Engineering in Agriculture, Environment and Food xxx (2017) 1–10

Contents lists available at ScienceDirect

Engineering in Agriculture, Environment and Food

journal homepage: http://www.sciencedirect.com/eaef

Temperature compensation method using base-station for spread spectrum sound-based positioning system in green house☆

Tomoo Shiigi [a,*], Naoshi Kondo [b], Yuichi Ogawa [b], Tetsuhito Suzuki [b], Habaragamuwa Harshana [b]

[a] Ocean Machinery Engineering, National Fisheries University, 2-7-1 Nagata-Honmachi, Shimonoseki, Yamaguchi, 759-6595, Japan
[b] Graduate School of Agriculture, Kyoto University, Kitashirakawa, Sakyo-ku, Kyoto 606-8502, Japan

ARTICLE INFO

Article history:
Received 21 July 2015
Received in revised form
4 February 2017
Accepted 12 March 2017
Available online xxx

Keywords:
Positioning system
Spread spectrum sound
Temperature compensation
Base-station

ABSTRACT

To apply Spread Spectrum (SS) sound-based positioning system in green house, measurement accuracy was investigated by using Base- Station (BS) for compensating temperature. In this experiment, normalized correlation value and correlation ratio were used to detect correlation peak of direct wave of SS sound. When 9 positions in actual greenhouse were measured, success rate to detect direct wave of SS sound was 99%. As the result, this correlation peak detection method is useful to detect correlation peak of direct wave. Average measurement error at each position was 55 mm and improved about 20 mm by using BS method. Moreover, when center correlation peak was detected, average measurement error was 15.5 mm. Thus, BS method enables SS sound-based positioning system to be useful in green house.

1. Introduction

Rail system or electromagnetic guidance system are often used for autonomous vehicle in factories and green house (Kondo et al., 2006). However, those systems have disadvantages such as high installation cost and difficulties in route modification after the installation. As an indoor positioning system, lot of methods are being researched, such as wireless LAN, RFID, camera, laser, sound, etc (Kamiya, 2005). Among them, the sound based positioning system has the capacity to create an inexpensive positioning system and to measure accurate position even if low sampling frequency is used because sound velocity is much slower than radio wave (Ward et al., 1997; Priyantha et al., 2000). Moreover, spread spectrum (SS) sound is capable of improving the noise tolerance (Girod, 2000).

However, for accurate positioning, compensation of both wind velocity and temperature is essential, because they change with time and location. Our research group developed wind compensation method using a Base-station (BS) and improved measurement accuracy at an outdoor field (Widodo et al., 2014). This compensation method calculates sound velocity vector in measurement field based on measuring the propagation time of sound from BS. It is possible to apply this method, for temperature compensation also. Temperature tends to affect sound velocity and needs to be compensated, especially in a green house. No paper, however, has reported measurement accuracy of SS sound-based positioning system that uses BS in a green house so far.

In this research, accuracy of SS sound-based positioning system in green house, based on the compensation using BS will be discussed.

2. Local positioning system based on SS sound

2.1. SS sound

SS sound was created by using M-sequence (maximum length sequence) with BPSK (Binary Phase Shift Keying) modulation in this experiment (Shiigi et al., 2010). M-sequence is one of pseudo random code. Auto-correlation value of M-sequence become 1 when phase of M-sequence is matched. However, autocorrelation value become $1/N$ when out of phase. Where, N is period of M-sequence. Therefore, it is easy to detect position in phase using this property. Cross-correlation value against different M-sequence or noise signal also become small value. It is, hence,

☆ Partly presented at the International Agriculture Conference in October 2005.
* Corresponding author.
E-mail address: shiigi@fish-u.ac.jp (T. Shiigi).

http://dx.doi.org/10.1016/j.eaef.2017.03.004
1881-8366/© 2017 Published by Elsevier B.V. on behalf of Asian Agricultural and Biological Engineering Association.

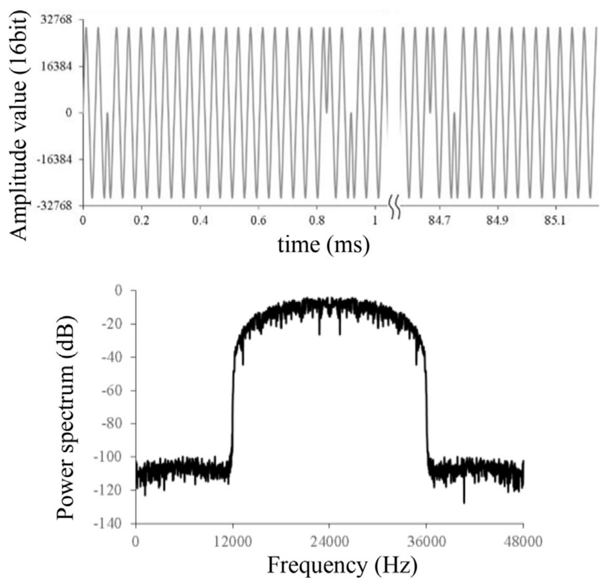

Fig. 1. SS Sound signal created from M-sequence with BPSK modulation and its frequency property.

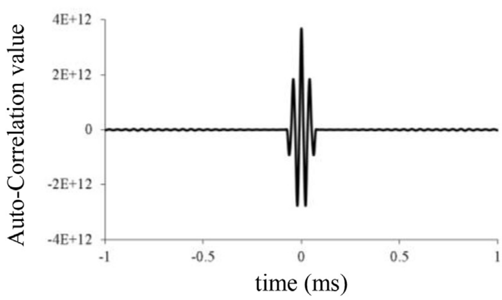

Fig. 2. Auto-Correlation function of SS Sound.

possible to distinguish between desired M-sequence and another signal by correlation processing. SS sound is capable of improving noise tolerance and signal identification by M-sequence property. Fig. 1 shows SS sound signal in this research. Period of M-sequence was 1023. Chip rate was 12 kcps. Carrier wave frequency was 24 kHz.

Fig. 2 shows auto-correlation function of SS sound which was used in this research. There are three large correlation peaks. Center correlation peak among three peaks indicates the position of SS sound signal without phase shifting.

2.2. LPS architecture

2.2.1. System configuration

Fig. 3 shows the configuration of SS sound-based local positioning system in this research. Three receivers (microphones) are set in the measurement area. Transmitter (speaker) moves within the area enclosed with receivers. This system measures distances between each receivers and transmitter then estimates the position at transmitter. This system configuration is called as inverse-GPS configuration.

2.2.2. Position estimation method

Transmitter sends SS sound and trigger signal which inform output time of SS sound from transmitter. In general, radio wave

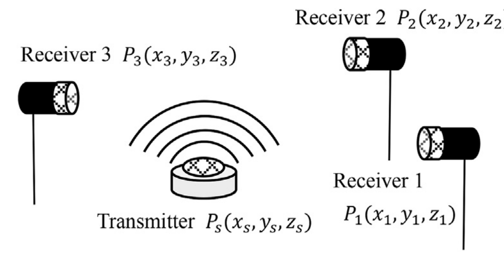

Fig. 3. Configuration of SS Sound-based Local Positioning System in this research.

and electrical signal are used as trigger signal because propagation velocity of radio wave and electrical signal is much higher than that of sound. Electrical signal was used as the trigger signal in this experiment.

A receiver that is connected to PC receives the SS sound and the trigger signal, and correlation value is calculated as shown in formula (1).

$$c_{1i}(t) = \sum_{\tau=0}^{N-1} s_1(\tau) r_i(\tau + t) \tag{1}$$

Where, t is the time of received signal, s_1 is the replica of SS sound from transmitter, r_i is the received signal of receiver i, N is the length of replica of SS sound.

Received time of SS sound t_i is estimated by detecting correlation peak of SS sound. Propagation times of SS sound Δt_i between each receivers and transmitter are calculated by formula (2).

$$\Delta t_i = t_i - t_{trigger} \tag{2}$$

Where, $t_{trigger}$ is the received time of trigger signal.

When positions of receivers (x_i, y_i, z_i) are known, distances between transmitter and receivers d_i are calculated as shown in formula (3).

$$d_i = V_i \times \Delta t_i = \sqrt{(x_s - x_i)^2 + (y_s - y_i)^2 + (z_s - z_i)^2} \quad V_i = 331.5 + 0.61 \frac{T_s + T_i}{2} \tag{3}$$

Where, V_i is the sound velocity, T_s is the temperature at transmitter, T_i is temperature at receiver i, (x_s, y_s, z_s) is position at the transmitter. If number of receivers are more than three, 3 dimension position of transmitter can be estimated. Because those formulas are nonlinear vector function, in general, they are solved as below. $f_i(x_s, y_s, z_s)$ is defined and linearized in a Taylor series about a reference point specified by (x_{s0}, y_{s0}, z_{s0}).

$$\begin{aligned} f_i(x_s, y_s, z_s) &= \sqrt{(x_s - x_i)^2 + (y_s - y_i)^2 + (z_s - z_i)^2} \\ &\cong \sqrt{(x_{s0} - x_i)^2 + (y_{s0} - y_i)^2 + (z_{s0} - z_i)^2} \\ &\quad + \left.\frac{\partial f_i}{\partial x_s}\right|_{x_s = x_{s0}} (x_s - x_{s0}) + \left.\frac{\partial f_i}{\partial y_s}\right|_{y_s = y_{s0}} (y_s - y_{s0}) \\ &\quad + \left.\frac{\partial f_i}{\partial z_s}\right|_{z_s = z_{s0}} (z_s - z_{s0}) \end{aligned} \tag{4}$$

Then, formula (5) is made by formula (3) and (4).

Please cite this article in press as: Shiigi, T., et al., Temperature compensation method using base-station for spread spectrum sound-based positioning system in green house, Engineering in Agriculture, Environment and Food (2017), http://dx.doi.org/10.1016/j.eaef.2017.03.004