euspen's 25th International Conference & Exhibition, Zaragoza, ES, June 2025
www.euspen.eu

Study on self-coupling recognition sensor using diffuse laser light

Yugo Ikegaya[1], Daiki Sato[1], Daisuke Mizushima[1], Norio Tsuda[1]

[1]*Aichi Institute of Technology*

yuike2001@gmail.com

Abstract

In recent years, the market for autonomous mobile robots has grown rapidly owing to the labor shortage caused by the declining birthrate and aging population, as well as the need to improve efficiency and reduce manufacturing and logistics costs. When developing an autonomous robot, blind spots around the robot are problematic. There are contact-type recognition sensors that can be incorporated into autonomous mobile robots; however, there are almost no noncontact recognition sensors. Therefore, we consider applying a self-coupling distance sensor that have been studying for this recognition sensor. The self-coupling type used in this study is a sensor in which the light-emitting and light-receiving parts are completed only by laser diodes, unlike the time-of-flight method and triangulation method. In previous studies, it has been successfully arrayed and measured using parallel beams. However, if the object to be measured is large, multiple laser diodes are required and it is difficult to create a sensing area using parallel beams. Therefore, we arrayed Vertical Cavity Surface Emitting Lasers, diffused parallel beams, eliminated gaps in the sensing area, and conducted basic research on the recognition sensors. First, we performed measurements using a Vertical Cavity Surface Emitting Laser with a single built-in photodiode as the diffused light, and confirmed that measurements were possible even when the object was 10 cm away with a beam diameter of 2.95 mm. This is expected to result in smaller and less expensive sensors.

Self-coupling effect, VCSEL, Recognition Sensor, Diffuse laser light

1. Introduction

In recent years, factory automation (FA) has been promoted to reduce labor costs, increase operating hours, and improve production efficiency on production lines in various factories. FA refers to the automation of processing materials, assembling parts, and transporting products during the production process. One of the problems in promoting factory automation is the high cost of equipment. Therefore, automation equipment, such as robots, sensors, and control systems, must be less expensive.

Autonomous mobile robots, Automatic Guided Vehicle (AGV) and Autonomous Mobile Robot (AMR) with built-in sensors such as capacitive, ultrasonic, millimeter wave, and laser sensors are mainly used to transport products [1]. When developing an autonomous mobile robot, blind spots of sensors around the robot are considered to be a problem. Here, we consider the development of an artificial skin-like sensor that can detect objects without contact by applying the self-coupled distance sensor.

The self-coupling effect used in this study is a phenomenon in which the light output increases or decreases owing to the interference between the emitted light and the reflected light from the object[2]. This phenomenon eliminates the need for a light-receiving sensor, and only a laser diode (LD) is required to complete the system, making it possible to reduce its size, weight and cost[3, 4]. In addition, the detection area can be expanded using an array.

In this study, the detection area was expanded by using a diffuse laser beam. Additionally, object detection was performed by attaching a blank piece of paper to the object to be measured.

2. Principles

2.1. VCSEL

This study used a Vertical Cavity Surface Emitting Laser (VCSEL) OPV310 manufactured by TT Electronics. This laser has a built-in photodiode and is less expensive than other lasers with built-in photodiodes. Figure 1 shows the static characteristics (25°C), and Figure 2 shows the oscillation wavelength characteristics (25°C).

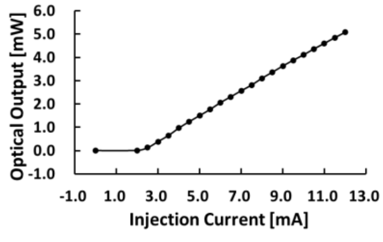

Figure 1. Static characteristics

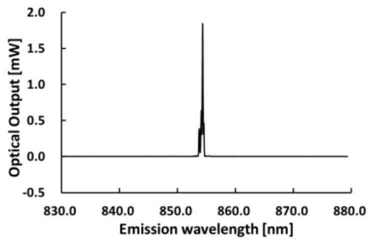

Figure 2. Wavelength characteristics

2.2. Self-coupled effect

The self-coupling effect used in this research is a phenomenon in which when a laser beam is irradiated onto an object to be measured, the light is reflected from the surface of the object, and part of the reflected light returns to the active layer of the laser. This phenomenon causes a slight fluctuation in the optical output of the laser. In Figure 3. and Equation 1, L is the distance from the LD to the object to be measured, λ is the oscillation wavelength, and n is the maximum number of interferences between the emitted light and reflected light.

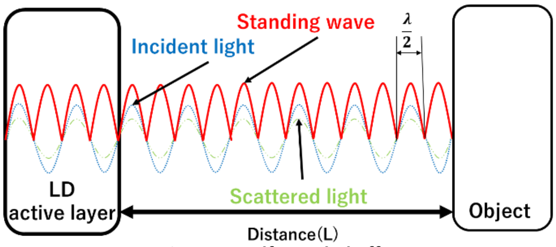

Figure 3. Self-coupled effect

$$L = \frac{\lambda}{2} n \qquad (1)$$

2.3. Detection principles

The principle of object detection is also explained. In this study, LDs are driven by an inflow of modulated triangular wave current. The LD oscillation wavelength is changed at a constant rate by the inflow of the triangular wave current. This satisfies the resonance condition of Equation 1, and the light intensity of the LD changes periodically. This signal is called the Mode Hop Pulse (MHP), and when the frequency component of the MHP is the MHP frequency F_{MHP}, Equation 2 is given.

$$F_{\mathrm{MHP}} = \left(4 f_{\mathrm{m}} I_{\mathrm{m}} \frac{1}{\lambda^2} \frac{d\lambda}{dI}\right) L \qquad (2)$$

where f_{m} is the modulation frequency, I_{m} is the modulation current, and $\frac{d\lambda}{dI}$ is the current modulation efficiency.

3. Measurement environment

Figure 4 shows the measurement environment used in this study. The drive circuit consists of a constant-current circuit and a suction modulation circuit. The output from the constant-current circuit is controlled by a function generator and is fed to ground to generate a triangular wave current. The generated triangular wave is designed to have a maximum current of 11.5 mA and a minimum current of 9.5 mA. The light-receiving part consists of an I-V conversion circuit and third-order high-pass filter. Since the LD used has a built-in photodiode, the self-coupled signal is converted into a current that flows into the photosensitive area. Therefore, it is necessary to convert the signal to voltage using the I-V conversion circuit. A third-order high-pass filter is used since this signal contains DC and noise components, such as wiring.

4. Measurement results

The measurement was performed by sticking a piece of paper with a lower reflectance than that of the reflective sheet conventionally used on the surface of the object to be measured. Figure 5 shows an oscilloscope image in which an object was detected, and Figure 6 shows an image in which no object was detected. In Figures 5 and 6, the green waveforms show the trigger signal, the yellow ones the self-coupled signal, and the pink ones the FFTed the self-coupled signal. Figure 5 shows the peak at 105.9 kHz, indicated by the red circle. The distance between the laser and the object was 10 cm, and the beam diameter was 2.95 mm. The beam diameter of the parallel beam was 1.93 mm. Therefore, the detection area was expanded by a factor of approximately 2.25. The same detection was also possible when the object was within 10 cm.

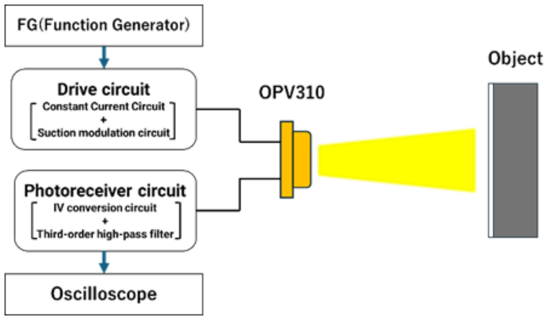

Figure 4. Measurement setup

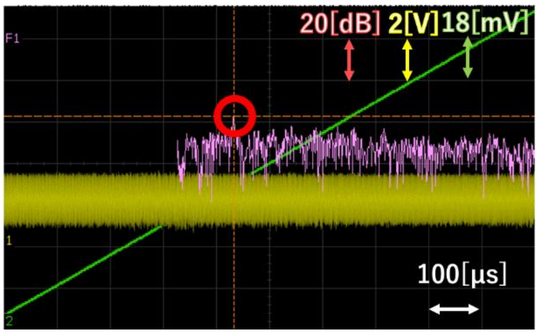

Figure 5. Object detection

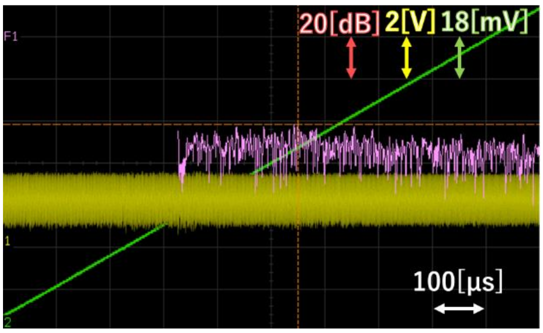

Figure 6. Object non-detection

5. Conclusion

Conventional self-coupling distance sensors had used parallel beams for detection, which result in blind spots in the laser package, and required the use of a large number of lasers. This was thought to result in sensor failure and high costs. Therefore, we considered changing the laser beam from a parallel beam to a diffuse beam to expand the detection area and eliminate blind spots when using laser arrays.

Using diffuse light, it was found that an object could be detected even when the distance between the LD and object was 10 cm and the beam diameter was 2.95 mm. As a result, the detection area was successfully extended by approximately 2.25 times. We believe that this leads to a cost reduction of the sensor and a reduction of malfunctions when the sensor is used.

References

[1] Takeshi Ando and Hiroyuki Uematsu 2019 Jrsj. 37(8) 703-706 (in Japanease)

[2] P. J. de Groot, et al. 1988 Applied Optics 27, 4475-4480

[3] Takeshi Yoshimatsu et al. 2014 IEEJ Trans. EIS, 134(12) 1796-1801 (in Japanease)

[4] S. Donati 2012 Laser & Photonics Reviews 6, 393-417