lag between wand motion and the motion of the image. By finding the difference of video fields between wand and the wand marker passes the same certain checkpoint on the screen, the latency can be determined with roughly resolution of 16 millisecond - the field time of NTSC video. Since typical VR systems currently experience latencies on the order of 40 to 150 milliseconds, this is sufficient for a quality check. We choose the checkpoint around the middle point of the wand motion because the speed of the wand arrives at maximum around the middle point. Therefore, the distance between the wand and the wand marker will be the maximum and we can make the judgement of whether the wand or the wand marker passes the checkpoint most precisely.

In our tests, we are using an InterSense-600 Mark2 tracking system. The IS-600 system is attached to an ImmersaDesk located in the Electronic Visualization Lab of University of Illinois at Chicago.

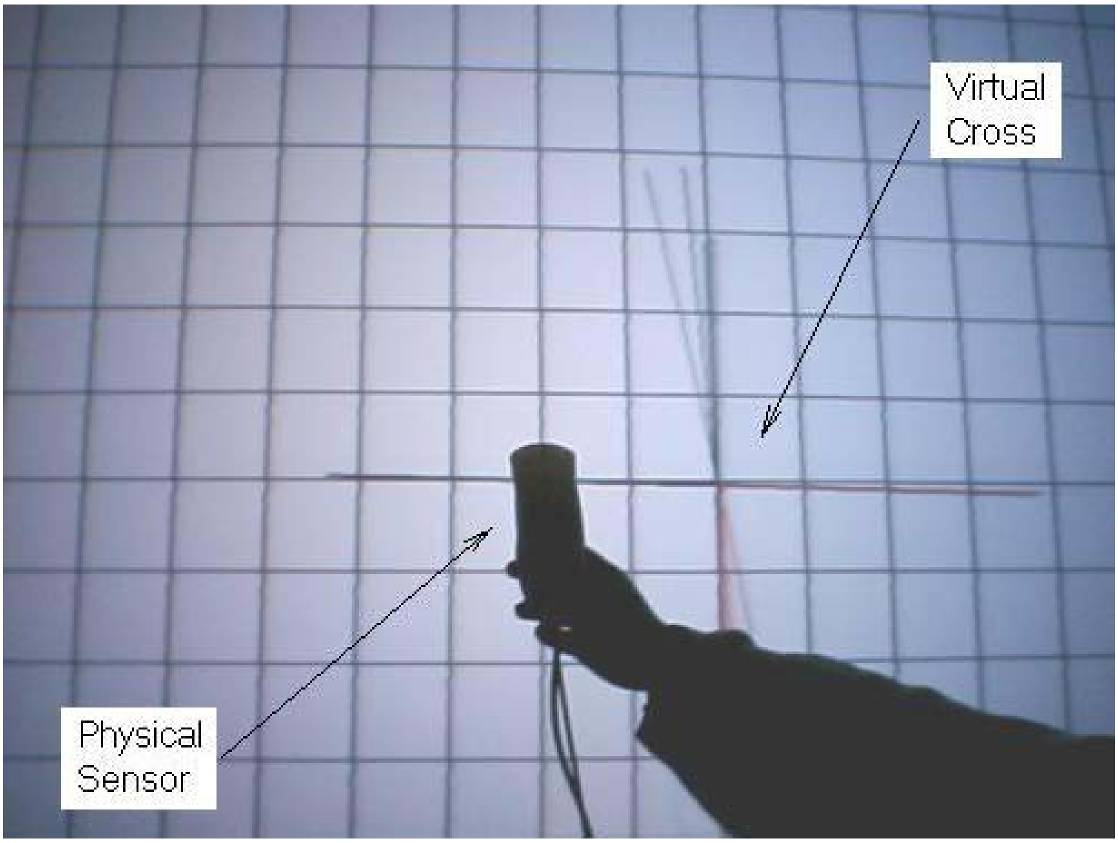

Figure 1 Physical sensor and virtual cross.

3. Analysis of the results

Through using this video-based measurement, we also conducted an analysis of different factors that influence the delay of a tracking system. In this analysis, we are mainly considering three factors that influence the delay in an IS-600 based tracking system: prediction, moving direction, connection type.

InterSense said that the model IS-600 with InertiaCube can predict motion up to 50 ms into the future [9]. The prediction value can be set on the base station of the IS-600 system. In our test, we use 3 different settings: 0ms, 25ms and 50ms.

Also when measuring the tracking delay, we found that the moving direction of the wand has some impact on the delay. So we consider the moving direction of wand as another factor. Apparently, there are 4 choices: up, down, left, right.

We have two kinds of connection types of the tracking system. One is to connect the IS-600 base station to the serial port of a PC, then the PC sends tracking data to the tracker daemon on a SGI machine using UDP socket (we call it with PC method). The other way is to connect the IS-600 base station directly to the serial port of a SGI machine (we call it without PC method).

The following are some tests we run with different settings. Because there are several factors that influence the result of out test, we use the "two factors with replication ANOVA" method to analyze the data.

Test1 Prediction

In this test, we use "with PC" connection method. The serial baud rate is 115200bps. We use different prediction values as different treatments, and use different moving directions as different blocks.

	pred. 0 ms	pred. 25 ms	pred. 50 ms
up	1	1	1.4
	1	1	1.4
	1.5	1	1.5
	1.7	1	1
down	3	1.9	2.5
	2.3	2	2.5
	2	2.2	1.6
	2	2.1	1.5
left	1.5	2	1.9
	1.3	1.4	1.5
	1.1	1.8	1
	1.2	1.7	1.4
right	1.9	2	2.5
	1.4	2	1.7
	1.9	2	2.1
	2.1	2.1	2.6

The null hypothesis is H_0: there is no difference between different prediction settings. The F-test gives a p-value of 0.78601, which means there is absolutely no evidence in favor of rejecting H_0. Intuitively, this means the prediction does not influence the delay.

Test2 Moving Direction

In this test, we use "with PC" connection method. The serial baud rate is 115200bps. We use different moving directions as different treatments, and use different prediction values as different blocks.

	Up	Down	left	right
pred.0	1	3	1.5	1.9
	1	2.3	1.3	1.4
	1.5	2	1.1	1.9
	1.7	2	1.2	2.1
pred.25	1	1.9	2	2
	1	2	1.4	2
	1	2.2	1.8	2
	1	2.1	1.7	2.1
pred.50	1.4	2.5	1.9	2.5
	1.4	2.5	1.5	1.7

1.5	1.6	1	2.1
1	1.5	1.4	2.6

The null hypothesis is H_0: there is no difference between different moving directions. The F-test gives a p-value of 1.61E-08, which means there is very strong evidence in favor of rejecting H_0. Intuitively, this means the moving directions have impact on the delay.

Test3 With PC and Without PC

In this test, we fix the prediction value as 25ms. The baud rate for both connection types is 115200bps. We use different connection types as different treatments, and use different moving directions as different blocks.

	Without PC	With PC
up	1.7	1.7
	2	1.7
	1.7	1.7
	2	1.5
	1.7	2.2
down	1.8	1.5
	1.7	1.5
	1.5	1.5
	1.6	1.5
	1.5	1.5
left	2.5	2
	2.5	1.5
	2	2.2
	3	2.3
	2.2	1.8
right	2.5	1.8
	2.2	2
	2.2	1.8
	2.3	1.5
	2.6	1.9

The null hypothesis is H_0: there is no difference between different connection types. The F-test gives a p-value of 0.000211, which means there is very strong evidence in favor of rejecting H_0. Intuitively, this means connection type have impact on the delay.

In order to test whether the average delay without PC is larger than with PC, we use Fisher's Sign Test, null hypothesis is H_0: delay without PC<=delay with PC, alternative hypothesis is H_1: delay without PC>delay with PC. The Fisher's Sign Test yields a p-value of 0.0021, which means there is strong evidence in favor of rejecting H_0. As Fisher's Sign Test is inherently a very conservative test, this result in fact shows that there is very strong evidence to support the conclusion that delay without PC>delay with PC.

The average delay without PC: 2.06 frames

The average delay with PC: 1.755 frames

4. Conclusions and Future Work

This paper has presented an end-to-end latency measurement method of virtual reality systems in projection based virtual environments. This method is very simple to implement, does not need unusual devices while ensuring certain precision. The analysis result of our system has helped us to make decision on configurations of our tracking systems.

The most labor-intensive part of this method is reading of time differences between the virtual marker and the physical sensor from video tapes. It took around 5 hours to review the tape of our experiment described in this paper. Also, Human reading will introduce errors by itself. Furthermore, the reader will be impatient after long time reading, which will make error even larger. Therefore, we are considering making the reading procedure automatic by computer vision technology, which will save time while increase precision.

5. Acknowledgement

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