A Simple Ultrasonic GPS System for Indoor Mobile Robot System using Kalman Filtering

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Abstract

*This paper introduces a simple indoor GPS system using ultrasonic sensor. Conventional ultrasonic GPS systems require at least 3 transmitters, which restricts update time of location information by 5 cycles/sec so that the ultrasonic waves from the 3 transmitters do not overlap. This system consists of 1 transmitter having ultrasonic and RF and 2 receivers. The transmitter irradiates RF and ultrasonic, and the receivers calculate corresponding distance with reference to the RF signal. The 2 distance values are used for determining the location of the transmitter by trigonometrically functions. Due to the characteristics of ultrasonic sensors, noise occurs in sensor values by surrounding temperature or obstacle. Location error is minimized by prediction and correction of the noise with Linear Kalman Filter. In order to prove the effectiveness of this system, experiments were carried out in a room dimensioned by 3.5m*2.2m, wherein the location error showed 2cm max.*

Keywords: Ultrasonic, GPS, Kalman Filter.

1. INTRODUCTION

Many R&D activities are being conducted on the mobile robots which are applicable to daily life. The existing commercial robots for civil uses, such as cleaning or guiding, are designed to carry out duties traveling certain paths as an assistant to human. Therefore, accurate travel to desired location is very important. However, the built-in sensors and algorithm are subject to accumulative errors caused by the restrictions and error in sensor, external disturbance, slip, or kidnapping, which might disable self-localization.

Many studies have been presented to solve this self-localization problem. The GPS system which is widely used in automobiles has large error range and is not available indoors. Landmark recognition system using images require expensive cost and weak for lighting. Recent development trend focuses on the GPS system using ultrasonic distance measuring, which is described in this paper, due to its practical applicability.

The simple GPS system described in this paper consists of 1 transmitter and 2 receivers which have RF and ultrasonic devices respectively.

Conventional ultrasonic GPS systems use transmitter located at high elevation as actual GPS or DGPS, or on the ground which irradiates RF or IR as synchronizing signal providing the receivers at opposite location with distance data.

Such systems calculate locations with the distance data measured with 3 or more receivers [1][2].

The system presented in this paper has a ground transmitter and 2 receivers, requiring simple installation and easier trigonometrically functions for calculation.

Accurate distance can be obtained by measuring the TOF(Time of Flight) value of the ultrasonic sensor. However, The TOF is more or less subject to be changed by the timer resolution of the built-in microprocessor, ambient temperature, or other dynamics of surrounding environment, resulting in the location error. In this study, simple Linear Kalman Filter is applied to estimate TOF more accurately, which in turn is used to calculate accurate distance value [3].

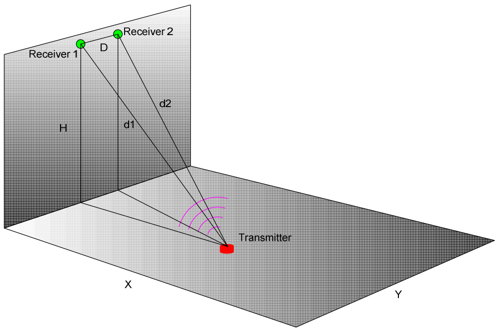

Fig. 1 System configuration

2. system description

2.1 Problems

The system that could detect location by using 3 or more of the above-mentioned transmitters as well as receivers had problems as follows [1],[2]

- The transmitter was placed at upper side to let a robot receive signals. When both ultrasonic sensors for obstacle avoidance and ultrasonic sensors for GPS made use of same frequency, the ultrasonic sensors for obstacle avoidance that perceived as noise the GPS signal.
- The wider location awareness space was, the more transmitters and receivers were required.
- At installation of ultrasonic GPS module, X and Y should have different location because of intersection point equation of a circle.

2.2 System Configuration

The GPS system presented in this paper consists of 2 receivers and 1 transmitter. Both the receivers and the transmitter use the RF signal for synchronization to obtain the distance data from the ultrasonic wave. As shown in Fig. 1, the receivers are located from the transmitter by a distance D and elevation H. The transmitter sends ultrasonic wave and RF signals to receivers. The distance is obtained in the receivers with the RF signal from the transmitter. The distance data is calculated using trigonometrically functions as illustrated in Fig. 2. In the Fig. 2 where there are 2 transmitters are shown, the portion in the opposite side of the wall can be disregarded since the receivers are installed on the wall.

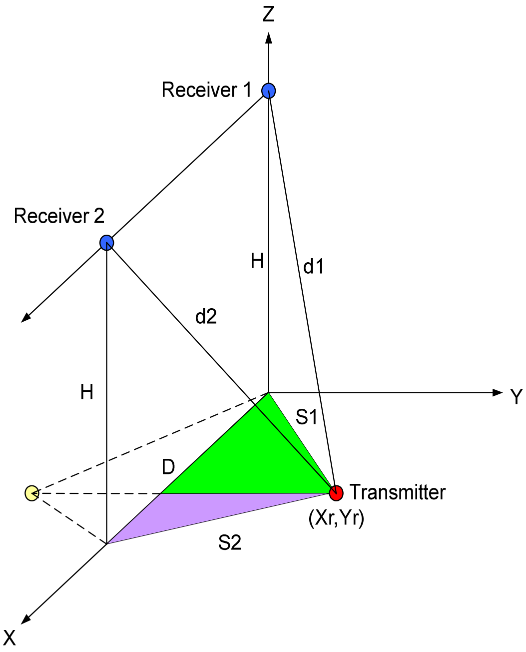

Fig. 2 Position calculation method

2.3 Position Calculation

The distances of D1 and D2 that were measured by using the transmitter's ultrasonic wave and RF could calculate S1 and S2.

$$d^2 = H^2 + S^2 \tag{1}$$

H, indicated height at receiver installation. The transmitter coordinates of Xr and Yr could be obtained in accordance with simple trigonometrically function of the following equations

$$S1^2 = Xr^2 + Yr^2 \tag{2}$$

$$S2^2 = (D - Xr)^2 + Yr^2 \tag{3}$$

Minus values of Xr and Yr were not used for actual coordinates.

2.4 Ultrasonic Sensor

At the experiment, the ultrasonic sensor made use of an integrated receiving and transmitting ST-203 model at 40Khz that could detect rear side of automobiles.

The GPS system had directivity of 90±10[deg] and detecting range of 0.3~2.0 [m] that were the most important [Figs.3~4]. The detecting range indicated distance that could reflect and receive ultrasonic wave.

The GPS system had detecting range of 4m because it did not make use of ultrasonic signals that returned after being reflected. The GPS system was found to have detecting range of max. 6.0 [m] at the experiment.

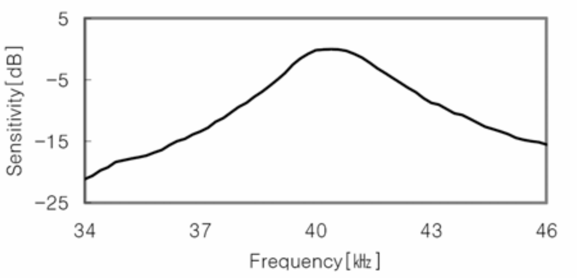

Fig. 3 Ultrasonic sensor frequency

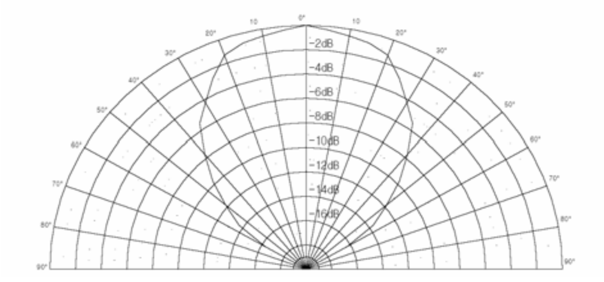

Fig. 4 Ultrasonic sensor directivity

2.5 Calibration

Two kinds of calibration were required to calculate location of the transmitter exactly.

Firstly, ultrasonic distance of both transmitter and receiver could be calibrated exactly when adjusting both $t[^{o}C]$ and Op-amp threshold perceiving ultrasonic receiving signal at the formula of radio velocity in the air.

$$V[m/s] = 331.5 + 0.60714t \qquad (4)$$

Secondly, location calibration was required. Without input of X and Y coordinate, setting of height could decide on location of transmitter exactly by setting process of initial location [Fig. 5]. when deciding on location of ultrasonic receiver [Fig. 2]. The perspective transformation for image processing was used to calibrate location.

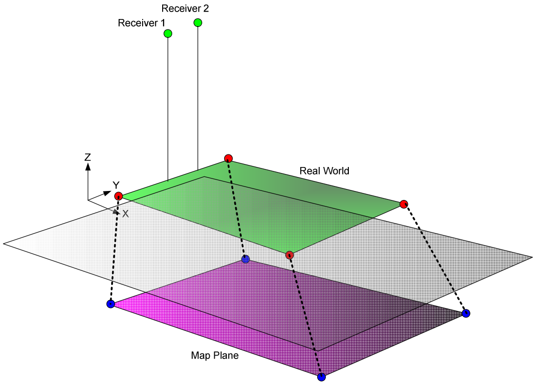

Fig. 5 Position calibration

(Perspective transformation method)

3. LKF(Linear Kalman Filter)

A technique which removes the noise, in real-time basis, included in the ultrasonic wave from the transmitter is required. Furthermore, fast noise removal is necessary for real-time basis distance measurement. The Kalman Filter is used to this end.

3.1 Process Model

The ultrasonic sensor's linear difference equation did not make change of sensor status at Kalman formula to set A = 1, and the sensor did not input control to set B = 0.

$$\begin{aligned} x_k &= Ax_{k-1} + Bu_k + w_k \\ &= x_{k-1} + w_k \end{aligned} \qquad (5)$$

And, measurement data was $z_k \in \Re^1$ to set H = 1 as follows:

$$\begin{aligned} z_k &= Hx_k + v_k \\ &= x_k + v_k \end{aligned} \qquad (6)$$

3.2 The Filter Equation and Parameters

Time update equation was:

$$\hat{x}_k^- = \hat{x}_{k-1} \qquad (7)$$

$$P_k^- = P_{k-1} + Q \qquad (8)$$

Where, $Q = 1$.

And, measurement update equation was:

$$\begin{aligned} K_k &= P_k^-(P_k^- + R)^{-1} \\ &= \frac{P_k^-}{P_k^- + R} \end{aligned} \qquad (9)$$

$$\hat{x}_k = x_k + K_k(z_k - \hat{x}_k^-) \qquad (10)$$

$$P_k = (1 - K_k)P_k^- \qquad (11)$$

4. Experiment

To conduct test of control system, the robot soccer system tested location controls of mobile robot. Each receiver having 1.8m height was put at corners of robot soccer middle MiroSot stadium to let all of ultrasonic sensors have viewing angle of all of the areas [Fig. 7]. In the experiment, not only one of ultrasonic transmitter but also two of receivers were used in addition to RF radio module. In the experimental environment, perspective transformation initialized location of mobile robot. The communication between the receiver and the transmitter was made in accordance with table of order made in advance to adopt direct call system[Fig. 6].

The main micro controller of transmitter and receiver adopted ATMEL Company's small-sized ATmega8 having RISC structure. BIM-II 433 MHz, Radiometrix Company's FM transmitting and receiving module, was used to transmit and receive signals at 38400Bps of baud rate. And, the receiver adopted external power supply of lithium polymer battery to put it at any place.

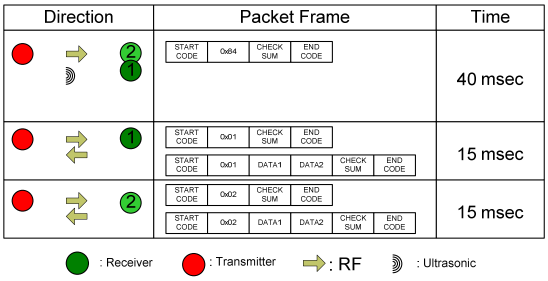

Fig. 6 Communication packets and time

The ultrasonic transmitter could transmit RF as well as ultrasonic wave to the receiver at the same time: Not only RF packet transmitting time but also arrival time of sound wave (340m/s) at 5m was added up to require 40msec. To bring distance measured at each receiver, A bi-directional packet transmission time of RF should be added up to require 70msec. Update could be done approximate 13 times a second.

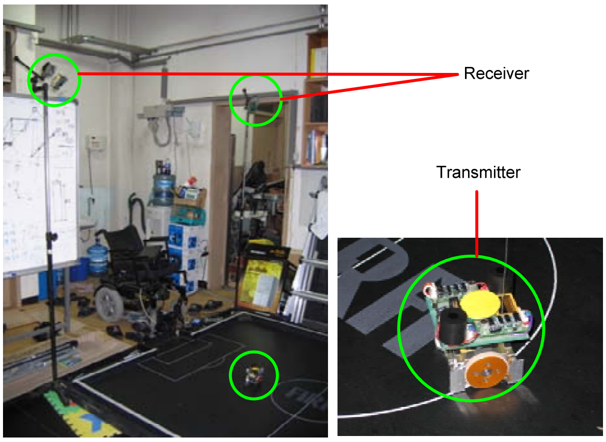

Fig. 7 Experiment environment

5. RESULT

The paper suggested a simple ultrasonic GPS system that a mobile robot could perceive its location. In the experiment, the robot could perceive location with error not exceeding 2cm to have inexpensive system that could be used at indoor [Figs. 9~10].

The test result showed that errors of ultrasonic distance and radio transmitting and receiving could not be neglected. The errors that occurred at random could make correction by using LKF to reduce them very much [Fig.8]. The transmitting and receiving node was under stop mode to indicate straight movement location of transmitter [Figs. 8~10]. The location errors between stop mode and movement mode did not exceed ± 2 Cm.

The GPS module required improvement as follows: Firstly, the sensor should be developed to perceive location at wider areas because not only arrival distance of transmitting signal of ultrasonic sensor but also beam angle was limited. Secondly, when putting receivers at many places, a sensor network was required to calculate distance between sensors.

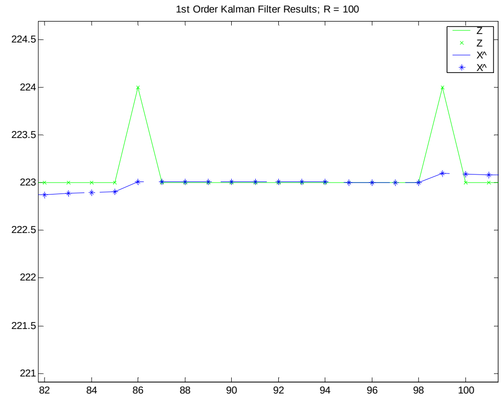

Fig. 8 Kalman Filter Result

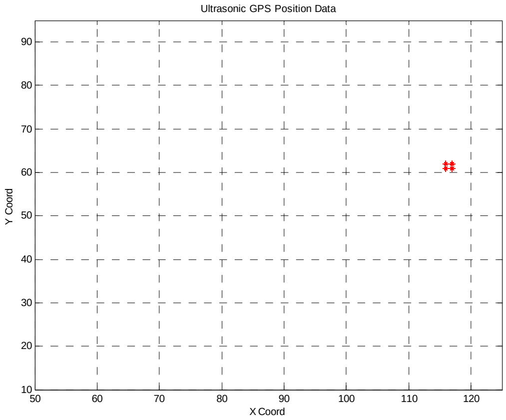

Fig. 9 Position data

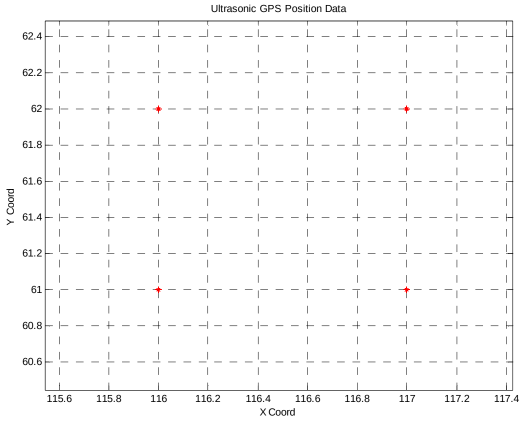

Fig. 10 Position data (Zoom)

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