Investigation and Demonstration of Local Positioning System Using Ultrasonic Sensors for Wide Indoor Areas

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Abstract. This paper proposes an indoor positioning system for detecting the location of a moving object such as a person or a goods trolley in a wide indoor area. Conventional system requires synchronization between transmission and receiving unit. As a result, they include not only an ultrasonic part but also a radio part to maintain synchronization. We have developed a system that uses only ultrasonic waves, that is, an asynchronous system. The system configuration and sequence of operation are explained and the verification system which includes H8, PIC microprocessors and a PC for positioning calculation is described. It was confirmed that the proposed method is valid and the positioning error is within 100mm.

Keywords: Positioning System, Ultrasonic Waves, Asynchronous System, Positioning Error, Navigation.

1 Introduction

The GPS(Global Positioning System) is widely used for determining position in an outdoor area. It has become a universal system and the location information provided by GPS is widely used in navigation systems and many other service systems [1]. However, for indoor positioning applications, no common system has been established and various schemes have been investigated.

Positioning systems that are based on ultrasonic waves have been proposed. These systems area based on the trilateration, that is, the distance between two points which is measured by the difference in propagation time of radio waves and ultrasonic waves is used for positioning [2]. The propagation time of radio waves is neglected in this system. Alternatively, time synchronization between transmitting and receiving units can be implemented in order to detect the propagation time [3]. Consequently, these systems use radio devices, so they become somewhat complicated and must satisfy the radio regulations, which are different for different countries.

We use inverse GPS methods [4], that is, an arrangement of a transmitting and a receiving unit that is the reverse of that of GPS. This scheme does not require synchronization or information on the distance between a transmitting and a receiving unit. Therefore, this type of positioning system can be built using only ultrasonic units

B. de Ruyter et al. (Eds.): AmI 2010, LNCS 6439, pp. 280–284, 2010.

and this both simplifies the system configuration and avoids the need to comply with radio regulations. The verification model is designed to confirm the feasibility of such a positioning system which uses only ultrasonic units. The feasibility and positioning accuracy have been confirmed by the experiment.

2 Indoor Positioning Method

There are two basic techniques that can be used for a positioning system which uses ultrasonic waves. The relationship between the transmitting and receiving units is shown in Fig.1. The first technique is a synchronous system, in which the receiving unit knows the time of transmission of an ultrasonic signal. In this type of system, the distances between each receiving sensor and the transmitter are obtained from the propagation time and the velocity of sound. Some systems regard the time difference between the arrival of radio waves and ultrasonic waves sent from the transmitter at the same time, as the propagation time of the ultrasonic waves. Conventional ultrasonic positioning systems are based on this principle. In this scheme, the propagation times of t_0, t_1 and t_2 may be determined because synchronization between the transmitter and the receiving unit is maintained or the time difference between the received radio and ultrasonic waves is regarded as the propagation time of the ultrasonic waves.

The other technique is based on an asynchronous system, in which the clock of the transmission unit is independent of the receiving unit. Therefore, the propagation time cannot be obtained in this scheme. Only the delay times of each receiving sensors can be detected in this scheme. The delay time means the time that has elapsed since the first receiving sensor detected the ultrasonic wave. Consequently, three delay times, that is, t_1, t_2 and t_3 can be obtained from four receiving sensors as shown in Fig.1. The synchronization of all receiving sensors is maintained because they are included in one receiving unit, in which one clock governs the timing of the receiving unit. This scheme does not require synchronization between the transmitter and the receiving unit, and so it makes it possible to simplify the system configuration and to avoid the need to conform with radio regulations.

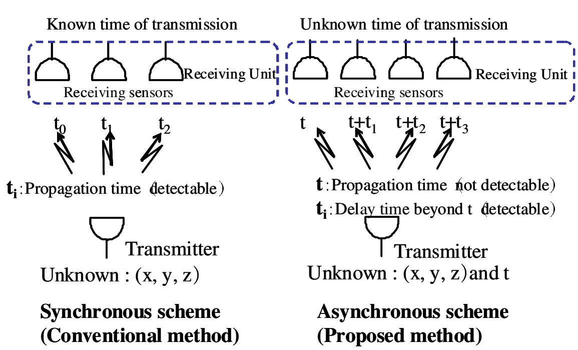


Fig. 1. Synchronous scheme and asynchronous scheme

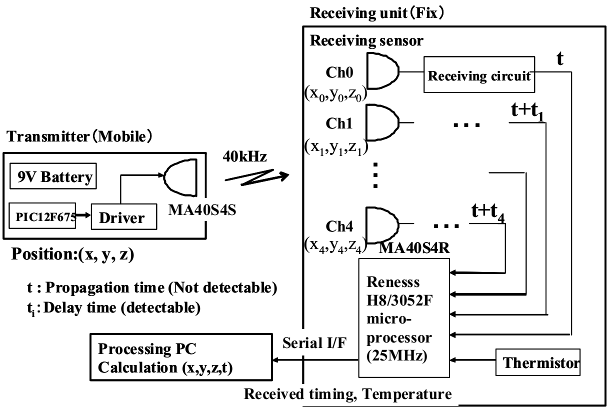


Fig. 2. Configuration of verification system

3 Positioning System Configuration and Its Sequence

The prototype system for verifying the scheme is shown in Fig.2. The positioning system consists of three units, that is, receiving unit, transmitter and signal processing PC. The Microchip PIC microprocessor is used to generate a 40 kHz on/off signal for the ultrasonic wave in the transmitter. The ultrasonic pulses are transmitted at a constant interval of 30ms and have a duration of 400μs.

The receiving unit is composed of receiving sensors, a Renesas H8/3052F microprocessor, the interface part for the PC, and the receiving circuits, each of which includes an amplifier and comparator. The number of receiving circuit is five, so five receiving sensors can be used for position calculation. The calculation is, in principle, possible with only four sensors but five sensors are used for certain position calculations, because there may be occasions where the relative positions of the transmitter and one receiving sensor make reception impossible. The output signals of the receiving sensors are amplified, and the comparators detect the arrival of the

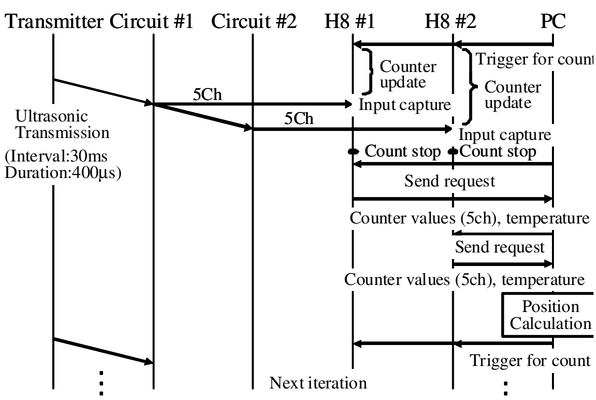
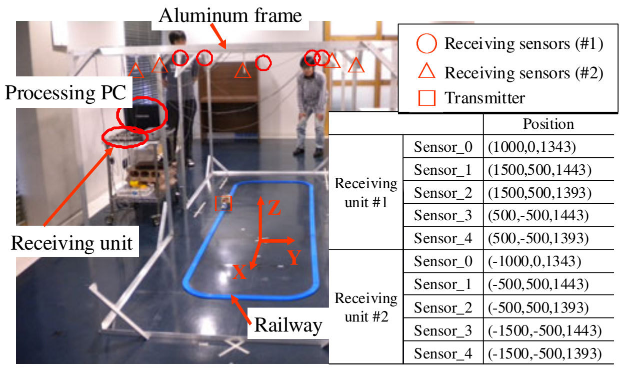


Fig. 3. System sequence of proposed system



		Position
Receiving unit #1	Sensor_0	(1000,0,1343)
	Sensor_1	(1500,500,1443)
	Sensor_2	(1500,500,1393)
	Sensor_3	(500,-500,1443)
	Sensor_4	(500,-500,1393)
Receiving unit #2	Sensor_0	(-1000,0,1343)
	Sensor_1	(-500,500,1443)
	Sensor_2	(-500,500,1393)
	Sensor_3	(-1500,-500,1443)
	Sensor_4	(-1500,-500,1393)

Fig. 4. Experiment configuration and sensor locations

ultrasonic waves at each sensor. The receiving sensors are Murata MA40S4R, whose diameter and height are 10mm and 7mm, respectively. The signal from the comparators in the circuits is captured by H8 processor ports and the counter values of H8 which indicate the receiving timing are sent to the PC via a serial interface. The thermistor is installed in order to monitor the ambient temperature.

The sequence of getting the received times, which are used to derive the delay time, from the receiving sensors via the H8 processors is indicated in Fig.3. The count start trigger to the two H8 processors is sent at the same time via the RS485 interface from the PC. The count values are held in each H8 micro processor when the associated sensor receives the ultrasonic wave. These values are sent to the PC and calculated to give the delay times. Five count values are obtained from the five ports that are connected to the five sensors.

The delay times t_i are calculated from these count values by taking into account the clock time of the H8 processors. Each count value is reduced by the count value of the first sensor to receive the ultrasonic waves, that is the minimum count value, in order to convert the counts to delay times. The position calculation is carried out taking account of the temperature, obtained as a voltage value from the thermistor, to determine the ultrasonic wave velocity c. The sequence from trigger to position calculation is repeated for subsequent iterations as shown in Fig.3. The transmitter and receiving units do not require synchronization, because only the delay time is used to calculate position.

4 Confirmation Experiment

The experimental configuration, the sensors installed in the frame and their locations are shown in Fig.4. The size of the railway track was used to evaluate the proposed scheme. Two identical receiving units were used for this experiment. The positioning results are shown in Fig.5. It was verified that positioning can be carried out without significant degradation of accuracy. The reason why the accuracy is degraded in this central region seems to be due to the drop the strength of the received ultrasonic wave. As the receiving signal becomes weaker, the fluctuation in the count values that are converted to time delay becomes large. However, the accuracy seems to be

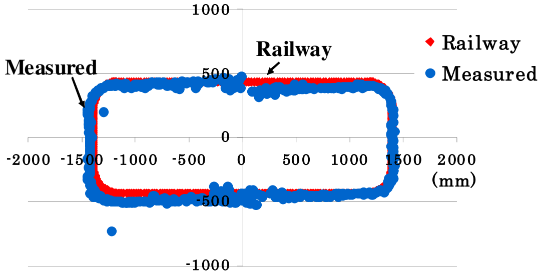


Fig. 5. Experiment result for proposed system

sufficient to detect the location of people who are walking. The peculiar result shown by the point at the lower left can be ignored by considering the moving velocity of the person. It has been verified that the proposed system architecture can be applied for any applications such as navigation in an indoor area, etc.

5 Conclusion

We have proposed an indoor positioning system which can be applied to the detection of the location of persons or moving vehicles in a factory. The main feature of the proposed system is that it uses only ultrasonic sensors. Therefore, it can be built more simply, compared with conventional systems and avoids the need to conform to radio regulations which differ from country to country. A verification system was built and the feasibility and accuracy of the proposed system have been confirmed by experiment. The accuracy is sufficient to monitor the location of person or goods vehicle in a factory, etc.

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