Proposal of a method for real-time detection of obstacle using line laser and camera

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Abstract

Automated guided vehicles (AGVs) have been widely used in factories and warehouses. Functions such as obstacle detection are indispensable for unmanned transport robots. We have developed a new approach for obstacle detection using a line laser and a camera. In this study, we improved the detection process of the system, made it real-time, implemented it on a robot, and verified the measurement accuracy of the system. As a result of measuring the distance to the obstacle and the size of the obstacle, the measurement error was small, within 20 mm, and it was confirmed that the system could detect the obstacle with good accuracy.

Keywords: Line laser, obstacle detection, camera, automated guided vehicle (AGV), indoor detection, autonomous mobile robot

1. Introduction

In recent years, the number of autonomous mobile robots in Japan has been on the rise, and it is expected to continue to increase in the future (Fig. 1.1).

Figure1.1 Domestic Autonomous Mobile Robot Market Spending Forecast[1]

Autonomous mobile robots are used in everyday life, such as drones and cleaning robots. Autonomous mobile robots are also being used in factories and warehouses in the form of unmanned transport robots, and there are high expectations for their use in unmanned operations.

Most of the AGV robots currently in use have a predetermined travel route (Fig 1.2), and the layout of a factory or warehouse cannot be easily changed. Even if the robot is restricted from placing cargo on its travel route, there is still the possibility that an obstacle may occur, causing the robot to collide with the obstacle and stopping the robot, resulting in poor transportation efficiency. Therefore, it is necessary to detect obstacles accurately and avoid them appropriately. In factories and warehouses, there are many cases where humans and robots work together, and irregularities may occur due to human movements. Therefore, we are developing a method using a line laser and a camera as a system that can be implemented at low cost and can detect a wide range of obstacles and detect their distance and size. In this study, we improved the detection process of the system, made it real-time, implemented it on an opposing two-wheeled robot, and verified the measurement error under various patterns such as stationary and moving.

Figure1.2 Example of using AGVs[2]

2. Principle

In this chapter, we describe the principles used in our research system.

2.1 Obstacle detection principle

As shown in Fig. 2.1, a green line laser is irradiated from the top of the robot toward the floor, and when the laser light line hits an obstacle, the obstacle is detected based on the change in the input image.

The principle of obstacle detection based on the line laser (green) extracted from the image is explained. Figures 2.2 and 2.3 show the extracted images of the line laser (green) in the presence and absence of obstacles. As shown in Fig. 2.2, when there is no obstacle, the extracted laser light image is an unbroken straight line. As shown in Fig. 2.3, when there is an obstacle, the area where the obstacle exists shows characteristic changes according to the shape of the obstacle. This difference is used to detect the presence or absence of obstacles and to calculate the height and width of obstacles and the distance between obstacles.

Figure 2.1 System image

Figure 2.2 When there is no obstacle

Figure 2.3 When an obstacle is present

Figure 2.4 Input image after processing

2.2 Calculating the size and distance of obstacles

In this section, we describe the calculation principle for determining the size (height and width) of an obstacle and the distance to the obstacle from the image after line laser extraction. Figures 2.4(a) and 2.4(b) show the images obtained from the input images after the preprocessing.

The obtained image has the x-axis in the horizontal direction and the y-axis in the vertical direction, with the upper left as the origin. Based on the number of pixels H_p and W_p in the presence of obstacles, the actual length is converted. y_{bias} is defined as the height from the bottom of the image to the position of the laser beam on the floor.

In order to convert the number of pixels to the actual length, we first need to find the shooting range of the camera. Figure 2.5 shows a diagram of the range of the camera.

Figure 2.5 Camera's shooting range

Figure 2.6 System positioning

The shooting range of the camera at the distance z from the lens can be calculated from the size of the image sensor (H_i , W_i) and the focal length f from the lens, as shown in Fig. 2.5, and can be obtained by Eqs. (2.1) and (2.2).

$$H_{max} = \frac{z \times H_i}{f} \quad [\text{mm}] \quad (2.1)$$

$$W_{max} = \frac{z \times W_i}{f} \quad [\text{mm}] \quad (2.2)$$

Figure 2.6 shows the positional relationship between the camera, line laser, and obstacles in this system.

The line laser and camera are placed on the y -axis with respect to the origin, and the line laser is irradiated in the z -axis direction to a point at a distance Z_0 . When an obstacle whose height is greater than or equal to H_r exists at a distance Z_r , the line laser is irradiated at the point P . In this case, on the vertical shooting range with respect to the point at distance Z_0 , it is equivalent to a line laser at the height H_{z0} . Therefore, the z -coordinate of the intersection of the two lines, the line (blue) connecting the line laser irradiation position H_{z0} on the vertical shooting range based on the point of the camera height H_c and the distance Z_0 , and the line

Figure 2.7 System positioning (3D image)

(green) connecting the line laser height H_l and the point of the line laser irradiated on the floor, is the actual distance Z_r from the obstacle, and the y -coordinate is the height H_r of the laser irradiated on the obstacle.

Figure 2.7 shows a three-dimensional image of Fig. 2.6 with the x -axis information added.

The width W_r of the obstacle can be calculated by the ratio of the number of pixels of the obstacle width to the horizontal shooting range and the image width based on the calculated distance Z_r to the obstacle. By the above process, the actual distance to the obstacle Z_r , the height of the obstacle H_r , and the width of the obstacle W_r can all be calculated with the known information.

2.2.1 Calculating the height of obstacles

Let $PICTURE_HEIGHT$ be the vertical resolution of the laser extraction image and H_p be the height from the floor to the laser in the image. The line laser irradiation position H_{z0} in the vertical shooting range with respect to the point at distance Z_0 can be expressed as Eq. (2.3). The line in the y - z plane connecting the height of the camera and the height H_{z0} can be expressed as Eq. (2.4). The line connecting the height of the line laser H_l and the point of the line laser irradiated on the floor is expressed by Eq. (2.5).

$$H_{z0} = H_{max} \times \frac{H_p}{PICTURE_HEIGHT} \quad [\text{mm}] \quad (2.3)$$

$$y = \frac{H_{z0} - H_c}{Z_0} z + H_c \quad [\text{mm}] \quad (2.4)$$

$$y = -\frac{H_l}{Z_0} z + H_l \quad [\text{mm}] \quad (2.5)$$

The y-coordinate of the intersection point of the two lines in Eqs. (2.4) and (2.5) is the height H_r at which the obstacle was irradiated by the laser. The equation for calculating H_r based on the formula for finding the intersection of two lines is shown below.

$$\begin{aligned} a &= \frac{H_{z0} - H_c}{Z_o} b = H_c \\ b &= H_c \\ c &= -\frac{H_l}{Z_o} \\ d &= H_l \\ H_r &= \frac{a \cdot d - b \cdot c}{a - c} \text{ [mm]} \quad a \neq c \end{aligned} \quad (2.6)$$

※a, b, c, and d represent the coefficients and y-intercepts of the line. There is no case where $a \neq c$ in this study.

2.2.2 Calculating the distance of obstacles

The distance to the obstacle is calculated from the intersection of the two lines in Eqs. (2.4) and (2.5) as in the calculation of the height H_r . Therefore, the z-coordinate of the intersection point of the two lines is the distance Z_r from the obstacle. The equation for calculating Z_r based on the formula for finding the intersection of two lines is shown below.

$$Z_r = \frac{d-b}{a-c} \text{ [mm]} \quad a \neq c \quad (2.7)$$

2.2.3 Calculating the width of obstacles

Let $PICTURE_WIDTH$ be the horizontal resolution of the laser extracted image and W_p be the number of pixels for the width of the obstacle in the image. The horizontal shooting range based on the calculated distance to the obstacle Z_r is shown in Eq. (2.8). The actual width of the obstacle is given by Eq. (2.9) based on the ratio of the number of pixels of the obstacle width to the image width.

$$W_{max} = \frac{Z_r \times W_i}{f} \text{ [mm]} \quad (2.8)$$

$$W_r = W_{max} \times \frac{W_p}{PICTURE_WIDTH} \text{ [mm]} \quad (2.9)$$

3. Proposed Method

3.1 System Overview

The system configuration used is shown in Fig. 3.1. The model proposed in this study consists of a line laser linearized by a polarizing lens, a camera, and a computer for image processing and robot control. The line laser is placed at a higher position and the camera is placed at a lower position. The line laser is aimed at the floor in an oblique direction, and the camera captures images parallel to the floor.

Figure 3.1 System configuration

Figure 3.2 Mobile Robot Specifications

The line laser is the MLXL series (wavelength: 520 nm), the camera is the Raspberry Pi Camera V2, and the computer is a Raspberry Pi 4.

Figure 3.2 shows the specifications of the mobile robot used in this study.

As shown in Fig. 3.2, we use the Raspberry Pi as the master and the Arduino Due as the slave to perform I2C communication and send operation commands from the wireless keyboard. The Raspberry Pi requests a change in the motor speed output, the Arduino outputs it through the driver, and the speed is adjusted based on feedback from the encoder. This makes it possible to move the robot at any speed. The Raspberry Pi and Arduino Due are both 3.3V tolerant and can be connected directly, but the motor driver and encoder are 5V tolerant, so a level shift circuit is used to communicate with the Arduino Due.

Figure 3.3 shows the parameter settings for the position constants used in this obstacle detection system.

Figure 3.3 Position constant parameter setting

The height H_l of the installation location of the line laser is set to 730 [mm], and the height H_c of the camera height installation location is set to 484 [mm]. The position of the line laser and the camera is set to the center of the front most surface of the robot as the origin. The line laser is irradiated at a position of $Z_0=800$ [mm] in the z -axis direction from the origin. The image sensor in the Raspberry Pi Camera V2 used as the camera is the Sony IMX219PQ. Therefore, the size of the image sensor, which is a constant inside the camera, is $H_i=3.68$ [mm] and $W_i=2.76$ [mm]. The lens focal length f of the Raspberry Pi Camera V2 is 3.04 [mm]. The size of the image captured from the camera is set to $PICTURE_HEIGHT=640$ [pixel], $PICTURE_WIDTH=480$ [pixel], and the height from the bottom of the image to the line laser irradiated on the floor is set to $y_{bias}=20$ [pixel]. The frame rate shall be 10 fps.

4. Experiment

4.1 Real-time obstacle detection accuracy verification (static state)

Even in a static state, the effect of the surrounding light source, such as fluorescent light, on each pixel value changes with time. Therefore, it is not always possible to obtain the same measurement results even when the robot and the obstacle are in the same position. In this section, we examine the scatter of data when the robot and the obstacle are stationary, and the measurement accuracy of the detection system itself.

4.1.1 Experimental Methods

The image of this experiment is shown in Fig. 4.1. In this experiment, an obstacle is brought closer to a stationary robot in 50[mm] steps from a point 800[mm] away, and measurements are taken for 10 seconds at each point (100 data points at a frame rate of 10 fps). The scatter of the data and the error from the true value are compared.

Figure 4.1 Experimental image (static state)
※Obstacle is a rectangle viewed from the front.

4.1.1 Experimental results

The results obtained in this experiment are shown below.

Figure 4.2 Distance measurement result (static state)

Figure 4.3 Height measurement result (static state)

Figure 4.4 Width measurement result (static state)

4.2.3 Discussions

The results show that the distance and height of the obstacle can be detected with an error of 18 [mm] at most compared to the theoretical value, which means that practical obstacle detection is possible. In the width measurement, the error is 150 [mm] at the distance of 800 [mm]. This is thought to be due to the fact that the laser beam irradiated on the obstacle and the laser beam irradiated on the floor appear to be at almost the same height in the image, and thus the initial value was output because it was not recognized as an obstacle. For the other data, the detection is considered to be practical as well as for distance and height. The difference between the maximum and minimum values in the measurement is about 10 [mm], and the influence of the surrounding light source is considered to be relatively small. The error is larger when the distance is closer, but this is due to the fact that the laser beam is irradiated more strongly when the obstacle is closer, causing the laser line to be thicker.

4.2 Real-time obstacle detection accuracy verification (moving state)

Autonomous mobile robots need to be able to detect obstacles correctly while moving in order to move safely in factories and warehouses. In this section, the system is operated by a robot moving at a constant speed against an obstacle, and the measurement accuracy of the data when detected in real time is verified.

4.2.1 Experimental Methods

The image of this experiment is shown in Fig. 4.5. In this experiment, the robot approached a stationary obstacle from 800[mm] away at a constant speed (150[mm/s]), and measurements were taken in real time. We compare the error between the time and the reference true value. In order to check the dependence of the measurement results on the shape of the obstacle, we prepared two types of obstacles, one rectangular and the other isosceles triangular.

Figure 4.5 Experimental image (moving state)

4.2.2 Experimental results

The results obtained in this experiment are shown below.

Figure 4.6 If the obstacle is a rectangle (moving state)

Figure 4.7 If the obstacle is a triangle (moving state)

4.2.3 Discussions

In this experiment, we verified the accuracy of the measurement while the robot was moving. The results show that in the area where the laser beam irradiated on the obstacle and the laser beam irradiated on the floor appear to be at almost the same height in the image, the obstacle is not detected. Therefore, the initial values of distance, height, and width are output. With the exception of this case, detection can be performed within an error of 20 [mm] regardless of the shape of the obstacle. Based on the above, we believe that practical obstacle detection is possible. When the three parameters (distance, height, and width) are combined into a single graph, the variation of the error in distance and height is common. This is due to the fact that the coordinates of the intersection of two lines are used to calculate the distance and height. As for the width, the error becomes larger as the distance to the obstacle approaches, as in the case of the measurement in the stationary state.

5. Conclusions

In this study, we aimed to enable the robot to avoid obstacles and run freely. We used a different approach than conventional obstacle detection methods, which using a line laser and a camera, to detect obstacles in real time while the robot is stationary and moving.

As for the detection accuracy of our system, the experimental results show that the distance, height, and width can be detected within 20[mm] in real time, except for the area of 40[mm] near the line laser irradiated on the floor. Therefore, it can be said that practical obstacle detection is possible.

In this study, we used the Raspberry Pi Camera V2, but its shooting range as a camera is limited. In the future, the use of cameras with wider angles and lower distortions will enable the detection of a wider range of obstacles. And we plan to increase the number of lasers with different irradiation angles in order to reduce the size of the undetectable area, which could not be compensated by our system.

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