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Use of Amplitude of Echo for Environment Recognition by Mobile Robots

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Abstract

This paper proposes a method attaching amplitude of ultrasound echo on reflecting points. A new omni-directional sonar, which we developed, can measure accurate distance and direction of the reflecting points, and it is possible to measure amplitude of the echo which corresponds to the reflecting points. We propose a method to add information from the amplitude of the echo on the reflecting points for environment recognition. This method can give useful information as like character of reflecting objects and it makes possible to corresponds each reflecting points with others using this information. We describe the proposed method and an experimental result to show its usefulness.

1 Introduction

An external sensor is essential for a mobile robot to respond to its surrounding environment and determine its position. There are many requirements for the external sensor. First of all, accuracy is important, and capability to know shape of environment is necessary for environment recognition [1].

An ultrasonic sensor is the most popular sensor for indoor mobile robots, because it is simple and gives distance information directly. Generally, the ultrasonic sensor was known as it has a big problem that it is difficult to measure accurate direction [2]. For using that sensor on mobile robots, there are popular methods assuming reflecting points exist center direction of the sensor heads and rotating the sensor heads to avoid its bad bearing accuracy, and accumulate those data to know environment [3]. In these methods, when a reflecting object is large as like wall, it seems reflecting points are spreading wide area. However, this is because echoes from larger object are stronger in amplitude, consequently, the beam-width of the transducer can be assumed getting wider. As physical property, an echo is coming back from the nearest points from the transducer. Hence, the assumption, the reflecting point is existing at the center direction of the transducer is incorrect, and we can say we are seeing a sort of illusion caused by difference of amplitude of echoes.

Recently we have developed an omni-directional sonar which can achieve accurate direction measurement [4]. The new omni-directional sonar can get accurate direction and distance information of reflecting points all around the robot in a single measurement. Consequently, it became possible to measure accurate environmental information including distance. However, unfortunately, those reflecting points can be obtained only as points, hence they are insufficient to know entire feature of the environment. As the result, it is necessary to do extra process to know the shape of the environment [5]. Moreover, it is important and useful to add information to the reflecting points for the process.

In this paper, we propose an environment recognition method by attaching information of amplitude of echoes on the accurate reflecting points. Amplitude of echo is deeply relating with shape of reflecting object in the environment, and we can get useful information from them which can be added to conventional information – distance and angle. Especially, we will be able to know identity of the reflecting object in different measurement.

In the next section, reflecting points and amplitude of echoes are explained as background. In Section 3, a new omni-directional sonar which we developed recently is briefly explained. And then we propose a method to use amplitude of echo for environment recognition in Section 4. Experimental result is shown in Section 5, and we discuss the proposed method in Section 6.

2 Background

2.1 Reflecting points

When an ultrasonic sensor is utilized in indoor environment, relatively smooth surface of the walls or other artificial objects are expected reflecting targets. The roughness of such surfaces is generally less than the order of a few millimeters. On the other hand, the wavelength of ultrasound used for such robotic applications in the air is typically between 5mm and 15mm (frequency from 25kHz to 70kHz). Therefore, since these variations in surface smoothness are generally smaller compared to the wave length, the surface of general objects can be regarded as a mirror for ultrasonics. In addition, such an object has an acoustic impedance completely different from that of air, resulting in total reflection of the ultrasonic signals.

For these reasons, reflection of ultrasonic wave in such environment can be regarded as specular. Since the transmission and detection of ultrasonic waves occur at the same point in the pulse echo method, the direction of ultrasonic wave propagation is normal to the reflecting surface. Therefore, it can be assumed in such environment that the ultrasonic reflecting characteristics shows vertical direction of surfaces.

When the direction of the reflecting point is accurately detected, it provides useful information and for recognizing the environment. For example, bearing angle of wall or accurate detection of narrow opening as like door way is important for indoor mobile robots [2].

However, directivity of conventional ultrasonic transducers are about from 30 to 60 degrees and it is too wide to measure the reflecting points accurately.

2.2 Amplitude of echoes

Amplitude of an echo in ultrasonic sensor for a mobile robot depends on various factors, especially directivity of transducer, distance to the reflecting object and shape of the reflecting object influence on amplitude.

In ultrasonic sensors for mobile robot, effect of propagation medium and surface material of reflecting objects are small. The propagation medium is air. Echoes are effected by humidity and temperature, but those effect in indoor human living environment is small. Consequently, there are not much effect on an amplitude of echo by the propagation medium. The acoustic impedance of objects in indoor environment are much different from air, and the most of objects are at the same condition.

However, effect of directivity of transducer, distance to the reflecting object and shape of the reflecting object can not be ignored.

An amplitude of echo can be modeled as following:

$$F_{out} = F_0 \cdot I_{dire} \cdot I_{dist} \cdot I_{shape}.$$

Here, F_{out} is amplitude of echo, F_0 depends on characteristics of propagation medium and reflector material, I_{dire} is directivity of transducer depending on direction to the reflecting point, I_{dist} depends on distance to the reflecting point and I_{shape} is shape of a reflector.

2.2.1 Directivity of transducer

Amplitude of an echo depends on direction which the echo is coming back from. This is depending on a transducer itself and how it is driven.

2.2.2 Distance to the reflecting object

When distance to a reflecting object is longer, the amplitude of echo become weaker, because of diffraction and absorption in the air. Amplitude of the received echo can be shown as following [6]:

$$I_{dist} = \frac{I_0 exp(-2mr)}{r^4}.$$

Here, I_0 is amplitude of transmitted ultrasound, m is attenuation coefficient depending on medium and r is distance to a reflecting object.

2.2.3 Shape of the reflecting object

When a reflecting point exists at the same distance and direction, amplitude of echo from a plane reflector is stronger than echo from an edge reflector. This is because the reflector can be considered as a specular reflector in narrow area, but it is not perfectly specular and a scattered echo return to the receiver. The ratio of amplitude from the plane and corner model to the edge model is shown as following [7]:

$$plane : edge = 1 : \frac{1}{2\pi\sqrt{\frac{r}{\lambda}}}.$$

Here, r is distance to reflecting point and λ is wave length of ultrasound.

3 Direction Measurable Sonar-ring

We have developed a new omni-directional sonar which can measure accurate direction to the reflecting points all around the robot simultaneously (Fig.1). This omni-directional sonar can measure accurate distance and direction to corners and edges, and the nearest points on plane reflectors, which consequently shows perpendicular to the incident direction of the plane surface. This can measure multiple reflecting points simultaneously and its bearing accuracy is better than one degree.

In the new omni-directional sonar, it transmits a pulse to all direction around the robot simultaneously, and receive the echo by multiple receivers at the same time and detect leading edges of the echoes and calculate accurate reflecting points by using time-of-flight. This system can achieve accurate omni-directional measurements in a single transmit/receive cycle. And also while the robot moves, movements of the reflecting points according to the motion of the robot can be observed. As the result, the robot could generate an environmental figure shown in Fig.3 by fusing odometry data at the environment shown in Fig.2. The measured reflecting points on the columnar reflectors remained at the same points. The measured reflecting points on the plane reflectors traverse along the surface of the plane reflectors according to the robot motion. However, the robot is proceeding to perpendicular direction to the plane at the bottom, the reflecting points remained at the same points and it can not figure out it is reflecting points from the plane.

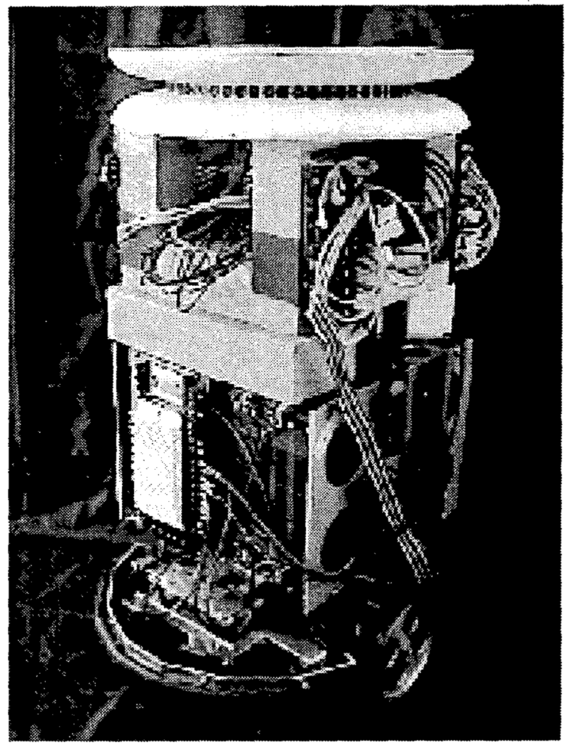

Figure 1: A omni-directional sonar sensor on a Yamabico robot.

4 Echo amplitude

The amplitude of echo has deeply relating with shape of the reflecting object. Hence, it is useful to detect amplitude of echo to estimate shape of reflecting objects.

4.1 Principle of amplitude measurement

Here, we propose to attach amplitude information on measured accurate reflecting points for getting better environmental information.

In the proposed method, we measure amplitude using detectable range of a transducer heading direction. The sonar-ring sensor uses multiple receivers at the same time, therefore amplitude can be measured by number of receivers which receive an echo from the same object. This method substantially makes sensitivity of a receiver lower by inclining transducer toward reflecting points, and measures amplitude. In other words, this method measure amplitude by directivity of transducers. Experimental results of receivers number using plane board and pole depending on distance is shown in Fig.4.

When it is adjusted with distance information we can get the property of the each reflecting point. As the result, the system can give distance, angle and amplitude information quantitatively.

4.2 Measurement process

In this system, measurement process of accurate reflecting points and amplitude of them are done simultaneously.

The sonar-ring transmit a pulse to all direction and receive echoes by all receivers simultaneously, and then store the echo into a wave memory [8]. From the stored wave memory data, leading edges of echoes are detected at each receiver and those detected leading edges are grouped corresponding to reflecting objects [4].

Reflecting points are calculated from time differences in time among grouped leading edges (detail are explained in [4]).

Amplitude information is given by the number of receivers grouped corresponding to echoes which come back from the same object. The calculation to compensate with

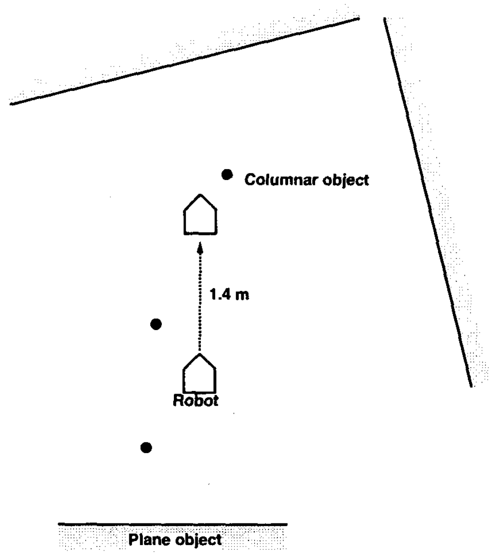

Figure 2: Scheme of experimental environment.

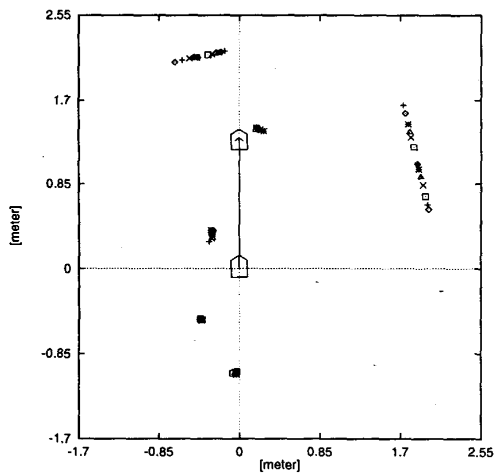

Figure 3: An experimental result fusing odometry data and accumulated reflecting points data.

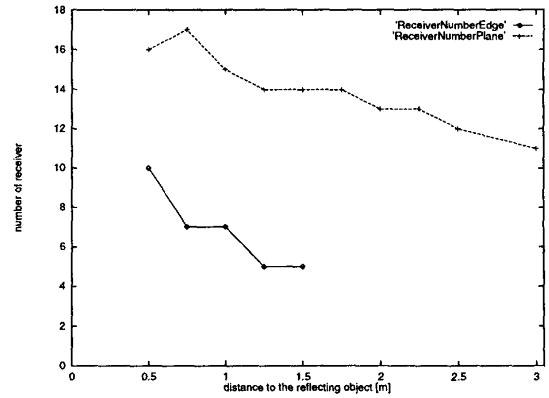

Figure 4: Number of receivers detected an echo. Horizontal line shows distance to reflecting object, and vertical line shows number of receivers which could receive the echo. Upper break line shows results using a plane board as a reflector, and lower line shows results using a pole as a reflector.

distance is performed based on experimental data. For this compensation, the distance compensation formula is made as pre-knowledge by experiments.

4.3 Advantages

Reflecting points are showing good characteristic of environment. And the information from amplitude is including shape information corresponding to the reflecting points. Consequently, reflecting points with amplitude are able to give better feature of environment, and also it is very effective to correspond each reflecting points with other reflecting points.

5 Experiment

An experiment of the proposed method was performed on a mobile robot, in which, the surroundings of the robot is consisted with flat several walls and poles. The robot with proposed sensor could measure the environment by only single ultrasonic pulse transmission.

A result of reflecting points in a single measurement at the environment shown Fig.2 is shown in Fig.6. Leading edges which were detected by multiple receivers in this experiment are shown in Fig.5. Each reflecting point is detected by following number of receivers:

$$A:5 \quad B:4 \quad C:8 \quad D:6 \quad E:7$$

In this experiment, a distance compensation formula was made based on experimental data in Fig.4. Using the data, an appropriate linear function to compensate the distance is gotten as follow:

$$A_{dist} = N + 2r.$$

A_{dist} is a resultant value of distance compensation, r is distance to the reflecting point, and N is number of receiver which could receive the echo.

Using this formula, each reflector got following amplitude information value:

$$A: 4.8 \quad B: 5.4 \quad C: 10.1 \quad D: 10.0 \quad E: 11.3$$

The result which shows vertical lines according to this value is shown in Fig. 7. In this result, we can tell the reflecting point C is also reflecting point from a plane as same as the reflecting points D and E.

6 Discussion

The proposed method attached amplitude information of echoes very easily and successfully and it could give useful additional information to reflecting points for environment recognition. The amplitude was able to give useful information relating with shape of an object, and consequently it could provide more useful environmental information for a mobile robot. Moreover, when a moving robot repeated the measurement, this information is extremely useful to correspond each reflecting point with another point of previous measurement, and this lead effective environment recognition for mobile robots.

It is known that amplitude of echoes from a plane and from a corner are almost the same. This difference needs to be distinguished considering other information as like motion of robots.

7 Conclusion

This paper proposed the method attaching information of the echoes amplitude on the accurate reflecting points in the sonar-ring sensor. Reflecting points can show the surface of the wall which is perpendicular to incident direction or the curved surface of the convex corner. In the proposed method, it was able to get information of amplitude easily and quantitatively. The experimental result showed usefulness of using the reflecting point and amplitude which contain the reflecting object information for the environment recognition by the mobile robots.

References

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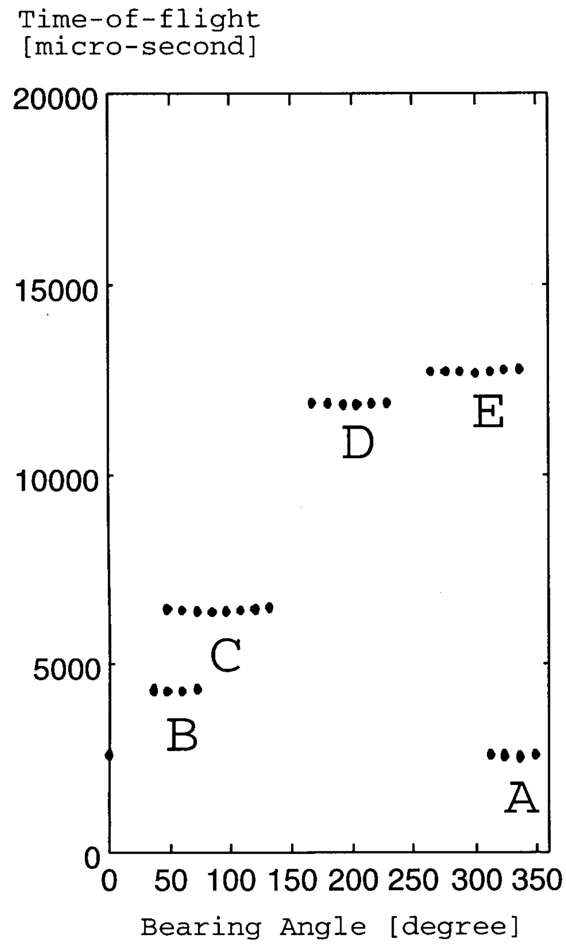

Figure 5: Leading edges which were detected by multiple receivers. Horizontal line is showing bearing angle of receivers, and vertical line is showing time of flight of each leading edge.

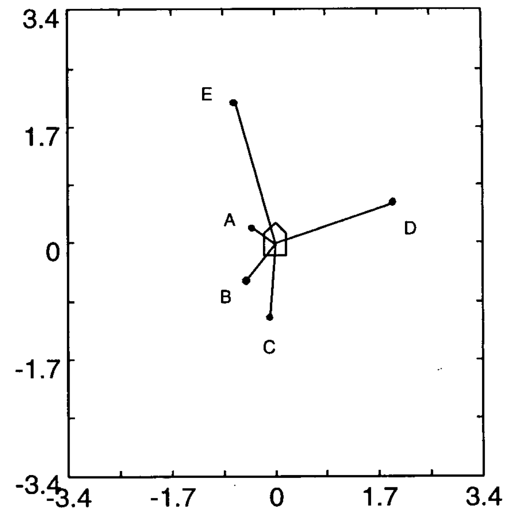

Figure 6: Calculated reflecting points from a single transmit/receive cycle.

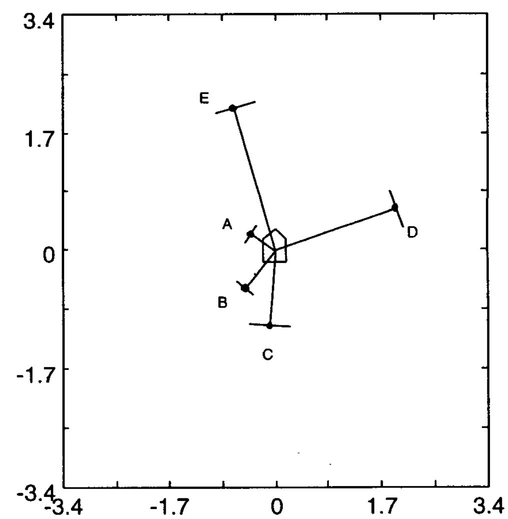

Figure 7: An experimental result, attaching amplitude information on reflecting points.