Broken rail detection system using laser

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Abstract. To ensure a safe train operation, some devices are applied to control the infrastructure and rolling stock work safely such as track, signalling system especially on densely trafficked lines using automatic train protection, rolling stock and etc. Track is a main part of infrastructure that has to be monitored before train operation passes it. By operation times, the rail will be decreased in quality due to several factors such as temperature and material durability. One type of rail damage that is often encountered is broken rails. If the rail breaks, the train passes through it can be derailed. To address this problem, a rail damage detection system will be developed using a laser beam. This rail detection laser will be designed as a prototype. The railroad tested was designed to have a gap that varies between 2 and 20 millimeters. A laser-based proximity sensor VL53L0X is placed between the front and rear wheels of the train prototype. Testing this system is successful in a dynamic way. It means that the measurement is done by advancing the prototype manually by hand, not using electricity. The results obtained from dynamic testing are obtained if the rail gap is wider, the range of peak values detected is greater based on monitoring through graphs.

1. Introduction
Train is considered as one of the modes of transportation that is able to offer excellent service, punctuality, comfort while operation, affordable prices in each class, guaranteed security, and much more. A train is not only as accommodation for passengers, but has served logistics expeditions too. The increasing interest of the public and business people towards the train has increased the frequency of passenger and freight train operations. With the increase in the frequency of train travel, automatically maintenance of train facilities and infrastructure also needs to be improved. The steps are from the availability of locomotives, wagons, signaling system including condition of the railroad track [1-5].

In this research, how to detect the right rail conditions becomes an issue that will be discussed thoroughly. Rail is the iron or steel rod devices that are placed on the ground to guide the direction of the train during the trip. The railroad connects from one train station to another. If the frequency of the trip increases, then the railroad will often be crossed. It will be affect the condition of the rail. For example, if a railroad track becomes more congested, then the rails on that road will get wear faster. If the rail is not maintained or even replaced, the rail will be increasingly eroded by the surface due to the influence of friction on the train wheels. Rail conditions are not only influenced by the frequency of train travel, but weather factors also play a role. In science there are phenomena of expansion and shrinkage. The science is related to railroad tracks. Rail lines are deliberately stretched to make room
for expansion during the day and recede at night. If the connection is made narrow, then the expansion of the rail can bend, crack, until broken. If the tracks are damaged, the trains that pass through it may experience slippage, plummeting, and even toppling over. With this dangerous condition, the train journey had to be diverted and even delayed. This will result in a buildup of passengers and delays to get to the destination station.

Now, the railroad company has run a rail inspection program, one of which is checking the quality of the rail by human as a railroad inspector [6-8]. Each officer must walk the distance specified in a particular sector and will alternate with other officers to check rails in other sectors.

Laser has applied to detect and map cracks automatically such as for concrete achieved by three steps such on shading correction in the original image, crack detection and crack mapping and processing [9]. In this study, a broken rail detection system using a laser will be developed. Laser stands for "Light Amplification by Stimulated Emission of Radiation". Laser is a mechanism that emits electromagnetic radiation in the form of light. Laser light is created by the movement of photons released by electrons as they fall from a higher energy level (Excited State) to the lowest energy level (Ground State) found in an atom. In an increasingly sophisticated era, the use of lasers is increasingly being used in various fields. In this study will be tested the use of laser light in the field of transportation, especially trains. If the laser prototype functions properly, then it is expected to be able to be implemented directly by the train operator to conduct regular rail checks.

2. Broken rail concept

2.1. Broken rail

A rail can be said to be broken if there are gaps in the same rail. In general, gaps that arise on the rails cover all sections of the rail (rail surface, rail head, rail body / web rail, and rail base / foot rail). Based on cases of broken rails that have occurred at several railroad crossing points, the cause of broken rails usually occurs due to high frequency of train operation, bumps on train wheels, as well as weather and temperature changes that result in shrinkage and expansion of rails. However, please note that the gap in the rail is different from the gap in the rail connector. In the rail connector deliberately provided a gap to make room for the rail shaft to shrink or expand depending on the surrounding temperature. This is done to prevent rails from bending during the expansion process.

![Figure 1. Rail structure.](image)

In the rail connector at Figure 1a, there is a part called a connector iron plate or jointbars. The function of jointbars is to maintain the movement of the rail expansion. The plate is mounted on the rail body. So that when the rail viewed from the side, the gap will be covered by the jointbars. However, cracks can still be seen on the surface, rail head and foot rail. Therefore, the rail gap that is covered by jointbars is not said to be a broken rail condition, but only an ordinary rail connector. But if the rail gap is clearly visible from the rail surface to the foot of the rail without being covered by jointbars then it is a broken rail at Figure 1b.
2.2. **Gap rail standard in Indonesia**

Between the two rails connected there must be a gap to allow the rail to expand. In Indonesia, this gap is defined as follows:

| No. | Rail length (meter) | At morning / Shady place (millimeter) | At daylight / Under the sun (millimeter) |
|-----|----------------------|--------------------------------------|----------------------------------------|
| 1   | 13.6                 | 9                                    | 5                                      |
| 2   | 11.9                 | 8                                    | 4                                      |
| 3   | 10.2                 | 7                                    | 4                                      |
| 4   | 6.8                  | 5                                    | 3                                      |

The table indicates rail gap standards based on the 1981 reference. However, over time, railroad operators have begun to change the standard rail length. To improve the safety and comfort of passengers and goods, the standard rail length has now been changed to 25 meters so that the number of rail connections can be reduced.

3. **Broken rail detection system design**

3.1. **Laser**

The LASER word stands for Light Amplification by Stimulation Emission of Radiation. It can be interpreted as an increase in the intensity of light by an aroused beam. After 30 years since it was discovered, the "laser" word became an absorption word that was used daily. Currently there are equipment that use laser work such as barcode detection, laser printing, until cutting hard materials. Lasers have a way of working which includes optics and electronics. The science of lasers is classified in the field of quantum mechanics. Actually, the laser is the development of MASER where the letter M stands for Microwave, which means microwave. Laser and maser work by the same way. But, laser and maser work at different wavelengths. Laser works on the infrared spectrum (infrared) where the wavelength is $10^{-5}$ meters to ultra violet (ultra violet) where the wavelength is $10^{-8}$ meters. While maser works on microwaves whose wavelengths are longer than laser, which are $10^{-2}$ meters. Laser that emit visible light are also called optical lasers.

Light Detection and Ranging or commonly called LIDAR is a method of measuring distance by reflecting a signal on an object. Basically, LIDAR has the same principles as radar (Radio Detection and Ranging). However, LIDAR reflects signals whose wavelengths are shorter, which is around $10^{-9}$ meters (usually laser) than radar waves, which are around $10^{3}$ meters. Calculation of distance is obtained based on the difference in time the wave is sent with the time the wave reflection is received. The time difference is called Time-of-Flight (ToF). In a LIDAR sensor there is an algorithm that is able to identify a regular pattern based on the ToF calculation. A LIDAR sensor is placed at one point and rotates in its place. LIDAR will emitting laser waves and bounce off the red dot. Based on the difference in distance and ToF, LIDAR will form a regular pattern in the form of a box. When the laser wave is reflected by a circle closer to the square, the reflecting point is closer than before. The reflecting point of this circle disrupts the regular pattern of the box. Thus, the circle can be said to be a disturbance.

3.2. **Distance sensor VL53L0X**

The VL53L0X sensor is an electronic module made by the electronics company ST Microelectronics. The VL53L0X sensor works based on the Time-of-Flight (ToF) principle. This device emits a VCSEL laser whose wavelength is 940 nanometers [11]. The emitted laser is a class 1 laser. It means that the emitted laser is completely invisible and safe when highlighted directly into the eye. Inside the VL53L0X sensor module is a component such as a black chip. The component is a laser transmitter.
and receiver. The laser emitted by the transmitter is then reflected by the object and is received by the receiver. This component will determine the ToF received by the sensor.

Figure 2. Illustration of LIDAR

Figure 3. Distance sensor VL53L0X

3.3. System design

A flow chart is a diagram that represents an algorithm by displaying steps in the form of symbols. Flow chart is an illustration in overcoming problems. The system algorithm in this study is illustrated by the following flow chart at Figure 4. Based on the flow chart above, the distance of the sensor to the rail body is called the reference input. The input is predetermined through programming. For example, the distance sensor from the rail body is 50 mm. Then the reference input in programming is filled by 50 mm. Next, the train will run and sensors will begin to fire laser waves along the rail body. If this wave shot passes through the rail gap, the wave will not detect a rail body in the area so the measured instantaneous distance will be more than 50 mm. If the measurement results are less than the reference input, the train will continue to run. However, if the measurement results exceed the reference input, the sensor can detect the rail gap. Then, the width of the rail gap is set manually by human hands. For example, the rail gap is set at a distance of 5 mm, 10 mm, and so on.

In Time of Flight system, distance can be measured by this formula:

\[ d = \frac{c \times t}{2} \]  

(1)

d = Distance to object  
c = The speed of light in the air (340 m/s)  
t = Time of Flight

In this research, the value of Time of Flight does not need to be known. Because the purpose of this study is to compare the measured distance value, hereinafter referred to as the measurement value, with the specified reference value. For dynamic measurements, the reference value is not the distance between the rail and the actual sensor because the sensor has a large error or interference value. So the reference value entered is slightly larger than the actual distance value. For example, if the real distance between the rail and the sensor is 90 mm, then the reference value entered is 100 mm. This is necessary to avoid measurement errors that lead to errors whether the rail is in a condition where there are gaps or not.

4. Results and analysis

Measurement is carried out dynamically and the distance between rail and the sensor is 90 mm. However, this study is only limited to the difference in measurement values for the various rail slits. The value is taken by taking several samples from the width of the rail gap. Then the distance measurement process is done by manually backing up the tool by hand. Each width of the gap will be sampled a value of 10 times. For the reference value, enter a value of 100 mm as a limit whether there is a gap or not on the rail.

The measured values are around 85 to 98 mm. The measurement value has not reached 100 mm. Moreover, when the gap condition is 2 mm the sensor cannot distinguish the rail condition when the
sensor crosses the gap as indicated at Figure 4a. The measured values are around 85 to 98 mm. The measurement value has not reached 100 mm. So when the gap condition is 3 mm the sensor cannot distinguish the rail condition when the sensor crosses the gap as indicated at Figure 4b. The measured values are around 85 to 98 mm. The measurement value has not reached 100 mm. So when the gap condition is 4 mm the sensor cannot distinguish the rail condition when the sensor crosses the gap as indicated at Figure 4c. The measured values are around 95 to 105 mm. The measurement value has reached 100 mm. But from 10 samples, only 2 samples made it past 100 mm. So when the gap condition is 5 mm, the sensor can start to distinguish the rail condition when the sensor is crossing the gap but it is not optimal as indicated at Figure 4d. The measured values are around 100 to 105 mm.

The measurement value has exceeded 100 mm. From 10 samples, only 1 sample did not cross 100 mm. So the 6 mm gap condition of the sensor can distinguish rail conditions when the sensor crosses the gap more optimally than 5 mm as indicated at Figure 4e. The measured values are around 104 to 112 mm. The measurement value exceeds 100 mm. So when the gap condition is 7 mm the sensor can distinguish the rail condition when the sensor crosses the gap as indicated as Figure 4f. The measured values are around 104 to 112 mm. The measurement value exceeds 100 mm. So when the gap condition is 8 mm the sensor can distinguish the rail condition when the sensor crosses the gap as indicated at Figure 4g. The measured values are around 110 to 115 mm. The measurement value exceeds 100 mm. So when the gap condition is 9 mm the sensor can distinguish the rail condition when the sensor crosses the gap as indicated as Figure 4h. The measured values are around 115 to 120 mm.
The x-axis represents the number of samples and the y-axis represents the measured value in millimeters. The bottom horizontal line represents the actual value, which is 90 mm. The horizontal line above it states the reference value, which is 100 mm. While horizontal lines above 100 mm are random values to predict measurement values, the value can be set by yourself like 125 mm, 150 mm, 175 mm, and so on. However, only a few tables display random values, and in figures 4a through 4c only display reference values.

The measurement value exceeds 100 mm. When the gap condition is 10 mm, the sensor can distinguish the rail condition when the sensor crosses the gap as indicated at Figure 4i. The measured values are around 125 to 140 mm. The measurement value exceeds 100 mm. So when the gap condition is 15 mm, the sensor can distinguish the rail condition when the sensor crosses the gap as indicated at Figure 4j. The measured values are around 160 to 175 mm. The measurement value exceeds 100 mm. So when the gap condition is 20 mm, the sensor can distinguish the rail condition when the sensor crosses the gap as indicated at Figure 4k.

5. Conclusion
From the experiments, it was found that for a rail gap below 5 mm, it could not be detected by the VL53L0X sensor, so that the condition was considered to have no gap. The starting sensor can be detected starting from a gap of 5 mm wide. However, for slit measurements of 5 and 6 mm, the sensor cannot fully detect the gap properly. As for the 7 mm rail gap and so on, the sensor is able to detect gaps well. It can also be concluded that when the rail gap is above 7 cm, if the width of the rail gap is
wider, the range of peak values will be greater based on monitoring through graphs. The system is supposed to be implemented directly to assist officers in checking the railroad tracks.

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