A Display-Based Tracking System: Display-Based Computing for Measurement Systems

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Abstract

In this paper, we introduce a two dimensional display-based tracking system. The system consists of a regular display device and simple photo sensors. It measures the position and direction of a receiver using fiducial graphics. The result of the measurement can be acquired in the same coordinate system as the graphics. Thus, this system no longer needs the measurement devices to be calibrated to the display devices. This is beneficial for Mixed Reality applications that synthesize virtual and real environments.

1. Introduction

Recent advances in display technology have led to proposals for communication and measurement using graphics display devices. In this paper, we introduce a two dimensional tracking system based on regular display devices. This system uses these devices to output arbitrary optical information including the division and multiplexing of time and space.

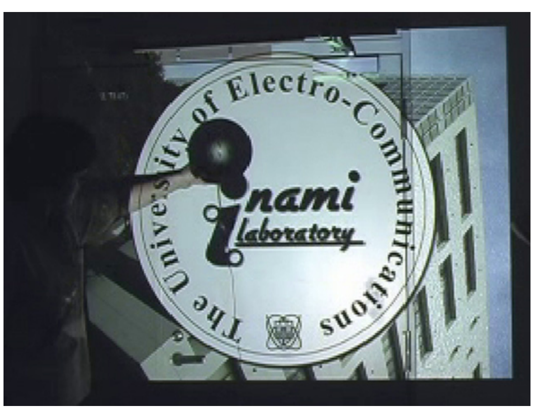


Figure 1: Snapshot of the proposed tracking system

This tracking system imposes fiducial graphics onto the projection area to track receivers using display devices. There are some studies to measure the position of receivers using projectors [1][2]. However, the methods presented in these studies need frames to detect the position of receivers. Thus, it is difficult to measure moving targets with regular projectors. In this paper, we propose fiducial graphics as locally projected optical scales for measurements. This system accounts for the need to measure both relative and angular position within one frame and can, therefore, track moving targets with regular display devices. Figure 1 shows a snapshot of this tracking system in use.

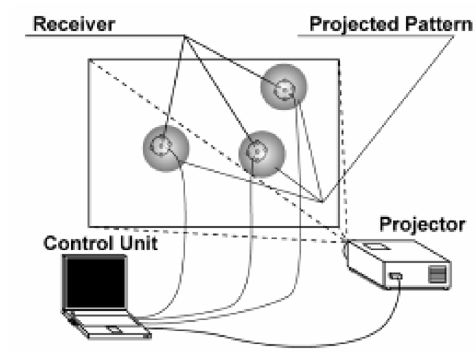


Figure 2: System configuration

Figure 2 shows the system configuration of this tracking system. This technique can be implemented with simple photo sensors. Thus, it is easy to use in many situations with regular display devices. Using this tracking technique, we have previously developed an augmented reality environment with small robots [3]. In this paper, we describe the detail of the tracking system and a pen-like device that uses the technique. To evaluate the performance of this tracking system several experiments were performed with the pen type device.

0-7695-3056-7/07 $25.00 © 2007 IEEE
DOI 10.1109/ICAT.2007.50

2. Display-based Computing

Display-based Computing is a concept to achieve communication with, measurement and control of, and appropriate presentation in, the real world by computers using display devices. Recent research efforts in DBC include Head-Mounted Projector based Augmented Reality environments [4][5], LED Projectors [6] and using LEDs for jam light [7]. Research in computer vision (CV) has also advanced dramatically worldwide. Traditionally, display devices such as projectors have been considered simply as complimentary to camera devices used in CV research: the projector projects optical information onto the space, while the camera captures optical information from the space. CV processes optical information from the real world by capturing images with camera systems. The tracking system presented here differs from this approach in that it outputs optical information superimposed onto the real world by projecting the images. CV uses the camera not only to record optical information but also for image-based tracking of robotic devices. Similarly, it is also possible to track a robot based on optical information projected by a display device.

3. Related Works

In this paper, we try to measure position and direction of receivers with simple sensors by drawing intelligent fiducial graphics. This method produces single frame measurements with fiducial graphics and receiver units. This is a major benefit in dynamic environments compared to prior display based measurement systems.

This study is related to research using display devices and optical information. Primary research themes in this area include the embedding of arbitrary binary patterns with DLP projectors [8], using a very high speed subfield of the DLP projector [9] detecting depth by projecting a pattern [10], wireless tracking using infrared rays [11], calibration matched to screen shape by detecting the position of optical sensors buried on screen [12], positional detection of the receiver in the projection area by brightness change using a projector [13]. The current state of high-speed optical communication is possible due to the spread of LED's, the high speed LCD, and the DLP. This has also seen dramatic advances in achieving communication with large capacity space selection and the division of time using projectors and lights. In the field of communication through displayed images, there are various related works, such as cellular phone communication with a large-scale display using hue-difference [14].

4. Methods

4.1. Fiducials with a single point sensor

To measure the position and direction of receivers, the proposed tracking system projects graphical scales onto the real environment using a display device.

One of the simplest methods of single frame measurements is multiplexing two patterns, as shown in Figure 3, on the entire projection area using different wavelengths. As long as it is possible to obtain absolute brightness accurately by the sensor, the position (x, y) can be obtained as:

$$x \propto A \qquad (1)$$

$$y \propto B \qquad (2)$$

In this expression, A is the sensor output receiving the pattern Figure 3(a) and B is the sensor output receiving the pattern Figure 3(b).

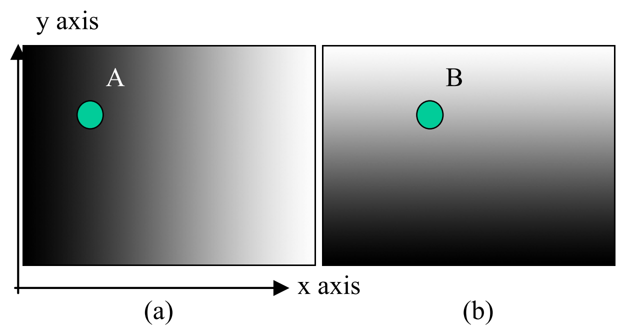
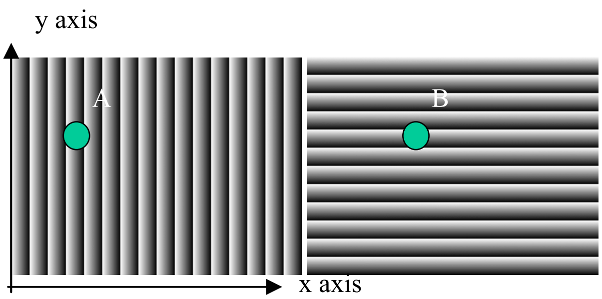


Figure 3: Fiducial graphics to obtain the absolute position of the sensor.

This method is not well suited to a wide projection area; because ambient light and noise appear directly as a measurement error , and the resolution depends on brightness depth. Considering this problem, we propose another fiducial graphic; shown in Figure 4. If the sensor moves, the fiducial graphic makes a saw tooth wave in the sensor input. We can obtain the sensor motion by checking the brightness information of this pattern.

With these fiducial graphics, normal background graphics can be displayed using a mask projected in the vicinity of the sensor. Using a single point photo sensor, the system can obtain brightness information from the sensor at very high speed. To multiplex these fiducial graphics, we can use the RGB channel with a normal projector. Additional possibilities include special projection devices using ultraviolet or infrared light. Also, polarized filters increase the number of available channels.



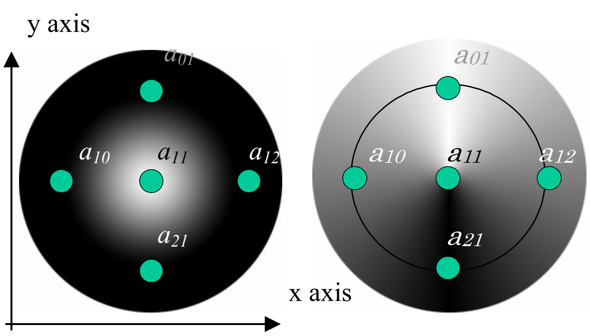
(a) (b)

Figure 4: Fiducial graphics to obtain the relative position of the sensor.

4.2. Fiducials with a sensor array

The fiducials with a single point sensor are very simple, allowing a high measurement frequency. However, the influence of noise and ambient lights is of concern. Also, these fiducials are scales of just a single axis. To make a two dimensional tracking system, we have to multiplex multiple fiducials. There is a method by which a single fiducial with a sensor array can produce multi-axis measurement.

We propose a tracking method with a photo sensor array. Primitive fiducial graphics are shown in Figure 5(a) and (b). These fiducial graphics can be used with two dimensional sensors such as CCDs and PSDs, but with single point sensor array, the measurement speed is significantly faster and the arrangement is arbitrary.



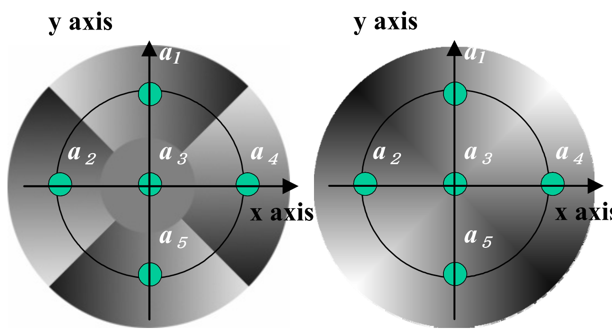
(a) (b)

Figure 5: (a) Position fiducial and (b) Direction fiducial.

Figure 6 depicts directional measurement. The virtual arrow shows the direction of the receiver unit as measured using 5(b).

The position of the arrow is obtained from by the standard center of mass calculation. The number of sensors can change arbitrarily. The points in the figures indicate the arrangement of photo sensors. Also, the brightest direction, θ, is calculated as center of mass in polar coordinates from Figure 5(b).

Figure 6: Snapshot of angular measurement.



(a) (b)

Figure 7: Position and angular fiducial graphics.

To measure position and angle at the same time, we propose the fiducial graphics shown in Figure 7(a). Differences dx and dy on the x and y axes, and the angle difference $d\theta$ in Figure 7(a) are calculated as follows:

$$dx \propto a_5 - a_1 \qquad (3)$$

$$dy \propto a_4 - a_2 \qquad (4)$$

$$\sin d\theta \propto a_1' + a_2' + a_4' + a_5' \qquad (5)$$

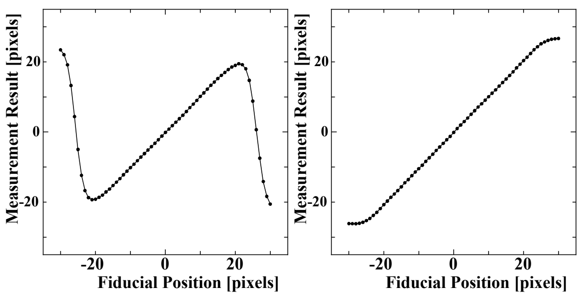
In these expressions, each a_n' indicates a_n-a_3. After a normalization of brightness, dx and dy can be accurately calculated from the fiducial shown in Figure 7 using the gradation changes along the x and y axis.

Figure 7(b) shows an improved fiducial that produces higher tracking performance. The variables in Figure 7(b) are calculated as follows:

$$dx \propto a_5 - a_1 \quad (6)$$

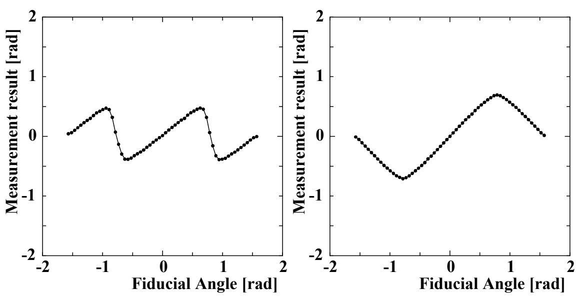
$$dy \propto a_2 - a_4 \quad (7)$$

$$\sin d\theta \propto a_2 + a_4 - a_1 - a_5 \quad (8)$$



(a) (b)

Figure 8: Positional characteristics of fiducials in the x axis. (a) shows the characteristics of Figure 7(a). (b) shows the characteristics of Figure 7(b).



(a) (b)

Figure 9: Angular characteristics of fiducials, (a) shows the characteristics of Figure 7(a). (b) shows the characteristics of Figure 7(b).

To assess the linearity of the fiducials, we translated and rotated them on a fixed receiver. Figures 9 and 10 indicate the characteristics of the fiducials shown in Figures 7(a) and 7(b). Figure 8 is the positional characteristic and 9 is the angular characteristic. Figure 7(b) shows better linearity than 7(a) due to the presence of a consecutive brightness borderline.

Using this display based technique, further fiducial patterns might be devised according to the demands of measurement accuracy and targets.

5. Current Implementation

5.1. Measurement Procedure

We developed a trial system to evaluate the position and direction tracking system. In this trial system, we implemented the fiducial graphics shown in Figures 5 and 7 with a sensor array. To use the fiducial graphics shown in Figures 5 and 7, we used the process shown in Figures 10 and Figure 11.

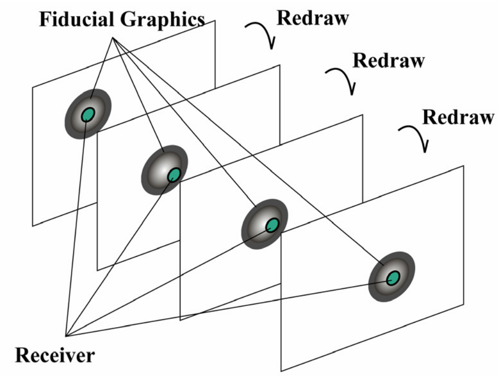


Figure 10: Redrawing of fiducial graphics.

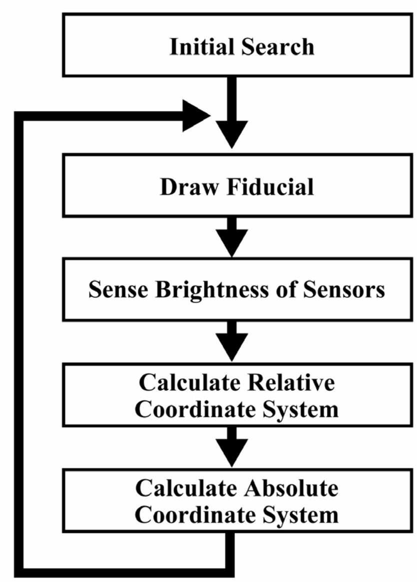


Figure 11: Tracking Process

In this process, the system draws the fiducial graphics at the initial position. When complete, it calculates the brightness to obtain the relative coordinates between the receiver and the fiducial graphics. A loop is then initiated with the system redrawing the fiducial graphics, adding the difference at each step.

5.2. Display Devices

Many types of display systems such as projectors and desktop monitors can be used with this tracking technology. In this implementation, we used a desktop monitor: DELL 1704FP. The spec of the native LCD panel resolution is 1024 x 768 pixels. The pixel pitch is 0.264 (mm). The display devices are connected to the PC with an analog RGB cable. The refresh rate of the system is 60Hz, and the refresh timing is synchronized to the V-Sync signal of the display devices from the computer graphics library. In the current implementation, some frames are slow to display on screen after the software has rendered them. This delay suppresses the tracking speed. But, display technologies are advancing quickly, so it poses no problems.

5.3. Receivers

In this trial implementation, we made photo sensor arrays. They consist of five photo sensors (TOSHIBA phototransistor TPS603A).

5.3.1. Regular Type. The receiver is installed with a MCU Microchip dsPIC30F2010 and an RS-232C interface, and transmits the A/D converted data to the PC. We observed a 0.5 (ms) pulse voltage change at each 5 (ms) brightness for some regular projectors. To reduce the influence of this voltage change, the MCU performs the analog to digital conversion every 0.5 (ms) for each sensor, and uses the lowest value of the result. Figure 12 shows a regular receiver. It has five sensors along the X and Y axis.

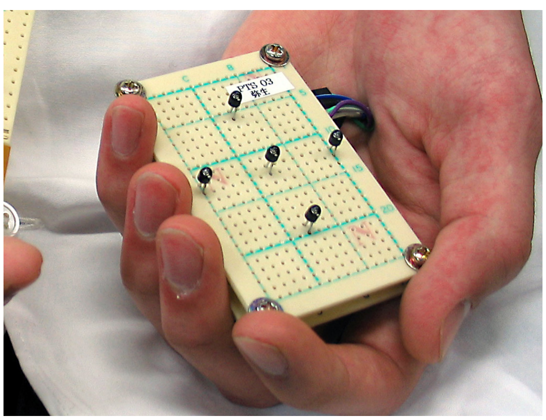


Figure 12: Regular receiver.

The sensor outputs are gamma corrected to liner characteristics using the least squares method. We used this receiver mounted on small vehicles in a related study [3].

5.3.2. Pen Type. To explore the possibilities of small receiver units, we also developed a pen type receiver unit with fiber optics. We added fiber optics and amplifiers to the regular receiver. Figure 13 shows the sensor head of the fiber optics. The diameter of the sensor array is 5.08(mm). Figure 14 shows the system configuration of the pen type system. This receiver unit works with a desktop monitor. The amplifiers strengthen information from the optics. Figure 15 shows the block diagram of the receiver unit. The layout of the fiber optics in the receiver head is similar to the sensor layout of the regular receivers. It can measure the brightness of the desktop monitor at five points. Figure 16 shows the electrical circuit of the receiver. Figure 17 shows a snapshot of the pen type receiver tracking.

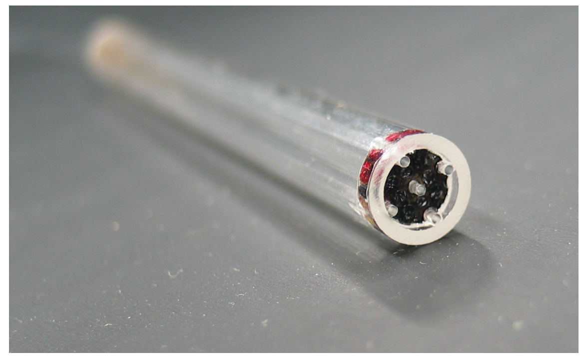


Figure 13: Sensor head of the pen device.

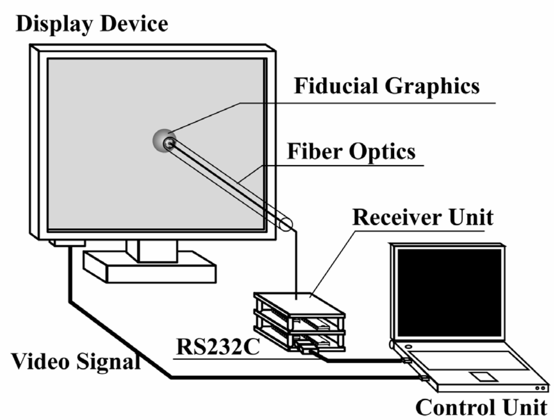


Figure 14: System configuration of the pen type receiver.

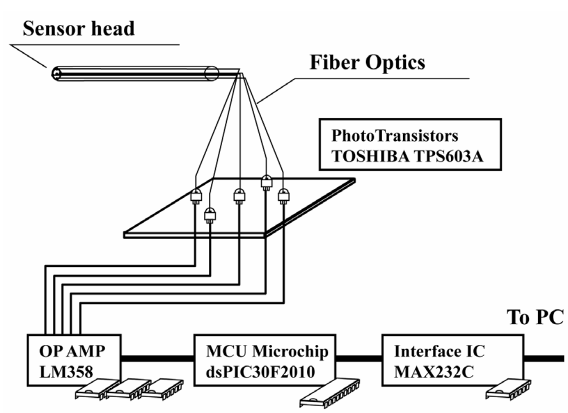


Figure 15: Block diagram of the pen type receiver.

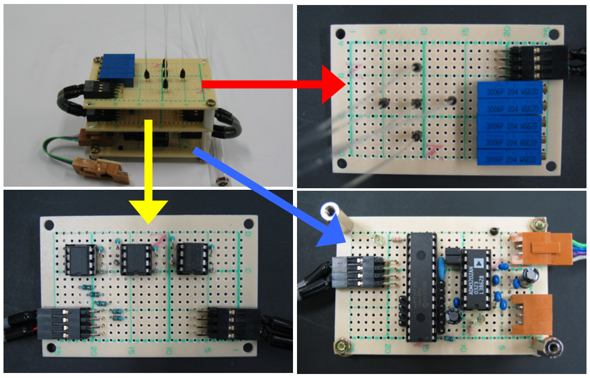


Figure 16: Electrical circuit of the receiver.

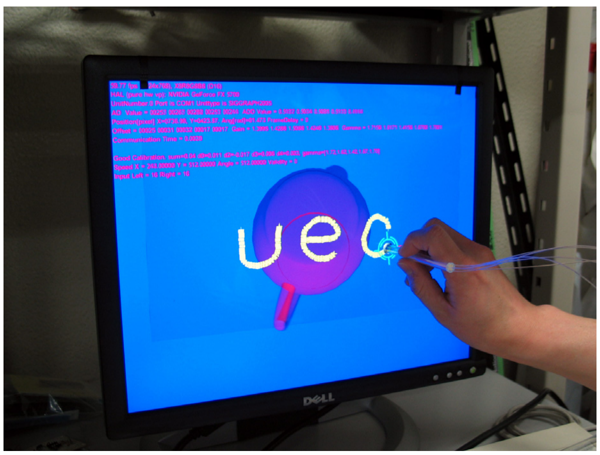


Figure 17: Snapshot of the pen type receiver tracking.

6. Experiments

To evaluate the accuracy of this tracking system, we conducted the following experiments. Figure 18 shows the experimental system.

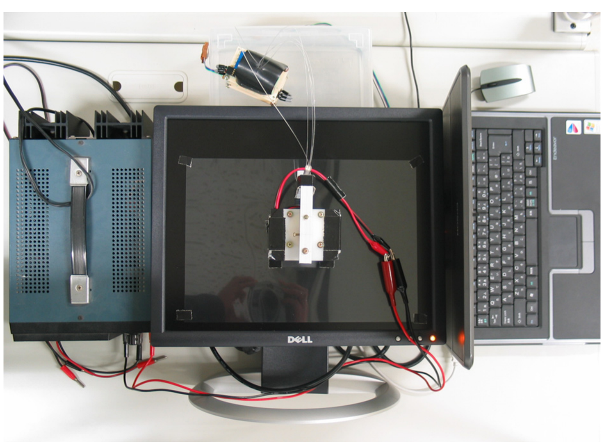


Figure 18: Photograph of the experiment

6.1. Static Accuracy

In this experiment, the static accuracy of the measurement was verified using the fiducial graphics shown in Figure 7(a) and (b).

The pen type receiver unit was measured on the display device in a fixed position. During the measurement, ambient light was changed to exam the robustness of the proposed tracking method. Tables 1 and 2 show the result of this experiment based for 5,000 samples. The averages are relative values based on dark environment.

Table 1: Result of the pen type receiver with the fiducial graphics shown in Figure 7(a)

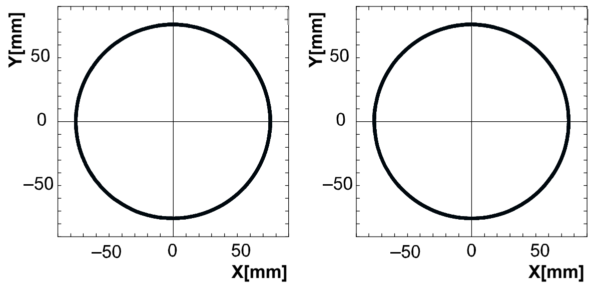
		Darkness (0Lux)	Fluorescent lamp(745Lux)
X(mm)	Average	0.0	2.4x10^{-2}
	Standard deviation	8.3x10^{-3}	9.6x10^{-3}
Y(mm)	Average	0.0	-2.8x10^{-3}
	Standard deviation	6.6x10^{-3}	8.1x10^{-3}
Angle(deg)	Average	0.0	6.8x10^{-1}
	Standard deviation	4.3x10^{-1}	5.6x10^{-1}

Table 2: Result of the pen type receiver with the fiducial graphics shown in Figure 7(b)

		Darkness (0Lux)	Fluorescent lamp(745Lux)
X(mm)	Average	0.0	-7.5x10^{-3}
	Standard deviation	8.0x10^{-3}	1.0x10^{-2}
Y(mm)	Average	0.0	-1.1x10^{-1}
	Standard deviation	6.6x10^{-3}	1.2x10^{-2}
Angle(deg)	Average	0.0	5.1x10^{-1}
	Standard deviation	1.5x10^{-1}	2.4x10^{-1}

6.2. Dynamic Accuracy

To evaluate the dynamic accuracy measurement, we conducted experiments with the fiducial graphics shown in Figures 7(a) and (b) with a moving receiver on a turntable. The receivers were installed 76.0(mm) from the center. The table was rotated at 5(deg/sec). In this experiment, the environment was dark: 0(Lux). Figure 19 shows the trajectories.



(a) (b)

Figure 19: Trajectories of the receivers. (a) is with the fiducial shown in Figure 7(a). (b) is with the fiducial shown in Figure 7(b).

Figure 20 shows distribution chart of the distance error from the average distance in polar coordinates. This chart is based on 3,800 samples. The standard deviation of the distance from the center with the fiducial shown in Figure 7(a) was 5.4 x 10^{-2} (mm) and with the fiducial shown in Figure 7(b) was 6.7 x 10^{-2} (mm).

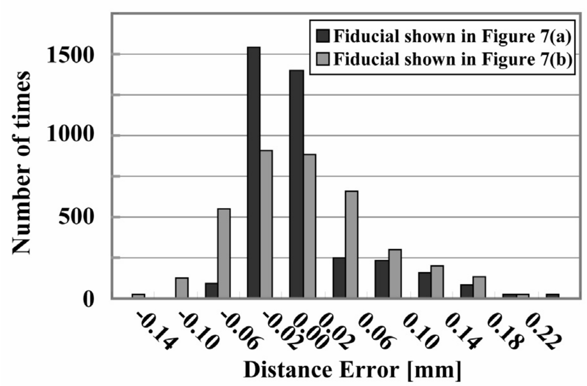


Figure 20: Distance error of the receiver.

To evaluate the tracking speed of the receiver's movement, we increased the speed of the receiver incrementally. The fiducial graphics shown in Figure 7(a) tracked up to 8(mm/sec) and 7(b) 18(mm/sec).

7. Discussion

In the experiments, the accuracy of the tracking system was evaluated when the receiver was at rest and in motion. In the static experiment, the fiducial graphics shown in Figure 7(a) showed a standard deviation x: 8.3 x 10^{-3} (mm), y: 6.6 x 10^{-3} (mm) in a dark environment. When the ambient light was changed from 0 (Lux) to 745 (Lux), the standard deviation increased to x: 9.6x10^{-3} (mm), y: 8.1x10^{-3} (mm), which is still sufficiently small for many applications. We tried to suppress the influence of ambient light by using multiple sensors. This produced robust results in flat ambient light. For the fiducial graphics in Figures 7(a) and 7(b) is the standard deviation on the angular measurement differs significantly. 7(a) shows 4.3x10^{-1} and 7(b) shows 1.5x10^{-1} in the dark environment. To calculate angle, 7(b) uses expression (8). This reduces the standard deviation due to a counterbalance of noise and ambient light.

The standard deviations of the measurement results of the moving receiver were larger than the static accuracy, but still smaller than the pixel pitch of the display device.

Tracking speed is limited by the graphics frame rate and the size of the receiver and fiducial. However, this tracking system can obtain the correct position and angle while tracking continues, because it measures the relative position and angle between the fiducial graphics and the receiver at every frame.

8. Future Works

In this system, the tracking performance and the measurement stability of this system represent a trade-off. The refresh rate of fiducial graphics is limited by the performance of the display device and software. On the other hand, the measurement frequency of an optical sensor is very high. Therefore, without redrawing, this technique allows measurement with much higher speed than redrawing during the tracking processes. A higher speed tracking loop might enable forecast methods based on high speed sampling.

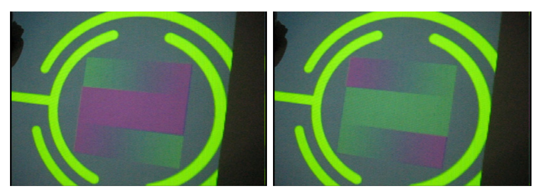


Figure 21: Invisible fiducial graphics

We also have plans to make invisible fiducial graphics using two images which are same brightness and opposite hue. Figure 21 shows prototype of the invisible fiducial graphics.

Work is also planned to use this tracking technique to control a multi-robot system.

9. Conclusions

In this paper, we introduced a two dimensional tracking system with regular display devices, and described fiducial graphics that successfully measured both position and angle in an experimental system. The use of fiducial graphics produces a strong match between the coordinate and tracking systems. The proposed system is, therefore, suitable for Mixed Reality applications.

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