Method for considering angle error in the position estimation of a moving target using ultrasonic array

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Abstract: In this study, we propose a method for reducing angle error in position estimation of a moving target. The distance between the transmitting array and target is approximated by two receiving sensors close to the transmitting array. This enables more accurate distance measurement between the receiving sensor and the target.

Keywords: Position estimation, Ultrasonic sensor, Trilateration, Angle error

Classification: Wireless communication technologies

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1 Introduction

Congested traffic in urban areas results in a large number of accidents at low speeds [1]. Automated driving technology has been developed to reduce the frequency of these events. To this end, the position of obstacles, such as humans and barriers should be estimated [2][3]. In this study, we focus on ultrasonic sensors already installed in numerous vehicles. Ultrasonic sensors are inexpensive and suitable for use in estimating short distances [4],[5]. However, they are not capable of position estimation. Furthermore, they have a narrow monitoring range. Thus, to apply them to applications such as obstacle detection, it is important to extend their detection range and position estimation [6].

We developed a system where the detection range is extended and position estimation is achieved by placing ultrasonic emitters and receiving sensors on an array [7]. In previous study, we confirmed that the system can measure up to 15 m, whereas the estimation error is only a few centimeters. However, the accuracy of the position estimation is poor, and the accuracy in the angular direction must be improved in particular.

In this study, we describe a new position estimation method that improves the accuracy of angular direction estimation [8]. In our setup, ultrasonic sensors are arranged in a linear array to realize position estimation. The sensor spacing is 15 cm, and eight sensors are used for position estimation. In this arrangement, the distance between sensors at both ends reaches 105 cm, and if the object is far from the vertical direction, the angle obtained by these sensors exhibits a large error. Specifically, the angle error occurs because of the difference in the distance from the transmitting array to the object and from the object to the sensors.

We propose a method of position estimation focusing on the two sensors closest to the transmitting sensor array to reduce the above angle estimation error.

Our goal is to accurately estimate the position of targets. Therefore, accurate distance and angle information are necessary. Thus, the proposed method aims to reduce the angle error and estimate positions with high accuracy. We successfully achieve to reduce the angle error from 10.9° to 0.069°.
2 System model

In Fig. 1, the system used in this study is presented. The transmitting array consists of eight ultrasonic transmitters, which facilitate in the enhancement of ultrasonic waves. The frequency of the wave is 44.5 kHz. The array transmits ultrasonic waves at $t = 0$, which are then reflected by a target. The receiving sensor array consists of eight ultrasonic sensors (here, the receiving sensor $i$ denotes the $i$th ($1 \leq i \leq 8$) receiving sensor from left to right), each of which receives the reflected waves. The receiver interval is 15 [cm]. The output power of the sensors is converted analog to digital and processed to obtain the distance.

The time $t_i$ denotes the time at which the output power of the receiving sensor $i$ reaches its maximum value. The detection distance, $D_i$, between the transmitting array and receiving sensor $i$ via the target is calculated as $D_i = V \times t_i$, where $V$ denotes the speed of ultrasonic waves. For each receiving sensor $i$, only the detection distance $D_i$ is obtained.

To estimate the target position, detection distances obtained from multiple sensors are used for trilateration.

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2.1 Trilateration

Fig. 2 presents the trilateration model. We assume that the position of the receiving sensor \( i \) is set as \((x_i, 0)\). The target position is expressed in terms of the positions of the sensor pairs \( i, j (i \neq j) \). The position of the target \((x_{(i,j)}, y_{(i,j)})\) is expressed as follows:

\[
\begin{align*}
    x_{(i,j)} &= \frac{(r_i^2 - r_j^2) - (x_i^2 - x_j^2)}{2(x_i - x_j)} \\
    y_{(i,j)} &= \sqrt{r_i^2 - (x_i - x_{(i,j)})^2}
\end{align*}
\]

where \( r_i \) denotes the distance between the target and receiving sensor \( i \).

Equations (1) and (2) are used to calculate all combinations of \( i \) and \( j \). When \( x_{(i,j)} \) or \( y_{(i,j)} \) is beyond 20 m, the calculated position is eliminated as the maximum detection distance is 20 m. The average of the target positions \((x, y)\) is calculated using \((x_{(i,j)}, y_{(i,j)})\), as follows, where \( N \) denotes the number of position estimates.

\[
\begin{align*}
    x &= \frac{\sum_{i=1}^{8} \sum_{j=1}^{8} x_{(i,j)}}{N} \quad (i \neq j) \\
    y &= \frac{\sum_{i=1}^{8} \sum_{j=1}^{8} y_{(i,j)}}{N} \quad (i \neq j)
\end{align*}
\]
2.2 Proposed approximate method

Trilateration requires the value of $r_i$, but only the value of $D_i$ can be measured. Thus, we must obtain $r_i$ from $D_i$. In our previous study, we assumed that $r = r_i$, and the distance $r_i$ was approximated as follows [7]:

$$r_i \simeq D_i/2$$  \hspace{1cm} (5)

where $r$ denotes the distance between the transmitting array and the target. The result of the conventional method shows that the distance between the transmitting array and the receiving sensor is proportional to the error between the actual value of $r$ and the estimated value of $r$.

Thus, in the proposed method, the two receiving sensors closest to the transmitting array are used for the approximation [8]. The proposed method assumes that $r_4 \leq r \leq r_5$ or $r_5 \leq r \leq r_4$ and $r \simeq r_4, r \simeq r_5$. Hence, the distance $r_i$ can be approximated as follows:

$$r_i = D_i - r$$

$$\simeq D_i - (D_4/2 + D_5/2)/2$$  \hspace{1cm} (6)

3 Experiment

(a) Proposed method

$$r_i = D_i - r \simeq D_i - (D_4/2 + D_5/2)/2$$

(b) Conventional method

$$r_i \simeq D_i/2$$

Fig. 3: Position estimation of the moving measurement target

We used an aluminum plate as a target because it reflects the waves more easily than other materials. The experimental conditions include a temperature of 15 °C, the speed of sound is 341 m/s, the width of the aluminum plate is 0.455 m, and the angle of incidence is -20 °. The actual moving trajectory of the target is $y = -\tan 70^\circ x$. The range of $y$ is $5 < y < 15$. An aluminum plate is placed on a slow moving platform and at a speed of 3.4 km/h.

In Figs. 3 (a) and (b) show the results of position estimation. The $x$ and $y$ coordinates depict the horizontal and vertical positions, respectively. Sensors are installed at the origin. Pink points depict the estimated positions.
of the target. The green line traces the approximate trajectory of the target by the pink points, whereas the blue line traces the ideal trajectory of the target. The distance between the red lines depicts the width of the aluminum plate.

In Fig. 3 (a), the distance \( r_i \) is approximated as shown in Eq. (6), and in Fig. 3 (b), it is approximated according to Eq. (5). As a result, the angle errors are \( 0.069^\circ \) and \( 10.9^\circ \), for the previous and our proposed method, respectively. We describe the angle error as follows:

\[
\text{AngleError} = |\theta_g - \theta_b|
\]  

(7)

Comparing the previous and proposed methods, the angle error reduces from \( 10.9^\circ \) to \( 0.069^\circ \). ICETC2020 shows the results of a target approaching from a direction of \( 30^\circ \) \[8\]. Almost the same angular accuracy was obtained in both cases. Hence, the proposed method improves position estimation accuracy.

4 Conclusion

In this study, we proposed a method to approximate the distance between receiving sensors and a moving target, which reduces the angle error in target position estimation. In the proposed method, the distance between the transmitting array and the target is approximated from the two receiving sensors closest to the transmitting array. This approximation attains a more accurate distance between the receiving sensor and the target. Position estimation experiment proves that the proposed method produces a small angle error and can accurately estimate the position of moving targets.

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