3D Positioning Acquisition System with Application in Real-Time Processing

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ABSTRACT

This work presents the development of a 3-Dimensional Positioning Acquisition System, proposed for applications in real-time processing.

The system is based on ultrasound sensors that present reasonable compromise between cost and flexibility. The signals from the sensors are processed in real-time and a position within a limited space can be obtained with a resolution of tenths of millimeters.

Among the applications suggested for the system, it is being implemented a dance-music interface, where the positions and gestures of dancers can be used to change musical parameters during live performances.

1. INTRODUCTION

The accurate determination of a position in 3-dimensional space is an increasingly important research area in many different fields. Research is led in areas such as robotics [1], industrial and process automation and virtual reality, among others, that continuously need more accurate measurement devices.

Techniques used in position acquisition systems usually need that the point to be determined, be totally free in space, that is, the presence of wires connecting the sample to the acquisition system is many times intolerable.

Henceforth, many techniques that allow the determination of a point or sample in space without the need of physical contact have been proposed. Among the important current techniques, it can be mentioned Artificial Vision and techniques that make use of electromagnetic waves or fields, infrared or ultra-violet light and ultrasound waves [2 - 5].

The artificial vision technique aims to identify the position of a specific point through the analysis of stereoscopic images obtained by a set of cameras. Its main advantage is the fact that it doesn't need a circuit or sensor in the point to be identified, although it presents a high computational complexity that makes it not feasible for real-time operations.

Among the techniques that utilize electromagnetic waves, the most popular is the GPS (Global Positioning System) [2, 3] that aims to determine a point anywhere on the surface of earth, with a precision of few meters. This is a generic system that can present good accuracy when used together with other techniques.

The use of light is based on interferometry techniques that present very high accuracy, around micrometers. The main disadvantage of these techniques lies on the fact that they are extremely directional, thus limiting the maximum angle covered by the sensor.

On the other hand, many of the problems described above can be overcome by the use of ultrasound waves [4, 5], a technique that may present a good relationship between the complexity of the circuits involved and the accuracy obtained.

In this article a system based on ultrasound sensors that performs the determination of a signal with an accuracy of hundreds of microns is presented.

2. ULTRASOUND SENSOR

Distance measurement techniques based on ultrasound waves have become popular due to their good inherent accuracy and simple signal processing. Distance measurement is based on the time the ultrasound wave takes to move from the emitter to the receiver. This time is called "time-of-flight" and is directly proportional to the distance measured. Basically, there are two techniques that perform this measurement: Measurement through Reflection and Direct Measurement.

The Measurement through Reflection is exemplified in figure 1, where it is desired to determine the distance between the wall and the sensors.

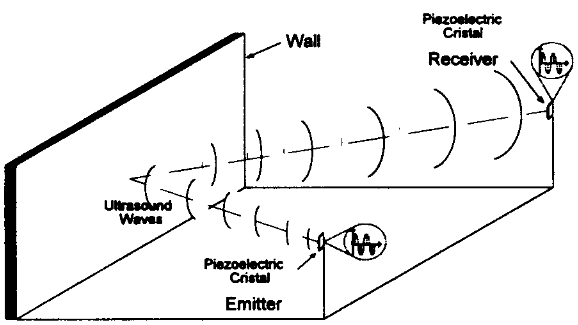

Fig. 1- Distance measurement through reflection.

The Direct Measurement technique is based on the propagation time of the ultrasound wave straight from the emitter to the receiver. The distance between the two transducers can then be evaluated.

One problem that arises from the use of time-of-flight in order to measure distances is the variability of the sound propagation speed in the air with ambient factors (temperature, humidity, pressure, air circulation and so on). This fact limits the use of this technique in some applications.

Some characteristics of the ultrasound transducers used in this work are presented below. Figure 2 shows the amplitude response of the transducer with respect to the distance between emitter and receiver and figure 3 presents the amplitude response of the transducer with respect to the angle between emitter and receiver (directionality).

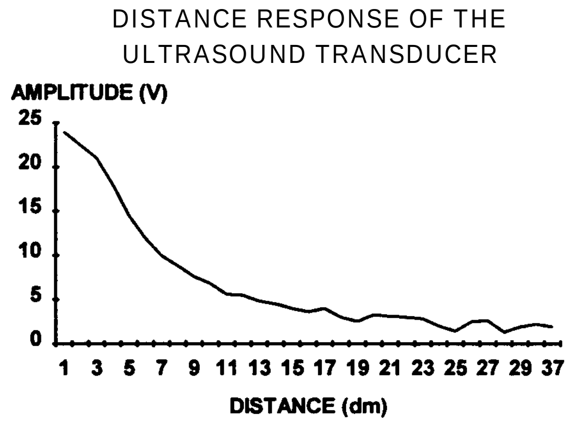

Fig.2 - Receptor sensibility to distance.

Analyzing figure 2 one can notice the relatively low range of this kind of transducer, that can also be lowered in presence of obstacles between the emitter and the receiver.

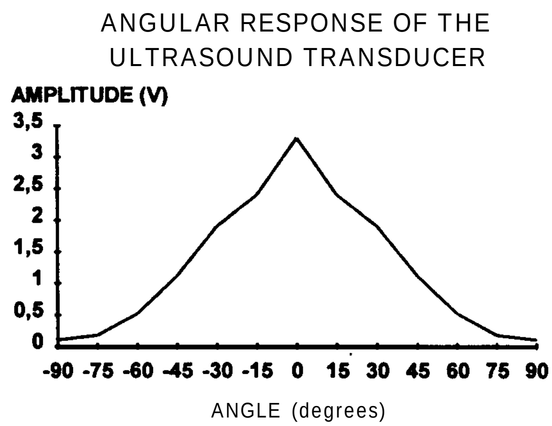

Fig. 3- Directionality of the transducer

According to figure 3, it can be seen that these transducers are relatively directional. This characteristic can be important in uni-directional systems, but it is a problem that has to be overcome in more flexible ones.

Alternatively, this technique presents as main advantages the resolution that can be obtained and the relatively low complexity of the involved circuits.

3. PROPOSED SYSTEM

The system is composed of a reference system, sample whose position one wants to determine (point to be determined) and an analysis software. Figure 4 shows a schematic diagram of the complete system.

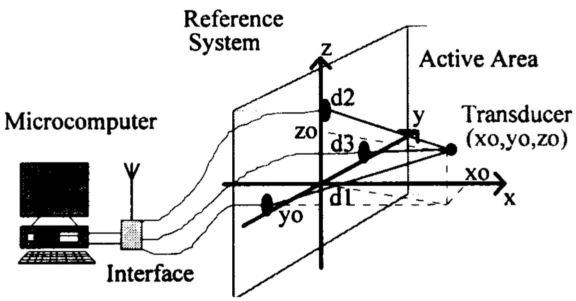

Fig. 4- Schematic diagram of the proposed system.

The reference system is composed of three ultrasound receivers that define a coordinate system for the space called Active Area. This space, together with the ultrasound power, define a maximum volume of use, that is, the dynamic range of the acquisition system. Each sample is composed, thus, of three coordinates (x,y,z) of a point. These coordinates are determined from the distances d_1, d_2 and d_3 of the point to each of three receivers.

The point is composed of an ultrasound transmitter, whose signal should be picked up by the receivers.

The management of the whole system is done through a microprocessed system. An IBM compatible PC was used to perform this task.

The general description of how the system works is the following: The PC sends a signal of start acquisition, called here reference signal. This signal is thus sent by radio frequency waves to the point whose position is to be determined. This signal starts an oscillator that stimulates the transducer to issue an ultrasound pulse. Radio frequency waves were used to obtain a wireless system. At the same time, the three counters are started, resetting and starting the count. These counters are started by the reference signal and stopped by the signals received by the ultrasound receivers of the reference system, as shown in figure 5.

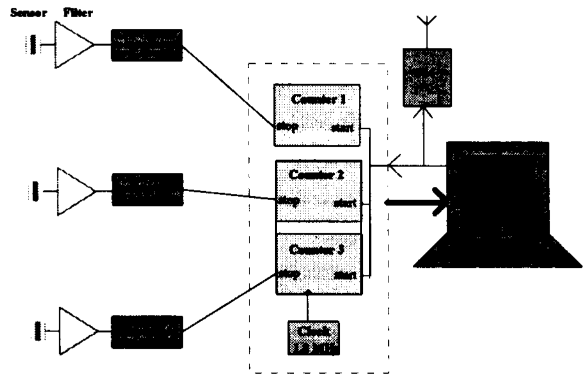

Fig. 5- Time-of-flight Counting System.

Figure 6 presents the principle of measurement of the distances d_1, d_2 e d_3 by the measurement of the time-of-flight from the reference signal issued by the computer. Each receiver gets the ultrasound signal in a different time, proportional to its distance to the transmitter. When the receiver identifies the ultrasound signal it stops its counter. When the three counters stop, the position sample is converted and the distances are determined.

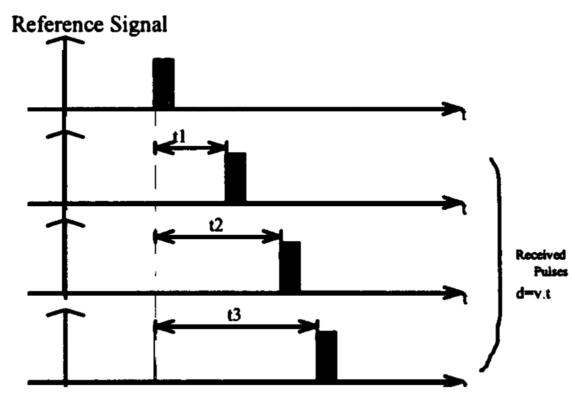

Fig. 6- Distance Measurement Principle.

The accuracy of the system depends on the dynamic range and on the number of bits allocated to each measurement. The counters used in the prototype have 16 bits, thus each position sample is composed of a vector (x,y,z) of 48 bits. In the case of a dynamic range of 7x7x7 cubic meters, the maximum theoretical resolution achieved is 0.188 millimeters. Using counters with frequency of 1.8 MHz the prototype presented a resolution of around 0.5 mm for the same dynamic range.

The maximum sampling frequency obtained (the time needed for each acquisition) was 65 Hz. This value is very satisfactory for many applications, such as the one presented in the next section.

It is important to notice that the sampling frequency depends directly on the actual dynamic range.

The directionality of the ultrasound sensors was overcome by the use of redundant emitters in the same point. Hence, the point becomes a sphere composed of ultrasound ceramic crystals. When an obstacle interrupts the wave, the corresponding counter counts to the final value because it doesn't receive the stop signal. This situation is analyzed by the system, indicating that either the point is out of the dynamic range or, through the analysis of previous readings, that the signal was interrupted.

Because one of the main characteristics of the system is the fact that it is designed for wireless applications, the ultrasound transmitter (point to be determined) must send a signal with considerable power in order to increase its range. However, it is highly desirable that the physical dimensions of the system remain small, hence limiting the size of its power source and consequently limiting the system's dynamic range. This problem can be overcome, depending on the application envisaged, through the use of a battery with higher energy capacity, however increasing its physical dimensions.

An alternative that is being investigated is the inversion of ultrasound transmitters and receivers, then keeping the ultrasound transmitters in fixed positions and using the ultrasound receiver in the position to be determined. This fact can allow a higher dynamic range because the batteries for the ultrasound transmitters have no limitations in weight and volume. Furthermore, the power required for the RF transmitter can be very small, due its higher efficiency and the short distance involved. The main disadvantage of this implementation is the higher sampling time required, because each reference transmitter must send one pulse at a time.

4. SYSTEM APPLICATIONS

The proposed system can be used in many areas, such as robot positioning control in a room and man-machine interface through virtual reality.

One present use of the system is as the main tool in a Dance-Music Interface [6], where dancers can control various music aspects through movements or their position on stage.

The interface is composed of a custom software that analyzes the dancers' movements or positions acquired by the system presented above and decides, according to pre-established rules, which MIDI (Musical Instrument Digital Interface) [7] parameter should be changed. The software is mainly based on a Fuzzy Inference System [8] in order to improve its ability of dealing with non-repetitive movements or non-accurate positions of human beings.

One example is shown in figure 7. The dancer's position on the stage (x,y) is defined as the system's input and the computer generated music volume is defined as the system's output. It was decided that a minimum sound volume circle was designed in the geometrical center of the stage, through the use of AND/OR rules between the stage's depth and width. Any displacement from this circle leads to an increase in the computer music output volume.

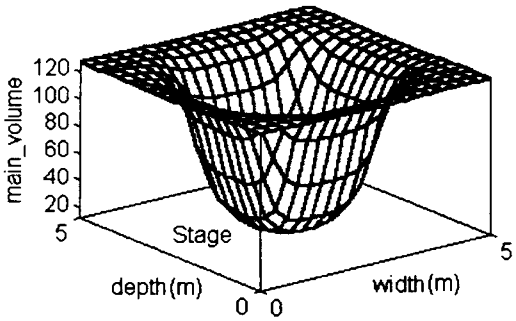

Fig. 7- Sound volume controlled by the dancer's position on stage.

5. CONCLUSIONS

This work presented a 3-dimensional position acquisition system based on the measurement of ultrasound waves time-of-flight. The system is composed of three ultrasound receivers and one transmitter (the point to be measured) connected to an IBM PC that analyses the time the wave takes to reach each of the receivers and computes the resulting distances, according to the speed of sound. Its current application is as part of a Dance-Music Interface where dancers' positions and movements control musical parameters.

6. ACKNOWLEDGEMENTS

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