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Wide-Area Obstacle Position Estimation Using Air-coupled Ultrasonic Sensor Arrays

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1. Introduction

We are working on an obstacle position estimation system using ultrasonic sensor arrays. We aim at a measurement time of 0.1 seconds or less and a measurement range of 10 meters or more for detecting obstacles in low-speed autonomous driving[1)]. Furthermore, our ultrasonic sensor array system can detect obstacles in the desired range with single irradiation without scanning the array by making the array vertically to the detection plane. In a previous study [2)], a method for estimating the two-dimensional existence probability density function (PDF) distribution of obstacles from the product of the PDF distribution of measured distance using the receiver arrays was reported. In such a method, the lack of array scanning makes obstacle position estimation poor angular accuracy, and the existence probability of obstacle position may expand in the angular direction. And the width of obstacles may also affect the existence probability.

In this paper, we report on position estimation experiments for three obstacles with different widths, a pole, an aluminum sheet, and a car, and compare their position estimation accuracy against those obtained by LiDAR.

2. System model

Figure 1 shows the system model of our ultrasonic sensor array system, and **Fig. 2** shows the configuration of the ultrasonic sensor array. The center of the measurement device is $(x, y, z) = (0, 0, 0)$; the x-axis is the horizontal direction, the y-axis is the frontal direction, and the z-axis is the vertical direction. The xy-plane at $z = 0$ is defined as the detection plane. As shown in **Fig. 2**, the transmitters are placed vertically to the detection plane, to form a wide horizontal and narrow vertical fan-shaped beam [1)]. The eight transmitters (center frequency: 44.5 kHz) are arranged at 0.012 m intervals, and the eight receivers are arranged at 0.15 m intervals. Both sensors were open-structure ultrasonic sensors manufactured by NGK SPARK PLUG.

In the position estimation[2)] in the proposed system, the measured distance by each sensor is considered to have its own error distribution. For i_o receivers, let us denote the coordinate of the i-th receiver r_i as x_{ri}, and the coordinate of the h-th reflection point t_h as (x_{th}, y_{th}). Consider that reflection points $t_1, t_2, ..., t_{ho}$ exist in the region where position estimation is performed. and t_{ho} exist in the region where the position estimation is performed. The propagation distance of the transmitted wave to be measured is shown in Eq. (1).

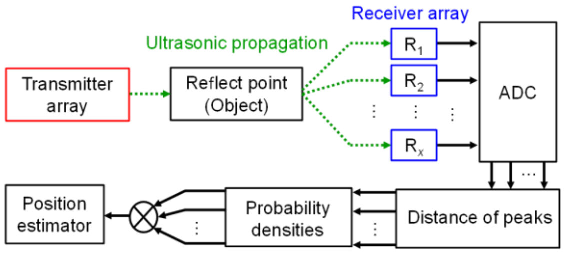

Fig. 1 The system model of the object position estimation using ultrasonic sensor arrays.

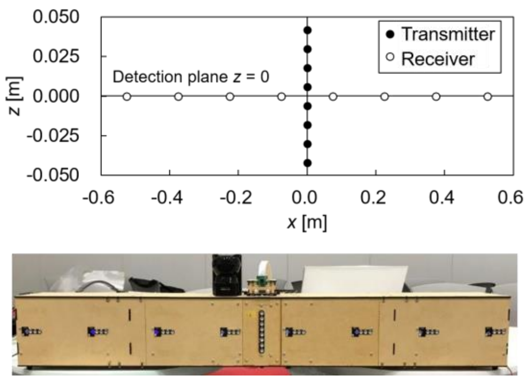

Fig. 2 Ultrasonic sensor array configuration and measurement device.

$$\tilde{l}_{othri} = \sqrt{x_{th}^2 + y_{th}^2} + \sqrt{(x_{th} - x_{ri})^2 + y_{th}^2} + \epsilon \tag{1}$$

When r_i obtains a set of distance measurements $\tilde{L}_i$, the PDF P_i that a reflection point exists at the estimated coordinates (x, y) is given by the estimated obstacle distance F_i, as in Eq. (2).

$$P_i(\hat{x}, \hat{y} | \tilde{L}_i) = \sum_{h=1}^{h_o} \exp\left\{ -\frac{\left(F_i(\hat{x}, \hat{y}) - \tilde{l}_{othri}\right)^2}{2\sigma^2} \right\} \tag{2}$$

The obstacle existence PDF P can be expressed as the total power of the PDF P_i for each receiver as in Eq. (3).

$$P = \prod_{i=1}^{i_o} P_i \tag{3}$$

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3. Experiment and Discussion

The proposed system was used to measure the pole (diameter 0.025 m), the aluminum sheet (width 0.455 m), and the car (width 1.8 m) as obstacles, and to estimate their positions. The objects were placed at (0 m, 15 m). The device was placed with the detection plane ($z = 0$) at 0.8 m from the ground. The burst wavelength was 1.0 msec and the measurement period was 150 msec. The variance σ^2 was calculated from the standard deviation $\sigma = 0.115$ obtained from repeated ranging of the aluminum sheet. For reference, LiDAR (Light Detection and Ranging, HOKUYO AUTOMATIC., YVT-35LX-F0, horizontal detection interval: 3°) measurements were taken simultaneously.

Figure 3 shows the plots of the PDF of the object obtained in Eq. (3), showing the points above 10% of the maximum P. Comparing the results from the proposed system with the actual setting position, the detection accuracy of both objects is about 0.15 m in the y-axis direction and about 0.5 m in the x-axis direction. Furthermore, the estimated distribution is similar to that of LiDAR plots. On the other hand, the pole could not be detected by LiDAR.

The spread of the plots along the x-axis was approximately 0.8 m for all objects, showing no effect on object width. The reflection paths change on objects with different widths, which may affect the measured distance at each receiver. However, the difference in measured distance is small when the width of the receiver array is limited, as shown in **Fig. 2**. Therefore, the difference is not obvious in the PDFs considering the error distribution. These results confirm that the width of the object does not significantly affect the position estimation in the proposed system and that the same level of probability density function can be obtained.

4. Summary

In this paper, we report on position estimation experiments for three obstacles with different widths. The results show that the position estimation accuracy of the pole (diameter: 0.025 m), the aluminum sheet (width 0.455 m), and the car (width 1.8 m) is comparable to that of LiDAR. In particular, the fact that the ultrasonic sensor array system could detect a 0.025 m wide pole, which LiDAR could not estimate, indicates that the ultrasonic sensor array system is effective.

We also found that the existence probability, Eq. (3), for three different obstacles, each having different width, is the same. In other words, our obstacle estimation method does not affect obstacle width or shape. However, the result also implies that if we want to measure the object width, we need some other information to measure the width of obstacles.

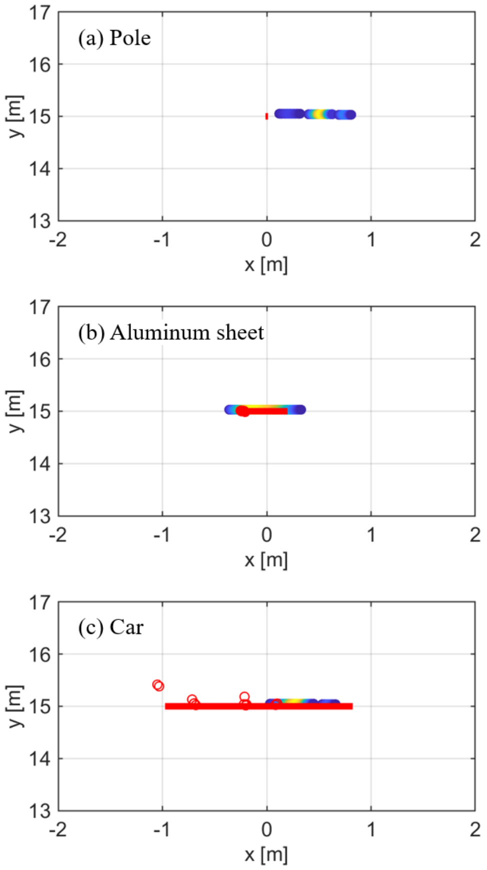

Fig. 3 Position estimation result: (a) Pole (diameter 0.025 m), (b) aluminum sheet (width 0.455 m), and (c) Car (width 1.8 m). Red lines indicate the actual object position. Blue circle plots are estimated positions by our system and red circle plots are those obtained by the LiDAR.

References

1. A. Tsujii, *et al.*: Proceeding of the IEICE general conference (2022) B-15-16, p.454. [in Japanese].
2. H. Hatano, *et al.*: 4th International Symposium on Wireless Communication Systems (ISWCS) (2007) 9826582