A Control System for the Robot Shopping Cart

Position Estimating and Self-Mapping System

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***Abstract*—In order to assist old or disabled people in supermarkets, we have developed a control system for shopping carts that automatically follow their owners. This system liberates old and disabled people from the burden of pushing shopping carts, because our proposing shopping cart is essentially a type of autonomous mobile robots that recognizes its owner and chases her. In this paper, we describe the control system of a novel robot shopping cart that follows the owner accurately and automatically. The accuracy is gained by the fared laser beam that the cart irradiates. The cart has a laser range sensor so that it can measure the position and distance of its owner. In order to obtain information about the moving direction and the moving distance, we supply a gyro-sensor and a rotary encoder on the cart. To fully exploit the benefits of high performance laser range sensor, we have developed a mapping algorithm and an estimation method for searching the position of the owner. The numerical experiments demonstrate that our control system for the robot shopping cart is satisfactory for practical use.**

Keywords-component; robot control systems; autonomic moble robot; laser range sensor(LRS); automatic mapping system;self-position estimation;

I. INTRODUCTION

We see the shopping carts in the supermarket everyday. Customers are pushing around them to carry the merchandises. They usually push the carts by using both of their hands. Therefore, if the customer has only one hand, or she has to hold her child's hand, pushing carts is a real burden for her. If she has two or more children, pushing shopping cart is almost impossible. In order to ameliorate the situation and assist the disabled, we have developed an automatic shopping cart that automatically goes after the user of the cart. By using our robot carts, it is possible for customers to pick up merchandises using both hands and to scrutinize the merchandises. Further, this system enables even people who cannot push a cart to enjoy shopping without human assistants.

The authors have studied robot shopping carts (Figure 1) [1]. This robot goes after its user using Laser Range Sensor (hereafter referred to as LRS). So far our robot shopping cart successfully follows its owner.

Figure 1. The shopping cart robot.

Even though this type of robot can successfully track and chase its user, but the ability is not perfect. There are many obstacles in a supermarket, such as shopping shelves and display tables, interfere the chase of the robot carts. The presence of other customers also prevents the cart from recognizing its owner. Autonomous mobile robots that successfully work in a super market must satisfy the following conditions. First, they must recognize the wall and the shelf as obstacles. Second, they must identify the moving objects such as people (other customers) as obstacles. In order to achieve these goals, the robot needs to possess a map of its environment and to understand the position where it currently is in the environment.

Recently, robotics research is active in various fields due to increasing demands for autonomous mobile robots [2] [3]. We can see them as a part of everyday life such as conveyer robots in indoor plants and security robots in offices. Mapping and location systems have been proposed in various ways [4] [5] [6] [7] [8]. However, there is no research on robots used in retail stores. In retail stores, mapping and location for an autonomous robot is extremely difficult in conventional ways. Because there are too many people come and go and shelves are lined up with the same regularity; it is too easy to be lost in a supermarket. In order to develop a practical shopping cart robot, we need to invent a new mapping system. In this paper we propose a new

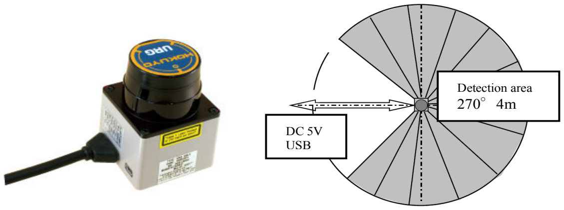

Figure 2. LRS "URG-04LX

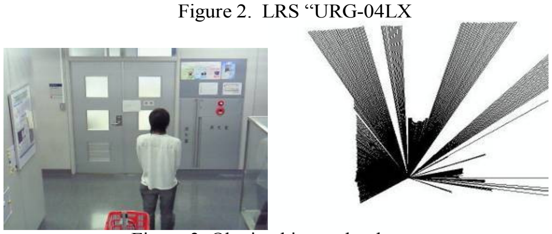

Figure 3. Obtained image by the sensor.

mapping method for our shopping cart robot to precisely follow its owner as well as for chasing its owner.

In this paper we present the development of a shopping cart robot that follows its owner. The user tracking system that uses LRS is installed in this robot. We also equipped the robot an automatic mapping self-positioning system.

The structure of the balance of this paper is as follows. In the second section, we present the control system that enables the robot cart to follow the user. It intensively uses LRS to locate the user. The third section reports the numerical experiments that demonstrate the feasibility of our robot shopping carts. Since our control is not perfect, and needs some complementary system to support the robot cart, we propose an automatic mapping system that uses LRS, and estimates the self-position on map, in the fourth section. Finally we conclude our discussion and propose future developments in the fifth section.

II. The Control System That Uses LRS to Follow Its Owner

Our shopping cart robot uses LRS "URG-04LX (made by Hokuyo Electric Machinery Ltd.)" (see Figure 2) to recognize surrounding circumstances such as the owner that the robot chases and obstacles.

This sensor can detect objects in the distance of 3m and in the azimuth of 240 degree on a horizontal plane by using the infrared ray laser light almost in real-time. Figure 3 shows experiment environment and the obtained image by the sensor.

A. Judging the user position

The following technique is used to judge owner's position. First, the system analyzes the data acquired from LRS and detects the boundary of user's both sides, then calculates the central angle between boundaries. This makes the system recognize the user's position. The robot follows the owner by this method (Figure4). We have observed that detection is accurate enough in the 3m range, and not affected by obstacles.

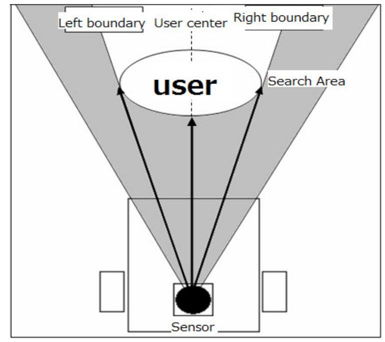

Figure 4. User detection method by sensor.

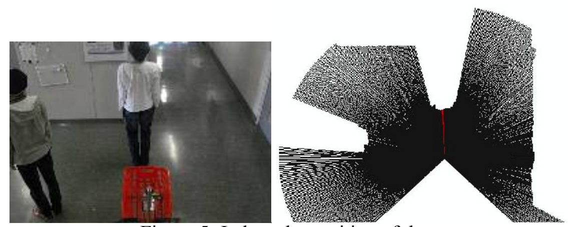

Figure 5. Judges the position of the user.

Figure 5 shows the result of an experiment that judges the position of the user. The system ignores the other customer located in the left-hand side.

B. Calculation motor operation amount

The speed of the motor of the shopping cart robot is determined based on the distance of the user and the following cart. The control system tries to make the cart robot always keep the distance of 1m behind the person whom it follows. The motor itself has a microcomputer and uses it for controlling its operation in PWM. The microcomputer calculates how much speed the motor should rotate and send it to the motor. The system uses the proportional control formula (1) to calculate the rotation speed. A gradual acceleration and deceleration of the motor can be achieved by this method.

$$\mathbf{R(t) = Kp \cdot (Vdes(t) - Vact(t)).} \quad (1)$$

R(t) is the calculated motor rotation speed. Vdes(t) is the target motor rotation speed, and Vact(t) is the current speed. Kp is the proportion control gain. The cart robot has two motors to provide locomotion left and right tires independently.

In order to accommodate the curve and the turnabout of the cart robot, the control system gives different rotational speeds to the right and left motors. It is possible to provide different speeds for right and left motors. When the speed is set to minus, the motor rotates in reverse direction.

The ratio of curve is calculated from the user's position through the right and left divergence. The distance between the user's position and the center line of LRS is calculated by using the cosine theorem. And then the curve value is obtained by using the formula (1). In this case, Vdes(t) is

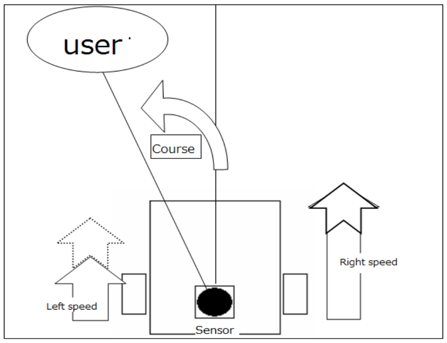

Figure 6. Speed instruction of motor.

set to 0. Vact(t) be the distance from the user to the central angle. Half the curve value is added and subtracted to the current motor speed right and left respectively. In this way the cart robot's turnabout can be achieved. Figure 6 depicts the situation.

III. Discussion of the Following System

We have evaluated our cart robot system through some numerical experiments. We have observed that as long as the user walks straight and her walking speed is less than two kilometers per hour, the robot can successfully follow the user. This constraint comes from two machine constraints: one is the maximum speed of the cart is about two kilometers, and the other is the maximum measurement distance of the LRS is about 4 meters. Therefore, as long as the user walks slowly without abrupt turning, the cart robot chases the user steadily. However, walking less than two kilometers per hour is severe constraint, and we have to improve the motors we employ to drive the cart so that the cart robot can follow whoever walks in natural speed.

When we improve the driving force for the cart robot, we have to take account the safeties. It must avoid any collision. We may have to equip the other micro-computer that solely detecting obstacles and avoiding collision with small infrared sensors.

IV. Automatic Mapping System That Used LRS

Even though the cart robot successfully follows the owner, the simple chasing mechanism made the cart robot collides to other customers or objects in a supermarket. In order to mitigate the collision problem, we introduce the map information to the cart robot. If the robot has map information of the operation area beforehand, it can detect obstacles such as walls and display tables as it compares the information obtained from LRS with the map, so that it can achieve safe operation. However, usage in a supermarket raises yet another problem; the layout of display tables changes frequently. Also considering practical use, it is unrealistic to expect someone in a supermarket input the map information to the cart robot, because each store has different layout. It takes too much time to prepare map information manually one by one. Even though 2D or 3D automatic mapping technology is setting improved and several camera on the ceiling of a market may produce the map of the layout, we would like not to install any special devices in the environment and would like to achieve our implementation closed in the shopping cart. Our solution to this problem is preparing the map information by the cart robot itself. In this section we propose the system by which the cart robot can make the map of the floor layout automatically by using LRS.

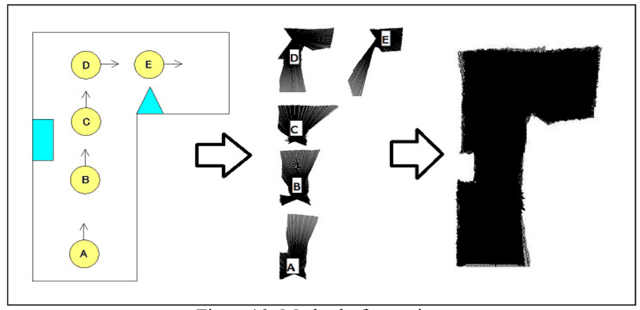

Figure10. Method of mapping.

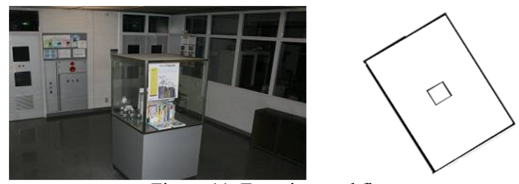
Figure 11. Experimented floor.

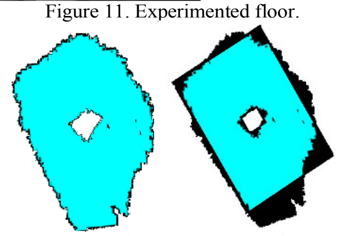
Figure12. Outcome of an experiment and error margin.

A. *Technique of mapping system*

The LRS we are employing has short sensing range; therefore we have made the system to produce a map by accumulating information of the surrounding environment little by little acquired from LRS as the cart robot proceeds, as shown in Figure 10. Because the moving direction of the robot was not able to be calculated with LRS alone, the terrestrial magnetism sensor was used for the measurement of the azimuth.

B. *Experiment of mapping system*

We conducted an experiment of the mapping system in a floor shown in Figure 11. Figure 12 shows the map produced the mapping system.

The current mapping system employs only LRS and the terrestrial magnetism sensor. The terrestrial magnetism was so unstable that the sensor produced erroneous data. We have found that it is so much unrealistic to relay on such an unstable element of terrestrial magnetism. Kambayashi et al.

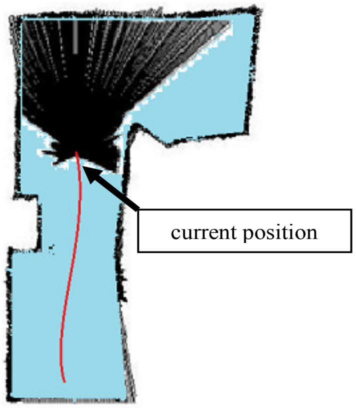

Figure13. Follow using map information.

employ RFID to locate the position of the robot and to determine the direction that the robot faces [9]. However, we would like to implement our system in much more general setting and not to install special devices such as RFID in the environment. We are proposing to add new sensors such as the rotary encoders so that we can measure the moving distance of the cart robot accurately as well as moving direction without any special equipments on the floor.

V. Conclusion and Future Development

A control system for autonomous shopping cart robot is presented. The control system makes the cart robot follows the owner of the cart so that it liberates the owner from pushing the shopping cart while browsing in a supermarket. The system should be a great assistance for disabled and old people as well as mothers who must hold their children's hands.

We also proposed a mapping system to prevent the cart robot from colliding to obstacles. The current system is far from perfect, but the accuracy of the mapping can be improved by adding new sensors such as the rotary encoders. Self-position estimation on the map is also under development.

Operations in the narrow aisle are required in the retail store. It is necessary to know at which position in the map that the cart robot is. The current system does not satisfy the requirement. By using the rotary encoder and the gyro sensor, however, the system can correct the error margin as it proceeds by comparing the information obtained from sensors and map information. Then the robot can advance while confirming the self-position, when it loses the sight of the owner. Figure13 shows the image what we are proposing.

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