Motion Capture System Using an Optical Resolver

Takuji Tokiwa[1,4], Masashi Yoshidzumi[2], Hideaki Nii[3], Maki Sugimoto[4], and Masahiko Inami[5]

[1] School of Engineering, Tokyo University
7-3-1, Hongo, Bunkyo-ku, Tokyo 113-8656, Japan
Department of Mechanical Engineering and Intelligent Systems
takujitokiwa@acm.org
[2] University of Electro-Communications
1-5-1, Chofugaoka, Chofu-shi, Tokyo 182-8585 Japan
yoshidzumi@hi.mce.uec.ac.jp
[3] Graduate School of Information Science and Technology, Tokyo University
7-3-1 Hongo, Bunkyo-ku, Tokyo 113-8656, Japan
hideaki_nii@ipc.i.u-tokyo.ac.jp
[4] Media Design Institute, Graduate School of Media Design, Keio University
4-1-1 Hiyoshi, Kohoku-ku, Yokohama, Kanagawa 223-8526, Japan
sugimoto@kmd.keio.ac.jp
[5] Graduate School of Media Design, Keio University
4-1-1 Hiyoshi, Kohoku-ku, Yokohama, Kanagawa 223-8526, Japan
inami@inami.info

Abstract. In this paper, we present a novel position measurement method that makes use of a couple of plane light sources created from an IR-LED matrix array and a photo-detector. The light sources emit light with the same frequency, but different phases, while the optical axes of the sources are set up orthogonally. Then, the signal place is diffused by the space with phase differences in each position. Finally, the signal received by the photo-detector is analyzed to determine the position.

Keywords: Motion Capture, Position Detection.

1 Introduction

With ubiquitous computing, the input and output of information for users is performed through various interfaces. Interfaces that are optimized for the location and circumstances of users are necessary, as well as a standardized interface. An optimized interface facilitates the input and output of information, disperses it effectively and offers the user the opportunity for new knowledge.

It is important in creating such an interface to ensure that the design retains basic functionality, that is, a combination of the accepted requirements and an environment that makes this possible, so that information appliances can be attached if necessary. Besides, an information environment not only responds to requests received from a user through an information terminal device, but can also detect via various sensors

J.A. Jacko (Ed.): Human-Computer Interaction, Part III, HCII 2009, LNCS 5612, pp. 536–543, 2009.

the position and actions of the user if necessary. The information given to a user is presented by means of information terminal devices, and also a combination of information appliances in the information environment. The presenting method depends on the location, circumstances and requests from the user.

It is important to realize such an environment that has the technology to detect both a user and the position of an information appliance easily in the information environment.

Consequently, techniques have been proposed and developed to detect a user and position, such as how to use RFID tags[1,2], how a marker is detected using image analysis technology[3-5], how distance is measured by supersonic waves, and so on, together with resolvers and "Polhemus"[6].

These techniques, however, have several weaknesses. For example, measurement precision depends on measurement time, while the system architecture is complicated as detection requires high-performance computers for analysis of images and data. Therefore, a technique has been suggested to measure information projected in the real world[7,8]. The measurement system is this case is simplified and easy to use.

Recently we proposed a technique that uses two plane light sources which flash on and off continually with a fixed phase difference and the same frequency. This creates a signal field with phase difference changes in a particular direction in the space, that makes the detection of a position possible, when the signal is measured by a photo-detector. Using this technique, device construction is simplified. Moreover, detection does not depend on the frame rate as is the case in movie capture using a video camera and position detection is continuous at high speed. The implemented system has, however, been developed only as a proof of concept. The device construction is complicated and cannot really be used in a ubiquitous computing environment. Consequently, in this paper, we examine an alternative method to detect phase difference on a computer to simplify device construction.

The paper is organized as follows. The basic concepts of the proposed technique are explained in the next section. An implementation as proof of concept and the results are reported in Section 3. An application of the proposed technique is described in Section 4, while potential future problems are considered in Section 5.

2 Optical Resolver

When light from two plane light sources, with a constant phase difference and that flickers with the same frequency, is composed in space, a signal field develops where a phase difference changes in a specific direction.

This technique occurs as a result of the following three principles.

1. The light emitted by a plane light source irradiates a finite space and has directionality. The photo-detector changes according to the angle between itself and the plane light source, if the distance to the photo-detector of the received luminance is fixed, and if the photo-detector always faces the center of the plane light source.
2. The synthetic light is measured at the position where the light output from multiple light sources overlaps.

3. When two signals, with identical frequency but whose undulating phases differ, are synthesized, a signal is obtained in which only the phase deviates in proportion to the ratio of the strength of the two signals.

The uniaxial angle detection system developed from these principles is explained in the next section.

2.1 Uniaxial Angle Detection System

The concept of the uniaxial angle detection system is illustrated in Fig. 1.

Plane light sources S_1 and S_2 flicker at $A\sin(\omega t)$ and $B\cos(\omega t)$ (where A and B denote amplitude, and ω is the modulated angular frequency). The luminance, however, does not become negative. Then, the AC component is changed by adding a positive offset to the sinusoid. Henceforth, only the change in this alternating current is noticed. Similarly, the luminance of the other light source is also changed to alternating current.

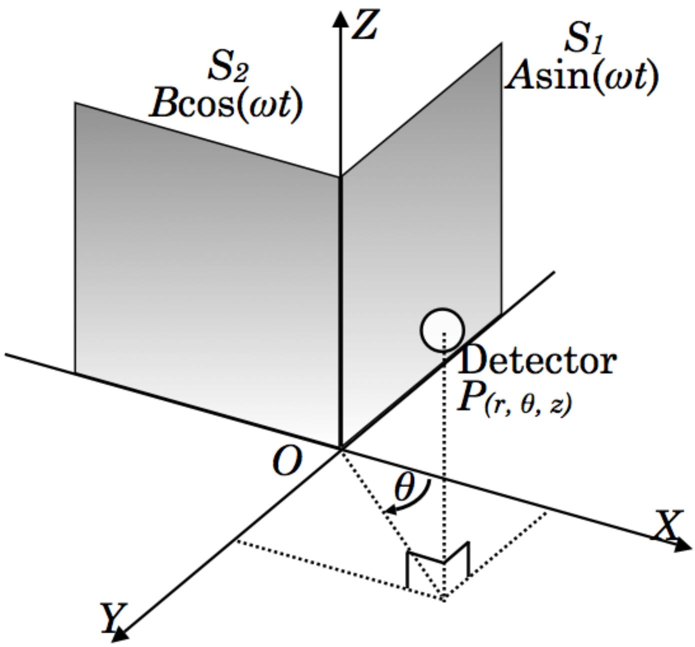

Fig. 1. Uniaxial Angle Detector

The following are determined as depicted in Fig. 1: the origin O, X-axis, Y-axis, Z-axis, and rotation angle θ. Luminance L_s, which is mesured by a photo-detector placed in the region $X, Y > 0$ (Z is constant), is defined by Eq. 1.

$$\begin{aligned} Ls &= A\sin(\omega t)\times\cos\theta + B\cos(\omega t)\times\sin\theta \\ &= \sqrt{A^2+B^2}\sin(\omega t+\phi) \end{aligned} \tag{1}$$

Phase difference φ is defined as $\varphi = tan^{-1} (Bsin(\theta) / Acos(\theta))$. This becomes $\varphi = \theta$, if $A = B$. Angle θ, measured between the X-axis and the original direction, is equal to the phase difference of the composite signal and the drive signal of the source of light that is detected by the light receiving element. The wavefront develops radially at the Z-axis center in the first quadrant of the XY plane. The proper phase difference φ is measurable by the phase detection. It is possible to ensure that the sampling rate does not depend on the modulation frequency of the light source. In addition, in practice, a light receiving element exhibits directivity. However, the problem of directivity is removed by the diffusion board which is installed at the front of the photo-detector and spherical solar batteries without directivity. As a result, the directionality of the photo-detector is not considered in Eq. 1.

2.2 Development of Uniaxial Angle Detector

A block diagram of the system produced is shown in Fig. 2.

A source of light arranged as a chip type infrared LED with wide directivity in the array state is substituted for the plane light sources. A "CL-190IRS-X" infrared LEDm manufactured by CITIZEN ELECTRONICS CO., LTD., was used as the LED. The plane light source mounted in the LED array is shown in Fig. 3.

According to the basic principles given in Section 2, the light source is driven by a sine wave. However, it is not easy to allow the luminance of an LED to be changed accurately in the sinusoid. Furthermore, this complicates the composition of the equipment. Thus the LED was actually made to flicker in accordance with a 1[kHz] rectangular wave.

The higher harmonics of rectangular wave were cut off by the filter in the phase difference detection circuit. A "TPS615" phototransistor manufactured by the Toshiba Semiconductor Company was used as the photo-detector. This component has directionality. The photo-detector was installed in such a way that it always faces the direction of the intersection of the light sources in the experiment. A "CD-505R2"

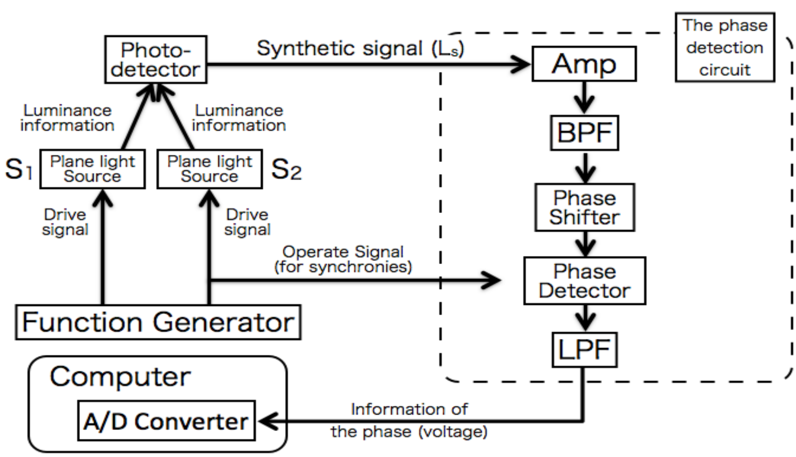

Fig. 2. System block diagram

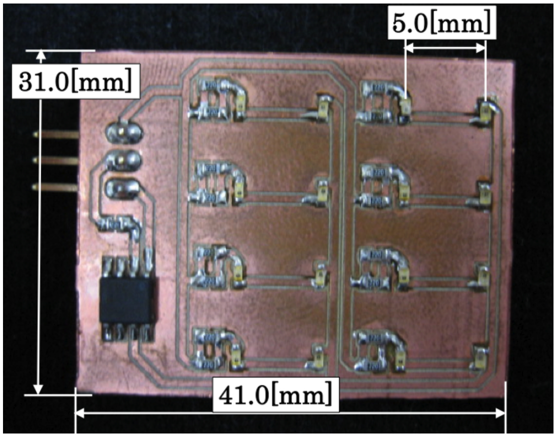

Fig. 3. PlaneLightSource

phase detector from NF Corporation. was used as a noise filter and for cutting out the higher harmonics and elements in the phase difference detection circuit [9]. The “CD-505R2” consists of the following: input differential amplifier, two post amplifiers, bandpass filter, phase shifter, phase detector, and lowpass filter. It is possible to decide the characteristics of each circuit by its resistance and the capacitor of the outside attachment. The phase-detector uses a rectangular wave in the reference signal, takes the inner product with the signal passed through the bandpass filter, and finally outputs a direct current through the lowpass filter.

3 Improvements to the System

The system described in Section 2 was developed to verify the concepts of the proposal, and uses a specialized custom-made analog circuit with masking. In addition, an AD interface board is used to allow the measurement result to be analyzed by a computer. These components are expensive, and the equipment itself is bulky, making it difficult to include the system in other equipment.

A ubiquitous computing environment comprises various components of information-processing equipment. For the proposed technique to be used in such an environment, it needs to be incorporated in this information-processing equipment. For this reason, it needs to be low-cost and small and should be simple to use.

On the other hand, computer performance has improved remarkably in recent years, making it possible to carry out digital signal processing, even without the use of specialized circuitry.

In the field of media arts, it has been proposed that the computer's audio input port and audio interface for music creation be used instead of the AD interface board [10].

Audio interfaces provide a large number of input ports at low-cost and enable system development using a software environment for realtime signal processing for audio and multimedia, such as “MAX”, “PD (PureData)”, “jMax”, and so on [11-15].

Since precision of processing is not guaranteed in these software environments, verification is necessary.

Consequently in the simulation, we examined the accuracy of a program for phase difference detection created in "MAX". The results of the simulation are shown in Fig. 4.

In the simulation, a square wave (5[Hz]) was used as the driving signal of the plane light sources. The angle varied between zero and 90 degrees, with an interval of 10 degrees. The signal driving S_1 was used as the reference signal. The band pass filter extracts signals of the basic frequency from the reference signal and the signal measured by the photo-detector. Signals extracted using filters are segmented by means of a flip-flop method. The difference in the starting time of the two signals is measured and denotes the phase difference.

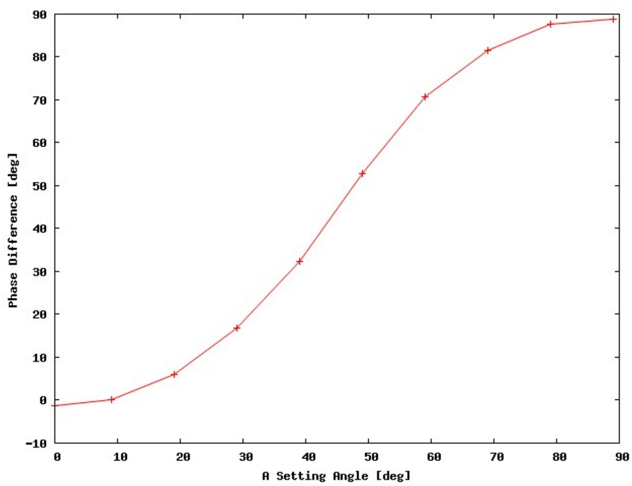

Fig. 4. Simulation results. (Signal field generated in a square wave 5[Hz], and measured with sampling rate 96k[Hz])

4 Application of the Proposed Technique

4.1 Two-Dimensional Position Detection System

Measurement in two dimensions becomes possible when the installed system is orthogonal to the direction of the signal field formed by two plane light sources.

Multiple signal fields can coexist by using a frequency that differs for every signal field.

Each signal field can be separated by orthogonal detection and a bandpass filter.

All angles and positions can be measured, if the phase difference is detected in every signal field.

4.2 Ubiquitous Computing Environment

The proposed technique can be used in an indoor ubiquitous computing environment. Plane light sources are included in lighting equipment, while receivers are included in information devices that comprise the ubiquitous computing environment. Then, information devices would be able to grasp positions autonomously, if these are within a signal field irradiated from the light source.

If combined in a information terminal for ubiquitous computing that allows a user to feel the direction of the source of information such as CoBIT [16], not only the perception of the user but also the terminal itself can grasp the direction of the source of information.

5 Conclusion

Conventional implementations of the proposed position sensing technique depended on a specialized and custom-made analog circuit module and an AD interface board. This made it difficult for incorporation in information devices used in a ubiquitous computing environment.

To solve these problems, an experimental phase difference detection program was developed and validated in a simulation in which it was implemented as an audio interface in a realtime audio/multimedia programming environment.

References

1. Tokiwa, T., Tokuhisa, S., Honna, Y., Shinozaki, T., Kusunoki, F., Nishimura, T., Iwatake, T.: Surround CoBIT: A method for presenting auditory information as a virtual acoustic field. In: International Workshop on Smart Appliances and Wearable Computing 2004 (2004)
2. Kusunoki, F., Isyama, A., Tokiwa, K., Nishimura, T.: The sensing board enhanced by interactive sound system for collaborative work. In: Proceedings of the 2004 ACM SIGCHI international Conference on Advances in Computer Entertainment Technology (2004)
3. Kato, H.: Marker tracking and hmd calibration for a video-based augmented reality conferencing system. In: Proc. 2nd IEEE/ACM Int. Workshop on Augmented Reality (IWAR 1999) (1999)
4. Rekimoto, J., Ayatsuka, Y.: CyberCode: Designing Augmented Reality Environments with Visual Tags. In: Designing Augmented Reality Environments (DARE 2000) (2000)
5. Kaltenbrunner, M., Bencina, R.: reacTIVision: A Computer-Vision Framework for Table-Based Tangible Interaction. In: Proceedings of the first international conference on Tangible and Embedded Interaction (TEI 2007) (2007)
6. Polhemus: Motion Tracking, 3D Scanning, and Eye Tracking Solutions from Polhemus, http://www.polhemus.com/
7. Kagotani, G., Kojima, M., Sugimoto, M., Nii, H., Inami, M.: PTS: Projector-based Tracking System, International VR. In: Media Art and Technology 2004 Proceedings, p. 27 (2004)

8. Raskar, R.: Rfig lamps: Interacting with a self-describing world via photosensing wireless tags and projectors. ACM Transactions on Graphics (TOG) SIGGRAPH 23, 406–415 (2004)
9. NF Corporation, CD-505R2, `http://www.nfcorp.co.jp/english/pro/fm/pha/index.html`
10. Jo, K.: Audio Interface as a Device for Physical Computing. In: Audio Mostly 2008 - a conference on Interaction with Sound, Piteå, Sweden, October 22-23, pp. 123–127 (2008)
11. Cycling 1974, Max/MSP (1974), `http://www.cycling74.com/products/max5`
12. Puckette, M., Apel, T.: Real-time audio analysis tools for Pd and MSP. In: Proceedings of International Computer Music Conference, pp. 109–112. International Computer Music Association, San Francisco (1998)
13. Déchelle, F., Borghesi, R., De Cecco, M., Maggi, E., Rovan, B., Schnel, N.: jMax: A New JAVA-Based Editing and Control System for Real-Time Musical Applications. In: Proceedings of the 1998 International Computer Music Conference. International Computer Music Association, San Francisco (1998)
14. Geiger, G.: PDa: Real Time Signal Processing and Sound Generation on Handheld Devices. In: Proceedings of the International Computer Music Conference, Singapore (2003)
15. Breidenbruecker, M., Geiger, G., Brossier, P., Hazan, A., Barknecht, F., McCormick, C., Nordgren, A.: RjDj, `http://www.rjdj.me`
16. Nishimura, T., Itoh, H., Nakamura, Y., Yamamoto, Y., Nakashima, H.: A Compact Battery-Less Information Terminal for Real World Interaction. In: Ferscha, A., Mattern, F. (eds.) PERVASIVE 2004. LNCS, vol. 3001, pp. 124–139. Springer, Heidelberg (2004)