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# Development of a New Brake Failure Early Warning System to Reduce Brake Failure Accidents in Indonesia

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**Abstract:** The increasing number of vehicles in Indonesia has heightened the risk of traffic accidents, with brake failure being a significant contributor, particularly in heavy vehicles, such as buses and trucks, on long downhill roads. According to the *Korlantas Polri* (Traffic Corps of the Indonesian National Police), brake failure is a leading cause of traffic accidents in Indonesia. KNKT (Indonesian National Transportation Safety Committee) investigations into 14 cases of brake failure revealed that brake overheating was the primary factor, exacerbated by high speeds, heavy loads, and steep terrain.

In response, the Anti Blong system was developed to prevent brake failure through early detection using smart sensors to monitor both the brake-lining temperature and road slope. Integrated with IoT, the system provides real-time warnings via a virtual assistant, both on the driver's smartphone and through an audible siren for nearby vehicles. Experimental tests of Anti Blong showed high effectiveness, with 98% accuracy in detecting brake temperature, 76% in slope detection, and 90% accuracy in its virtual assistant's performance, making it a promising solution for improving heavy vehicle safety in Indonesia.

*Keywords:* **Brake failure, experimental overheating, sensor, temperature.**

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## 1. Introduction

The very high number of vehicles in Indonesia can increase the number of traffic accidents. Based on data from the *Korlantas Polri* (Traffic Corps of the Indonesian National Police), in 2022, Indonesia recorded approximately 137,851 cases of land traffic accidents, which caused 27,351 fatalities (KNKT, 2023). In addition to casualties, traffic accidents result in material losses. The Ministry of Transportation stated that the material losses incurred by the state due to traffic accidents in 2021 reached 246 billion rupiah.

There are three main factors that cause traffic accidents: human factors, road conditions, and vehicles (Wildan et al., 2020). The vehicle factor can be directly controlled by the driver (Wildan, 2023). The brake system is one of the most important components in a vehicle and must always be in top condition to ensure the safety of drivers. Brake reliability greatly affects safety while driving; thus, its maintenance should not be neglected (Puhn, 1985). Brake failure is a significant contributor to traffic accidents both in Indonesia and globally.

In Indonesia, brake failure accounted for 5.7% of road accidents from 2019-2021 (Khairina & Erwandi, 2022). Factors contributing to brake failure include overheating, low brake fluid, and inadequate maintenance (Oduro, 2012). Motorcycles are particularly vulnerable, with a 20-fold higher risk of fatal accidents compared to cars.

To address this issue, innovations such as Anti-Lock Braking Systems (ABS) for motorcycles (Kumaresh et al., 2017) and integrated cooling systems (Khatami et al., 2023) have been proposed. Improved brake materials, like magnetic composite brake blocks, have shown promise in enhancing brake performance (Muflikhun et al., 2023). Comprehensive strategies involving driver education, vehicle safety regulations, and infrastructure improvements are crucial to mitigate traffic accidents in Indonesia (Santosa et al., 2017).

Cases of brake failure experienced by heavy vehicles (both buses and trucks, as summarized in Table A of the Appendix, generally occur at high speeds on long downhill roads. Based on these 20 accident cases, a hypothesis emerged that vehicles, both trucks and buses, when passing along long winding downhill roads, have a high potential for accidents resulting from brake failure.

There are several causes of brake failure, but the most important is brake linings that experience overheating (KNKT, 2023). Overheating can cause brake failure because the brakes themselves work less than optimally (Sukamto & Bardi, 2013). Overheating is accelerated and worsened by fast vehicle speeds, excessive heavy loads, and sharp slopes or steepness of road terrain.

Based on Table B of the Appendix, human factors and vehicle conditions are the primary causes of road traffic accidents, with 17 and 14 recorded cases, respectively, from 2020 to the first semester of 2023. Although infrastructure and environmental factors recorded no incidents, the significant role of human error and vehicle-related issues, such as brake failure due to overheating (KNKT, 2023).

In addition, brake pads are also one of the leading causes of brake failure. Brake pads are components found in every vehicle to slow down and stop the vehicle. When the vehicle speed is high, the brake lining has a load of up to 90% of the load on other components. Asbestos brake linings can endure temperatures up to 200°C, but they begin to lose effectiveness at 250°C. Meanwhile, brake linings made from non-asbestos materials consist of four to five types of fiber, including Kevlar, steel fiber, rock wool, cellulose, and carbon fiber. These brake pads can endure temperatures up to 360°C, making them generally more stable (Anjasmara et al., 2015).

Until now, no specialized technology has been developed for the early detection of brake failure. The existing technology summarized in Table C of the Appendix only involves modifications to the existing braking system to reduce vehicle speed. Efforts to reduce the heat generated during braking have also been developed, such as an anti-overheat forced cooling system for vehicle disc brakes (Dewanto & Wijaya, 2010). Although it can detect brake temperature, the output of this forced cooling system can be dangerous. Spraying water when the brake components reach the maximum working temperature can cause the rotor disc to become warped (Danaher et al., 2009).

Many features support monitoring of the brake system; however, this system cannot detect the potential for brake failure from the brake-lining temperature parameters. Therefore, Anti Blong (means "no brake failure" in English) is proposed to become a brake failure early detection system designed to prevent brake failure in heavy vehicles through the use of multifunctional smart sensors. The system consists of a temperature sensor that detects overheating of the brake lining, which is classified into three safety categories, and a slope sensor that detects downhill road terrain. With the support of the Internet of Things (IoT), the system provides audio instructions via an app on the driver's smartphone and warns against brake failure, as well as emitting a loud siren to warn other motorists in the vicinity.

Unlike systems such as Eaton VORAD that use radar to detect hazards and on-board diagnostic systems that monitor vehicle malfunctions (Danaher et al., 2009; Woll, 1993), Anti Blong focuses on preventing brake failure due to overheating and long downhill road conditions without changing the vehicle's braking system. This system is expected to improve safety and become a solution for drivers and the government for heavy vehicles (Lin et al., 2005; Zekavat, 2004).

## 2. Materials and Methods

The concept behind designing the Anti Blong system is to develop an early detection system for brake failure on heavy vehicles that accurately detects the potential for brake failure by classifying it into three safety categories using the fuzzy logic method (Nazemizadeh et al., 2014). The system aims to be preventive by minimizing the risk of accidents due to brake failure, and it is applicative and adaptive, which makes it easy to apply to all types and generations of heavy vehicles without altering the brake system. The system design process began with a comprehensive literature study of traffic accidents involving heavy vehicles due to brake failure, focusing on the causes and conditions of such accidents. Additionally, the latest available technology for preventing and detecting potential brake failure was thoroughly investigated (Khatami et al., 2023).

The design and development of the system were executed with the assistance of Autodesk Inventor and Autodesk Fusion to create an applicable detection system structure. Furthermore, Blynk was used for web and application development (Usha et al., 2024). Testing and evaluation were conducted through a simulation method, which involved remote control of a 1:18-scale miniature truck, as well as direct testing of the equipment on the actual truck.

### *2.1 System Design Planning*

Anti Blong, which functions to prevent brake failure on heavy vehicles, must have a temperature sensor to detect overheating on the brake pads and slope sensors to detect possible downhill road terrain. In this study, a thermocouple was used as the sensor. Thermocouples are widely used to measure the temperature in brake systems, but their accuracy can vary. Acicular grindable thermocouples have shown promising results, with temperature deviations of 7-19% compared to infrared thermography for brake pad materials (Nosko et al., 2022). Thermocouple measurements can also detect the onset of thermoelastic instability in brake systems (Lee & Barber, 1994). Overall, thermocouples provide a reliable method for measuring brake temperature.

The system is also equipped with Internet of Things (IoT) to guide and warn the driver in the vehicle so that brake failure does not occur, and there is an output in the form of a loud siren sound as a danger signal to nearby drivers as a mitigation measure to reduce the scale of damage that can be caused by an accident due to brake failure. All of these systems are integrated into a box for easy application to all types of vehicles, especially heavy vehicles, without changing the existing braking system.

This system aims to prevent brake failure due to overheating of vehicle brake linings and long downhill road conditions, which trigger an increase in the brake lining temperature. The working concept of Anti Blong is illustrated in Figure 1, where when a heavy vehicle is moving, all sensors take input data according to each indicator.


Figure 1. Anti Blong system working concept.

The elevation sensor begins to detect the terrain being traversed in the form of slopes or flat road terrain. Once it is detected that the vehicle is starting to enter a downhill road, the system will give a warning sign to the driver via an LEDlight and buzzer sound on the vehicle dashboard, accompanied by audio instructions via notification from the smartphone so that the driver immediately reduces speed and uses a low gear.

When the driver starts braking, the temperature sensor begins to detect the temperature of the vehicle's brake lining. If the brake-lining temperature remains in the low-risk category (0-50%), the green LED light will turn on. However, if the brake lining temperature continues to increase to 51-80% of the maximum temperature or enters the medium-risk category, the LED lights up yellow, which is accompanied by a buzzer sound. Then, audio instructions from the smartphone are provided to warn the driver to immediately pull over the vehicle and stop first so that the vehicle's brake-lining temperature returns to normal.

Under certain conditions when the vehicle actually experiences overheating (81%-100%) in the brake linings, a danger sign in the high-risk category will appear, namely a red LED light and buzzer sound, accompanied by audio instructions from the smartphone for the driver to use the existing emergency brake. Apart from that, the siren will sound loudly outside the vehicle as a warning sign of danger to other drivers in the vicinity.

The control system of Anti Blong is shown in Figure 2. The system begins by providing the ESP32 hardware with program code containing several commands. The program code was written using the Arduino IDE based on the C++ programming language. The completed program is then uploaded to the ESP32 via serial communication. The uploaded program is stored in the ESP32 memory.

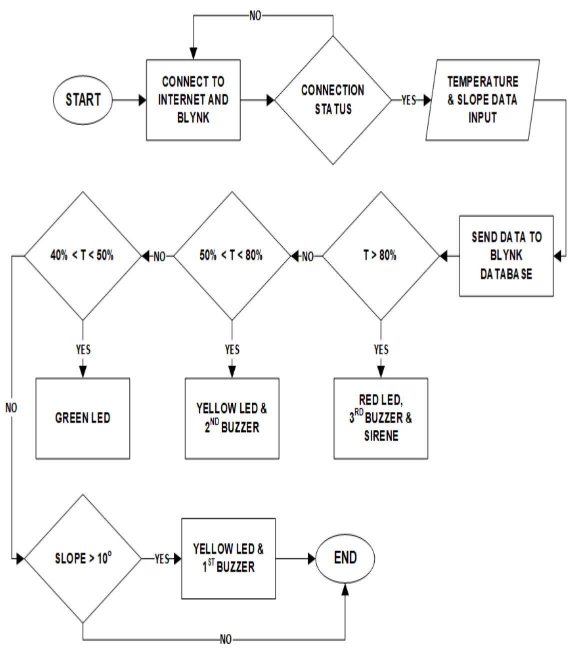


Figure 2. Flow diagram.

The first command is to connect the ESP32 to Wi-Fi and Blynk. Then, if the ESP32 is disconnected from the Wi-Fi network, the ESP32 is given the command to reconnect to the Wi-Fi and Blynk. The next command instructs the ESP32 to retrieve the temperature and tilt sensor data. The ESP32 retrieves the temperature data from the max6675 sensor via SPI communication. The ESP32 obtains raw data in the form of acceleration and angular velocity from the MPU6050 sensor via I2C communication.

After collecting data from the sensors, the ESP32 sends the sensor data to the Blynk database via the internet. The next command involves the logic concerning the temperature. The first condition is checked if the temperature is above 80%. If so, the ESP32 will turn on the red LED and buzzer in Pattern 3. If the first condition is not met, then the second condition is checked. The second condition checks whether the temperature is below 80% or above 50%. In this case, the ESP32 will turn on the yellow LED and buzzer under Pattern 2. If the second condition is not met, then the third condition. The third condition checks whether the temperature is below 50% or above 40%. If so, the ESP32 will turn on the green LED. If none of the conditions from the first to the third are met, the operation proceeds to the next command. The subsequent command is similar in structure and addresses the logic concerning slope conditions. If the slope condition exceeds 10°, the ESP32 will activate the yellow LED 2 and the buzzer with tone pattern 1. If this condition is not met, the command will return to the beginning and repeat the operation continuously.

The Anti Blong electronic system depicted in Figure 3 illustrates the direct flow of power and data. The Anti Blong power source was a battery with a voltage rating of 12 V and a capacity of 7.2 Ah. The LM2596 buck converter reduces the voltage from the 12-volt battery to the 5-volt microcontroller. The 5-volt voltage output from the step-down circuit was used as the power supply for the microcontroller, sensor, buzzer, and LED components. The relay is used to turn the siren on and off automatically according to the microcontroller data output. The battery life was estimated to be equivalent to vehicle operation for 18 hours on one trip.

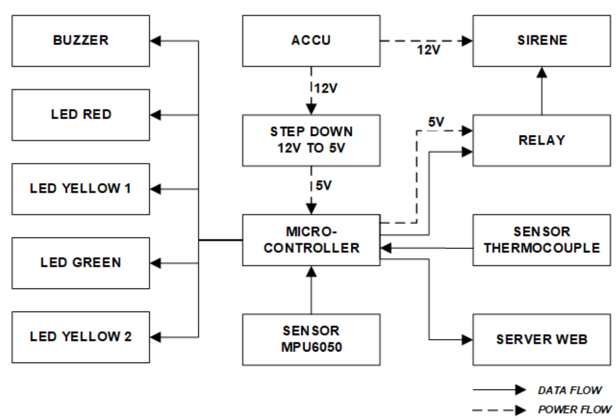


Figure 3. Electrical system diagram.

### *2.2 Implementation of the Anti-Blong System*

The Anti Blong system can be directly applied for the early detection of brake failure and can provide virtual assistance for preventing brake failure based on web and Blynk. The brake failure detection function is supported by several components: sensors, an ESP32 microcontroller, a battery, and actuators integrated into the Anti Blong control box.

The control box of Anti Blong is 120 mm in height, 250 mm in length, and 150 mm in width. On the cover of the tool, there is an on/off switch button, four LED lights for each indicator, and one buzzer actuator. Next, inside the box, there is one dry battery, a relay module, a thermocouple temperature sensor module, a gyroscope tilt sensor module, a buck converter, and an ESP32 microcontroller serving as the system control center, as depicted in Figure 4.


Figure 4. Physical form of the Anti Blong system.

The node device, as depicted in Figure 5, comprises the GY-521 sensor utilizing the MPU-6050 chip from InvenSense and the MAX6675 thermocouple sensor, along with an ESP32 microcontroller, BC547 transistor, and buzzer, LED, and siren actuators. The gyro sensor, thermocouple, and ESP32 are assembled on a single printed circuit board. The ESP32 device connects to Wi-Fi and Blynk on the web and smartphone applications. The temperature data are retrieved from the MAX6675 sensor via SPI communication (Pravalika & Prasad, 2019).

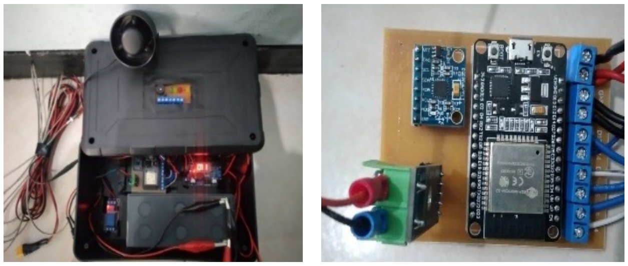

Figure 5. Node devide on Anti Blong system.

The ESP32 obtains raw data in the form of acceleration and angular velocity from the MPU6050 sensor via I2C communication. After collecting data from the sensors, the ESP32 sends the sensor data to the Blynk database via the internet (Nasution et al., 2019). Additionally, the function "Virtual Assistant Prevention of Brake Failure," which is in the developmental stage of a creative initiative, was created by establishing a web server and application based on Blynk. The IoT system consists of web and Blynk applications as well as node devices integrated into the control box.

### *2.3 Anti Blong System Testing*

Testing was conducted to determine the performance of Anti Blong. The calibration of the sensors is the initial step in the testing process. Four types of tests will be conducted, i.e., a) temperature sensor function testing, b) tilt sensor function testing, c) web and application function testing, and d) virtual assistant testing for preventive audio notifications on smartphones. These tests aim to verify the functionality and reliability of the system components and features to ensure that Anti Blong effectively detects and prevents brake failure incidents in heavy vehicles.

The temperature parameter testing begins with the use of a flame heat source, such as a gas lighter, directed directly at the thermocouple sensor to simulate temperature variations. Then, direct testing was conducted on the truck brake linings (Sukamto & Bardi, 2013). Anti Blong was tested by driving the truck on a downhill road and periodically applying brakes. Subsequently, the green, yellow, and red LED actuators, buzzer, and siren were tested. During the test, a gas lighter with a temperature ranging from 40°C to 50°C was directed at the thermocouple continuously for 8 sec. It is assumed that temperatures below 60°C fall into the low-risk security category, temperatures between 60°C and 80°C fall into the medium-risk category, and temperatures above 80°C fall into the high-risk category.

Direct testing was then conducted on a Mitsubishi FUSO FM 517 HS vehicle equipped with air-over hydraulic drum brakes and supported by an exhaust brake braking system. Operational brake lining temperatures within 4 hours range from 38°C to 93°C. Consequently, the test was conducted assuming the following conditions for the control system: temperatures below 42°C for the low-risk category, temperatures between 42°C and 43°C for the medium-risk category, and temperatures above 43°C for the high-risk category.

The testing conducted in this research uses a scale-down approach because the system is still in the early stages of development. However, the testing is expected to simulate real-world conditions, where the system can realistically detect brake system failures. Scale-down methodologies for brake pad experiments have been explored to accelerate development and reduce costs, aiming to maintain the thermal and mechanical characteristics of full-scale systems (Frangieh et al., 2023; Singireddy et al., 2022).

The second test, road slope parameter testing, was initially conducted on a small truck with remote control, which was first driven downhill. Simulation testing was then performed using a remote-control truck by installing the system on the vehicle. Subsequently, the truck was operated on a sloping road with a gradient of approximately 20°-30°. Finally, direct testing was conducted on a Mitsubishi FUSO FM 517 HS truck equipped with air-over hydraulic drum brakes and supported by a load exhaust brake system. The experiment was completed in a selected area in Surabaya, where the slope ranged from 20° to 30° and the descent road had a length of approximately 100 meters.

This testing approach is crucial, as previous studies have shown that impact angles in real-life accidents often exceed the 20° used in European standards, suggesting a need for review (Abraham et al., 2016). Additionally, road slope significantly affects vehicle performance, fuel consumption, and emissions, with slopes exceeding 5% considered unsuitable for freight corridors (Posada-Henao et al., 2022). Research on road angle estimation techniques has been conducted to improve vehicle safety systems (Hashemi et al., 2017), while vehicle trajectory analysis on slopes has been used to inform roadside safety guidelines (Carrigan & Ray, 2019). By conducting real-world testing on steep slopes, the proposed method aligns with existing research on vehicle stability and braking performance, thereby contributing to improved road safety and accident prevention strategies.

In addition, web and application functional testing entails a comprehensive assessment of the Anti Blong system's performance and functionality. This includes interactive testing to guarantee smooth and responsive operation of web user interfaces and applications. In addition, this testing involves validating the provided features, including the capability to control the device via an application and real-time monitoring of device status. Blynk Pro software for commercial prototyping was used as the platform for developing applications that allow users to control IoT devices via smartphones. Blynk offers a diverse array of features and widgets, along with integration capabilities with various hardware and microcontrollers.

In the meantime, the testing of virtual assistant precautionary audio notification on an Android smartphone aims to ensure that audio notifications can be received and understood clearly by users, providing relevant information in a timely manner. In addition, the testing verifies the virtual assistant's ability to offer effective preventive instructions and suggestions in emergency circumstances requiring quick action. Using smartphones as a virtual assistant platform allows users to access preventive notifications anytime and anywhere. The goal of this testing is to ensure that preventive audio notification systems on smartphones positively contribute to increasing user awareness and response to emergencies.

## 3. Results and Discussion

The results of tests conducted on temperature parameters simulated with a gas lighter are presented in Table 1. In the table, a "1" in the Green LED, Yellow LED, Red LED, Buzzer, and Siren actuator column indicates that the actuator is on, while a "0" signifies that the actuator is off. The obtained results indicate that the sensor accurately reads the temperature, and the actuators were turned on according to the conditions set in the control system correctly. Based on this test, the system achieved 100% accuracy.

Table 1. Thermocouple temperature due to gas lighter.

| Time | Temp. | LEDs | | | Buzzer | Sirene |
|---|---|---|---|---|---|---|
| | | Green | Yellow | Red | | |
| 01:13:38 | 38.25 | 0 | 0 | 0 | 0 | 0 |
| 01:13:40 | 62.25 | 0 | 1 | 0 | Pattern 2 | 0 |
| 01:13:41 | 75.00 | 0 | 1 | 0 | Pattern 2 | 0 |
| 01:13:42 | 89.25 | 0 | 0 | 1 | Pattern 3 | 1 |
| 01:13:45 | 104.25 | 0 | 0 | 1 | Pattern 3 | 1 |
| 01:13:54 | 81.25 | 0 | 0 | 1 | Pattern 3 | 1 |
| 01:13:55 | 79.00 | 0 | 1 | 0 | Pattern 2 | 0 |
| 01:14:03 | 67.25 | 0 | 1 | 0 | Pattern 2 | 0 |
| 01:14:11 | 61.25 | 0 | 1 | 0 | Pattern 2 | 0 |
| 01:14:13 | 59.75 | 1 | 0 | 0 | 0 | 0 |

The results of the direct testing of the temperature parameters on the truck are presented in Table 2. The table illustrates that the sensor test data accurately detected temperature rises, and the actuator responded by turning on according to the established conditions in the control system. The accuracy of the system was found to be 100%.

Table 2. Thermocouple temperature on a real truck (Mitsubishi FUSO FM 517 HS).

| Time | Temp. | LEDs | | | Buzzer | Sirene |
|---|---|---|---|---|---|---|
| | | Green | Yellow | Red | | |
| 10:50:58 | 41.50 | 1 | 0 | 0 | 0 | 0 |
| 10:51:14 | 42.00 | 1 | 0 | 0 | 0 | 0 |
| 10:56:39 | 42.25 | 0 | 1 | 0 | Pattern 2 | 0 |
| 10:56:45 | 42.50 | 0 | 1 | 0 | Pattern 2 | 0 |
| 10:57:55 | 42.00 | 1 | 0 | 0 | 0 | 0 |
| 10:58:20 | 42.00 | 1 | 0 | 0 | 0 | 0 |
| 10:58:46 | 42.50 | 0 | 1 | 0 | Pattern 2 | 0 |
| 10:58:55 | 43.25 | 0 | 0 | 1 | Pattern 3 | 1 |
| 10:58:12 | 43.00 | 0 | 1 | 0 | Pattern 2 | 0 |
| 10:58:31 | 42.50 | 0 | 1 | 0 | Pattern 2 | 0 |
| 11:00:27 | 41.75 | 1 | 0 | 0 | 0 | 0 |

The test results of the parameters are presented in Table 3, illustrating the outcomes of the simulation test on a remote-controlled truck. In the table, a “1” in the Green LED, Yellow LED, Red LED, and Buzzer actuator column indicates that the actuator is on, while a “0” signifies that the actuator is off. The table demonstrates that the sensor effectively detected downhill roads, achieving an accuracy of 88.89%. Additionally, the actuator functioned according to the commands from the control system, resulting in an actuator accuracy of 100%. Table 4 lists the results of measuring the slope of the truck. The findings indicate that although the sensor readings were somewhat less accurate and stable, the actuator operated effectively.

Table 3. Road slope on truck model.

| Time | Slope | Yellow LED | Buzzer |
|---|---|---|---|
| 15:59:25 | -4.898 | 0 | 0 |
| 15:59:26 | 11.375 | 1 | Pattern 1 |
| 15:59:27 | 16.675 | 1 | Pattern 1 |
| 15:59:28 | 25.337 | 1 | Pattern 1 |
| 15:59:29 | 28.523 | 1 | Pattern 1 |
| 15:59:30 | 29.825 | 1 | Pattern 1 |
| 15:59:32 | 26.209 | 1 | Pattern 1 |
| 15:59:35 | 27.063 | 1 | Pattern 1 |
| 15:59:36 | 5.994 | 0 | 0 |

Table 4. Road slope on a real truck (Mitsubishi FUSO FM 517 HS).

| Time | Slope | Yellow LED | Buzzer |
|---|---|---|---|
| 12:34:56 | 1.147 | 0 | 0 |
| 12:34:57 | 4.808 | 0 | 0 |
| 12:34:58 | 13.434 | 1 | Pattern 1 |
| 12:34:59 | 26.529 | 1 | Pattern 1 |
| 12:35:00 | 23.19 | 1 | Pattern 1 |
| 12:35:03 | 37.48 | 1 | Pattern 1 |
| 12:38:36 | 20.411 | 1 | Pattern 1 |
| 12:38:37 | 8.091 | 0 | 0 |
| 12:38:38 | 5.483 | 0 | 0 |

On the other hand, web function testing was also conducted in conjunction with the implementation of the Anti Blong system on vehicles. The results indicate that the web and application can accurately read data, as demonstrated by graphs and large temperature and slope values on the web dashboard, as seen in Figure 6. The proposed system achieved an accuracy of 90%, which indicates that it functions well according to the Blynk control system.

To address internet connectivity challenges in remote areas, the Anti Blong system can incorporate an offline mode using edge computing, allowing real-time local data processing and triggering audio-visual alerts without relying on cloud servers. Stored data can be uploaded once network access is restored for further analysis, similar to an airplane black box system. Optimizing the virtual assistant’s offline use by preloading safety instructions and emergency guides further enhances its reliability. By integrating these solutions, the Anti Blong system can function effectively regardless of network conditions, providing reliable brake failure detection and preventive notifications even in the most remote locations.

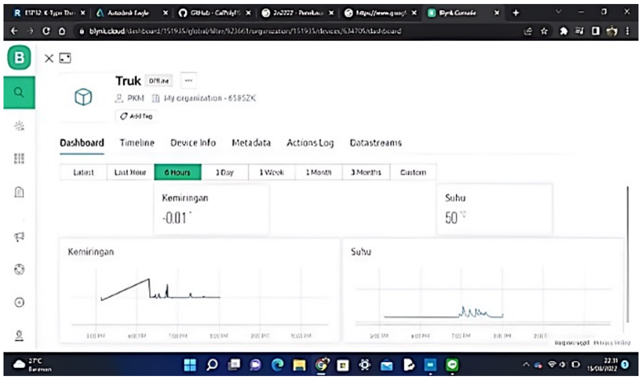


Figure 6. Test results on the web.

## 4. Conclusions

Anti Blong is an early detection system for brake failure that uses a multifunctional smart sensor to prevent brake failure in heavy vehicles. This system has two main functions: early brake failure detection, which is supported by a node device, and a preventive virtual assistant integrated with the web and applications via the Internet of Things. The Anti Blong system tests included temperature and tilt parameter tests, performed both under the original conditions and through simple tests using a gas lighter. In addition, web and application function tests were conducted along with notification tests on smartphones. The results of the Anti Blong tests on the sensor and actuator functions showed an accuracy of 98% for the brake-lining temperature parameter and 76% for the slope parameter. The test results for the virtual assistant showed an accuracy of 90%. This indicates that the Anti Blong system can work optimally without affecting the performance of the vehicle's braking system. To further strengthen the Anti Blong system, future improvements should focus on obtaining clearer data on actual brake failure causes rather than relying solely on accident data. Integrating black box technology would enable real-time monitoring of critical brake parameters, such as temperature, pressure, wear level, and fluid conditions, allowing for more precise correlations between failures and operational conditions. In addition, refining the slope detection accuracy through enhanced sensor calibration and machine learning models can improve brake performance prediction. Expanding testing to diverse real-life conditions, including road surfaces, weather influences, and load capacities, would further ensure system robustness. These enhancements will make the Anti Blong system a more comprehensive, data-driven solution, significantly improving heavy vehicle safety and reducing brake-related accidents.

## Conflict of interest

The authors have no conflict of interest to declare.

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## APPENDIX

Table A. List of truck and bus brake failure accident cases in Indonesia (Wildan et al., 2020).

| No. | Time of Event | Scene | Number of Victims |
|---|---|---|---|
| 1 | July 30, 2016 | Gekbrong Sukabumi Route, Cianjur | 18 died, and dozens were seriously injured |
| 2 | April 30, 2017 | Ciloto, Puncak | 11 died, and dozens were seriously injured |
| 3 | June 24, 2017 | Falling into a ravine in Belik, Purbalingga | 6 died, and dozens were seriously injured |
| 4 | January 6, 2018 | Cikampek Toll Road | No victims |
| 5 | February 10, 2018 | Bend Emen, Subang | 26 died, and dozens were seriously injured |
| 6 | September 8, 2018 | Cikidang, Bumiayu | 21 died, and dozens were seriously injured |
| 7 | December 10, 2018 | Kretek Flyover, Bumiayu | 13 died, and dozens were seriously injured |
| 8 | December 22, 2018 | Ujung Berung, Bandung | No victims |
| 9 | June 2, 2019 | Contraflow on Jatingaleh Toll Road. | Dozens of serious injuries |
| 10 | September 2, 2019 | Cipularang Toll Road | 9 died, dozens were seriously injured |
| 11 | September 16, 2019 | Way Kanan, Lampung | 8 died, dozens were seriously injured |
| 12 | December 22, 2019 | Purwosari Malang, Pasuruan, East Java | 8 died, dozens were seriously injured |
| 13 | December 24, 2019 | Pagar Alam, South Sumatra | 38 died, and dozens were seriously injured |
| 14 | December 28, 2019 | Kalikangkung Toll Road | Dozens of serious injuries |

Table B. Number of factors causing road traffic accidents based on the year of accident occurrence (2020 – First semester of 2023).

| No. | Description | Year of Accident Occurrence | | | | Total |
|---|---|---|---|---|---|---|
| | | 2020 | 2021 | 2022 | 2023 | |
| 1 | Human | 4 | 7 | 6 | 0 | 17 |
| 2 | Vehicle | 4 | 7 | 3 | 0 | 14 |
| 3 | Infrastructure | 0 | 0 | 0 | 0 | 0 |
| 4 | Environment | 0 | 0 | 0 | 0 | 0 |

Table C. Current support technology for truck and bus brakes.

| No. | Innovation | Description | Lack |
|---|---|---|---|
| 1 | Mercedes-Benz Active Brake Assist 5 | Combines a camera and radar sensor to detect objects in front of it and automatically activates the emergency brake (Kiesewetter et al., 1999). | There is no early detection of brake failure. Vehicle brake systems need to be changed, which is difficult to apply to all types and generations of vehicles. |
| 2 | Volvo Engine Control | Collaboration between the Engine Control Unit (ECU) and brake servo with the Throttle Position Sensor (TPS) allows the TPS to hold the throttle at a certain opening when this feature is activated via a button on the steering wheel. At that time, the gyro sensors work together to detect the presence of an incline or descent (Schwartze-Eidam, 2007). | It does not detect failures in the brake system, such as overheating of brake pads. |
| 3 | Retarders | The retarder brake functions to reduce the speed of the vehicle. The retarder is usually installed on the gearbox or axle. There are two types of retarder brakes: electric and hydraulic. Electric retarders use the electromagnetic induction principle and have rotor and stator components (Pandey et al., 2015). | There is no early detection system for brake failure.<br>This retarder brake only functions when the bus is at a fairly high speed. If used at low speed (e.g., uphill), the function of the retarder brake is not optimal. |
| 4 | Engine Braking | A method for decelerating a vehicle by lowering the transmission gear to create a vacuum in the combustion chamber without using wheel brakes (Manolache-Rusu et al., 2019). | There is no early detection system for brake failure. |
| 5 | Exhaust Braking | Exhaust braking means decelerating the vehicle by closing the valve in the vehicle's exhaust, causing the exhaust gas to be compressed and returned to the cylinder (Palanisamy et al., 2018). | There is no early detection system for brake failure. |
| 6 | US Patent 20080246335A1 | A method for detecting fault conditions in the hydraulic brake system of a vehicle with a hydraulic brake circuit (Spieker et al., 2005). | Not yet realized<br>There is no early detection system for brake failure. |
| 7 | US Patent 20050146212A1 | An invention comprising an auxiliary braking system including an auxiliary braking device (Cannon, 2005). | There is no early detection system for brake failure. |
| 8 | US Patent 3711827 | A brake failure warning light that monitors various functions (Houseman, 1970). | Does not assess temperature magnitude during operational conditions |
| 9 | US Patent 3480333 | An apparatus for providing an indication to a vehicle operator failure of either the front or rear brakes (Stelzer, 1969). | There is no early detection system for brake failure. |