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Development of an Automatic Recharging System for Intelligent Robots using an Anisotropic Ultrasonic Sensor

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Abstract: It is essential to supply electrical power continuously to mobile robots to keep moving. We studied how to make a mobile robot return to a recharging station autonomously by using specially designed ultrasonic sensors when a battery is low. A principle to calculate location and rotation angle of a mobile robot from recharging station was suggested. An anisotropic ultrasonic sensor system, we call it AniBat^{TM}, made it possible, because the unique sensors had such a wide horizontal beam directivity ranging from 150˚ up to 200˚. By only a few sensors, four sensors, an ultrasonic signal could be perceived within 180˚ wide-open whole front area of a recharging station and the mobile platform was returned accurately to the station.

1. INTRODUCTION

A mobile robot stops working once a battery runs out. For mobile robots to keep working, it must be possible to make an autonomous return to a recharging station before a battery is flat.

To make an autonomous return to a charging station successful, the mobile robot must keep aware of where it is located, and it should know its exact angle formed between the robot and the charging device to keep rectifying its location.

Infrared sensors have been being used for a position perception for an autonomous return so far. It works out as follows: A mobile robot finds its way to a recharging station by perceiving the location of the station with a technique comparing infrared signal radiated from the charging device with the intensity of IRED signal measured from a surrounding receiving sensor.

However, this method using infrared sensor often fails to work out the function properly when there are obstacles between a recharging device and a robot, or when one party is far away from the other, or when a direct light such as sunlight shines, et cetera.

In this study, using a few unique sensors with a wide horizontal beam directivity called "anisotropic ultrasonic sensor, AniBat^{TM}", we have researched a method in which a mobile robot can perceive where it is located even in a long distance from a charging station, and a method to reckon accurately an angle formed between the robot and the station when approaching each other.

2. ANISOTROPIC ULTRASONIC SENSOR, AniBat^{TM}

2.1 The Principle and Feature of Anisotropic Ultrasonic Sensor

In an ultrasonic sensor, AniBat^{TM}, with asymmetric beam directivity, the principle was applied that a diffraction of the wave depended on the wave length and width of aperture when ultrasonic waves radiated from an oscillating plate passed through aperture.

The developed sensor, as shown in Fig.1, was designed to have a horizontally wide ultrasonic directivity of about 180 degrees and is adjusted to get a vertical directivity ranging from 40 degrees to 60 degrees. With such directivity features, a mobile robot could perceive very wide area horizontally, while it can avoid unwanted signals vertically.

Only two anisotropic ultrasonic sensors are used to cover a whole front side of a charging station.

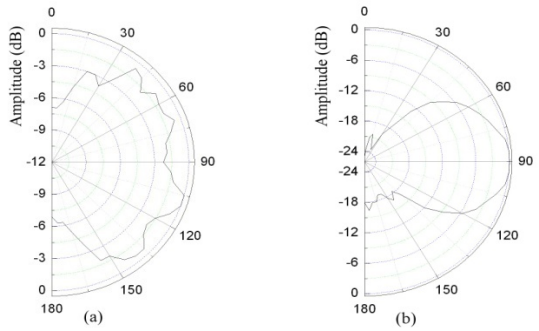

Fig. 1. The directivity of anisotropic ultrasonic sensors: (a) horizontal directivity and (b) vertical directivity

2.2 Distance Measure using Ultrasonic Sensors

If an ultrasonic transmitter and a receiver stand face to face and the receiver sends a trigger signal to a transmitter by wireless communication such as Blutooth, then the transmitter generates ultrasonic waves.

The distance from the transmitter to the receiver is determined by measuring the time that ultrasonic signals

emitted from transmitter reaches to the receiver with Equation (1).

Where Δt is the time to take until the receiver get the signal after a transmitter sends forth an ultrasonic signal, r is the distance between sensors, and C is sound speed.

$$r = \Delta t \times C \tag{1}$$

3. HOW TO RETUREN AUTONOMOUSLY

In this study, we have researched a method in which a mobile robot can get connected to a recharging device correctly by accurate localization of position and angle of a robot, two pairs of sensors between the robot and the device.

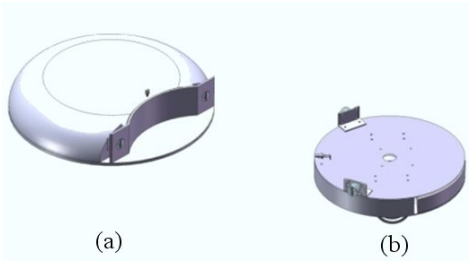

Fig.2 (a) A recharging station and (b) a mobile robot.

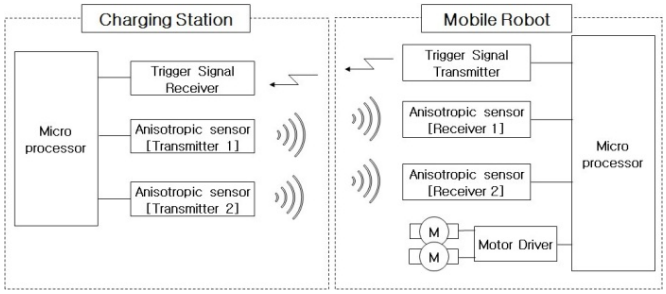

Fig. 3. The schematic diagram of automatic recharging system

3.1 How to Operate

A mobile robot sends wireless communication signal with codes, trigger signal, which enables transmitter to operate with its option.

A recharging device analyzes the signals and makes the transmitter in the station work selectively. A mobile robot measures the time from when it sends trigger signals to the ultrasonic signal reaches a receiver, and then converts into distance between two devices.

Then, by comparing distance values of two receivers from the recharging the angle of a mobile robot is calculated. Based on the parameters, the robot controls a motor and connects to the charging station.

3.2 Localization of Position and Angle

In Fig.4, d1, d2, d3, and d4 are distance between ultrasonic sensors. Then, the coordinate of the receiver S1 is obtained by Equation (2) and Equation (3).

$$Y_1 = \frac{\sqrt{C(C-D)\times(C-d_1)\times(C-d_2)}\times 2}{D}, \quad C = \frac{D+d_1+d_2}{2} \tag{2}$$

$$X_1 = \sqrt{Y_1^2 - D^2} \tag{3}$$

Similarly, the coordinates for the receiver S2 can also be figured out.

$$Y_2 = \frac{\sqrt{C(C-D)\times(C-d_3)\times(C-d_4)}\times 2}{D}, \quad C = \frac{D+d_3+d_4}{2} \tag{4}$$

$$X_2 = \sqrt{Y_2^2 - D^2} \tag{5}$$

The angle between a charging device and a robot is given by Equation (6).

$$\theta = \tan^{-1}\frac{Y_1 - Y_2}{X_1 - X_2} \tag{6}$$

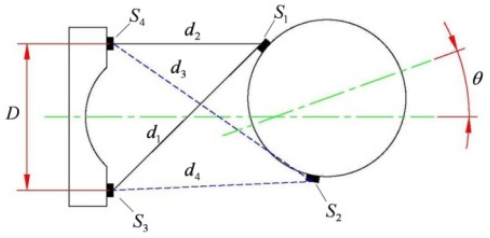

Fig. 4. Configuration of the recharging station, a mobile robot and ultrasonic sensors

4. CONCLUSIONS

We have presented a method to calculate location and angle of a mobile robot from a recharging station by using only four ultrasonic sensors. This method enables a robot to get precisely connected to the station when returning. By using unique ultrasonic sensors called "anisotropic ultrasonic sensors" with a horizontally very wide directivity, ultrasonic signals could be effectively perceived in whole front-side of a recharging device with only a few sensor. It made coordinate operation simplified. As the results, we could realize to make an automatic recharging system for a mobile robot very easily.

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