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REAL-TIME WEIGH IN MOTION (WIM) MONITORING SYSTEM BASED ON OPTOELECTRONICS AND WHATSAPP GATEWAY

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ABSTRACT

The increasing mobility of motorized vehicles, such as trucks, has positively contributed to regional growth and connectivity in Indonesia. However, this development has also introduced significant challenges, particularly road damage caused by overloaded vehicles. Such damage not only jeopardizes the safety of road users but also incurs substantial economic costs due to infrastructure maintenance and repair. This research utilizes a real-time Weigh-In-Motion (WIM) monitoring system based on optoelectronic technology and a WhatsApp gateway. By combining the precision of optoelectronic sensors with the accessibility of communication through WhatsApp, this system aims to accurately and promptly detect overloaded vehicles. The study focuses on integrating the real-time WIM monitoring system with optoelectronic devices and WhatsApp-based communication. The methodology involves applying varying loads to the fiber optic sensor system, ranging from 1 kg to 10 kg, with loading time variations of 100 ms, 250 ms, 500 ms, 750 ms, and 1000 ms. The programming aspect uses Arduino and Virtual Basic (VB) to support the hardware system for real-time detection by the optoelectronic components. The results demonstrate that the developed fiber optic sensor performs optimally, as evidenced by the data trendline showing alignment at the same point during both ascending and descending conditions. Furthermore, the system successfully provides user notifications via WhatsApp when detecting threshold data at a load of 6 kg crossing the fiber optic sensor system.

Keywords: Real-time; WIM; loads; fiber optic sensors; WhatsApp

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INTRODUCTION

The increased motorized vehicle mobility on highways has positively impacted Indonesia's economic growth and regional connectivity. Trucks play a significant role in supporting this growth among the various motorized vehicles. According to data from the Central Statistics Agency (BPS), Indonesia's number of motorized vehicles—specifically trucks—was 5,299,603 in 2021. This figure increased by 4.3% in 2022, reaching 5,528,669 as of the latest data update on February 23, 2023 [1]. However, this development also presents significant challenges, particularly road damage caused by excessive vehicle loads or overloading. Such damage not only jeopardizes the safety of road users but also incurs substantial economic costs related to infrastructure maintenance and repair.

On August 31, 2022, the Toll Road Regulatory Agency (BPJT) reported that overloading vehicles could negatively impact toll road operators, increase the risk of accidents, and lead to inefficiencies due to deteriorating road conditions. Overloading-induced Road damage has resulted in an annual budget increase of IDR 43.45 trillion [2].

In recent years, research has been conducted on the effects of overloading on road damage. The findings of these studies indicate that overloaded vehicles significantly contribute to road deterioration [3–5] and a reduced lifespan of road sections [6–9]. This indicates that the overloading of motor vehicles, particularly trucks, is a severe issue in Indonesia.

To respond to these challenges, this study proposes developing a real-time Weigh-In-Motion (WIM) monitoring system based on optoelectronics and a WhatsApp gateway. The system is designed to offer an effective solution for accurately and swiftly detecting overloaded vehicles. The proposed approach integrates optoelectronic technology, including fiber optic sensors and electronic components, with WhatsApp as a communication gateway. This integration will enhance efficiency and accountability in managing highway overload issues and significantly improve road safety. The sustainable implementation of this system could be applied to monitoring weighbridges across Indonesia, ensuring a safer and more secure road network.

The urgency of this research lies in creating a WIM monitoring system capable of providing real-time information to relevant stakeholders, such as traffic regulatory authorities and road maintenance agencies. This capability is crucial for taking preventive measures before road damage worsens. Additionally, the system can serve as a tool for identifying specific vehicles that frequently violate load regulations, enabling more effective supervision and enforcement actions.

The principle of fiber optic sensors is based on the deformation of optical fibers, where fiber length or curvature variations influence light transmission. These fibers are installed either embedded within the road surface or attached to its underside. As vehicles pass over the sensors, the weight of the vehicles induces micro-bending or strain on the fibers. The transmission of light, facilitated by a light source, is affected by these deformations, altering the refractive index of the light within the fibers. This change in the refractive index impacts the light transmission. The modified light signal is then detected by photodetectors, converted into electrical signals, and subsequently processed to calculate parameters such as vehicle weight, speed, and classification [10,11].

Fiber optic sensors were selected over other sensor types for several reasons. When compared to inductive loop sensors, fiber optic sensors offer superior accuracy, enhanced durability, and simpler installation. Compared to piezoelectric sensors, fiber optic sensors provide a longer lifespan, greater sensitivity, and better resistance to environmental factors. Relative to capacitance sensors, fiber optic sensors demonstrate higher accuracy, greater immunity to noise, and reduced maintenance requirements. Finally, fiber optic sensors offer increased sensitivity, superior durability, and easier installation than strain gauge sensors [11].

Researchers worldwide have extensively researched weigh-in-motion (WIM) systems using fiber optic sensors and electronic devices. The effectiveness and feasibility of simulating the Vehicle Bridge Interaction (VBI) system using fiber optic sensors on a scaled-down model have been tested. The findings indicate that fiber optic sensors can perform highly accurately under various conditions [12].

Similar research has been conducted on developing moving load measurements using Fiber Bragg Grating (FBG) sensors. The methods employed in the study included non-destructive testing and a Falling Weight Deflectometer (FWD) with asphalt as the medium. The findings indicate that the FBG sensor can effectively detect strain within the asphalt medium [13].

Further research on moving loads at weighbridges using the B-WIM (Bridge Weigh-In-Motion) method based on fiber optic sensors has been conducted. The findings indicate that, under the designed conditions, this method can accurately identify vehicle speed, wheelbase, and axle weight [14].

Another similar study elucidates that optical sensor-based WIM systems enhance load limit enforcement, which is advantageous for highway authorities. Additionally, these systems contribute to the maintenance of road infrastructure and improve road user safety [15].

Other equivalent research can explain the technology of using fiber optic sensors in real-time in transportation systems. The application of this technology can monitor temperature, stress, strain, and load-displacement well. This research also shows that fiber optic sensors are a superior technology in the transportation industry [16].

Further research on moving loads using fiber optic sensors has been conducted. The sensor developed in this study enables the measurement of vehicle load and speed without needing an additional speed sensor. The results indicate that this method is reliable and closely aligns with speed values [17].

Other studies have demonstrated that fiber optic sensors can detect light loss due to macrobending. These findings are valuable for the real-time detection of flexible moving loads [18].

In 2023, researchers studied Weigh-In-Motion (WIM) systems based on fiber optic sensors. The results indicated that increased load values on a dummy dump truck corresponded with higher fiber optic light loss values. This fiber optic sensor design demonstrated that WIM can be effectively detected.

However, prior studies have not focused on real-time WIM monitoring utilizing optoelectronics and WhatsApp gateway technology. The scheme aims to combine the advantages of optoelectronic technology with the cost-effectiveness of WhatsApp communication. The research integrates the real-time WIM monitoring system using optoelectronic devices with the WhatsApp gateway communication system. This research is expected to offer an innovative and cost-effective solution to mitigate the negative impacts of excessive highway vehicle loads. Consequently, the results are anticipated to positively enhance the sustainability of transportation infrastructure and improve road user safety.

METHOD

This research consists of three main stages. The first stage is to set up a WIM monitoring system circuit using optoelectronic devices consisting of fiber optic sensors and electronic elements. The second stage is to create a warning system program if anomalous data is detected in WIM monitoring. The anomalous data indicates that an excessive load is crossing the system. The third stage integrates both stages with the WhatsApp gateway communication system so that the warning system notification is sent directly to the user's WhatsApp gateway.

The method used in this study is the macro bending of optical fiber. The creation of macro bending comes from WIM, which crosses the optical fiber sensor. The type of optical fiber used in this study is single mode. The advantage of this single-mode optical fiber is that it has low attenuation, the value is 0.05 dB/km [19]. WIM in this system is obtained from the scale’s weight placed on a dummy dump truck. The independent variables used are load (kg) and time (ms), while the dependent variable is voltage (volt).

The working principle of optoelectronics proposed in this proposal is that the 1310 nm light source transmits light to a 50:50 fiber coupler. Then, the light is forwarded to the reference and modulation optical fibers. The reference optical fiber is an unloaded optical fiber, while the modulation optical fiber is an optical fiber subjected to a moving load. The light sensor receives the light output from both optical fibers. Furthermore, the light output received by the light sensor is converted into voltage data. This is called data acquisition (DAQ). The data obtained from DAQ is in the form of voltage (V), which is then processed into transmittance data with the equation [20].

$$T = \frac{V_{mod}}{V_{ref}} \tag{1}$$

Description:
T = transmittance
V_{mod} = modulation fiber optic voltage value (volts)
V_{ref} = reference fiber optic voltage value (volts)

The way this monitoring system works is that DAQ continuously takes data. Then, the data will be sent to the Internet of Things (IoT) service, namely Blynk and If This Then That (IFTTT). Blynk plays a role in presenting data in visual form, or in this case, it is called the web User Interface (UI). This web UI is built using a widget provided by Blynk called a gauge. The function of the gauge is to display historical data in the form of real-time data and graphs. Another service used is IFTTT, the benefit of which is to activate the WhatsApp notification service and connect to a Google spreadsheet. This is useful for storing data sent by the DAQ device. By determining the voltage threshold data, when the voltage received by the DAQ passes the anomalous data criteria, IFTTT will request that a warning system notification via WhatsApp be sent to the user. The research scheme can be seen in Figure 1.

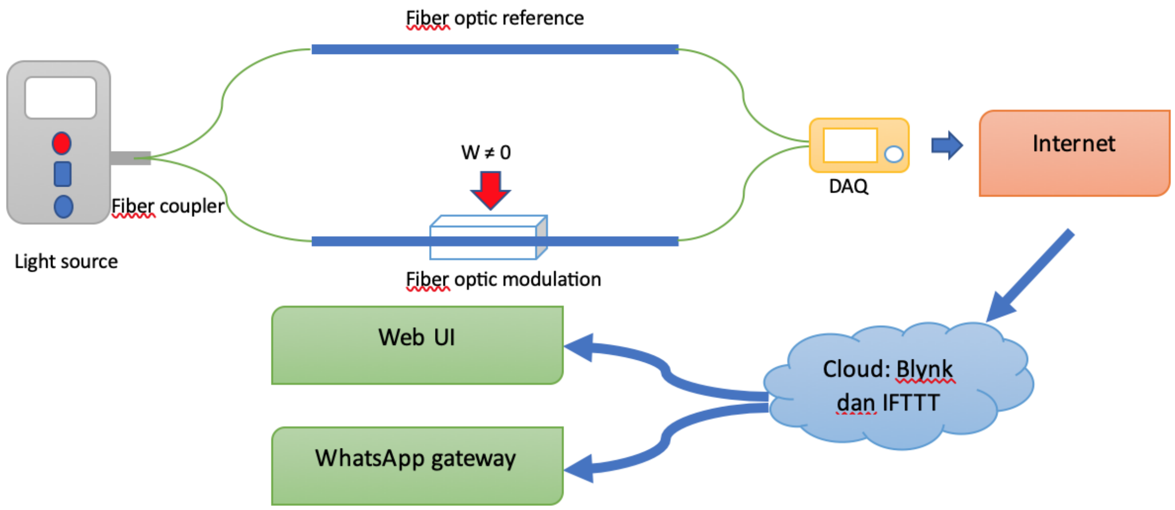


Figure 1. Research scheme of real-time WIM monitoring system based on optoelectronics and Whatsapp gateway

Based on previous years' research, the principle of moving loads crossing the WIM system changes the diameter of fiber optic. The continuation of the study developed in 2024 is that the change in diameter produces voltage data that is read in real-time by the web UI. The data generated in the study is expected to be able to identify anomalies. Anomalous data is indicated by a change in voltage value that decreases too significantly. This means that there is an excess load crossing the WIM sensor system. Through the proposed research design, when anomalous data is present, a warning system notification is hoped to enter the user's WhatsApp gateway. The concept of integrating optoelectronic technology and the WhatsApp gateway proposed in this study can be seen in Figure 2.

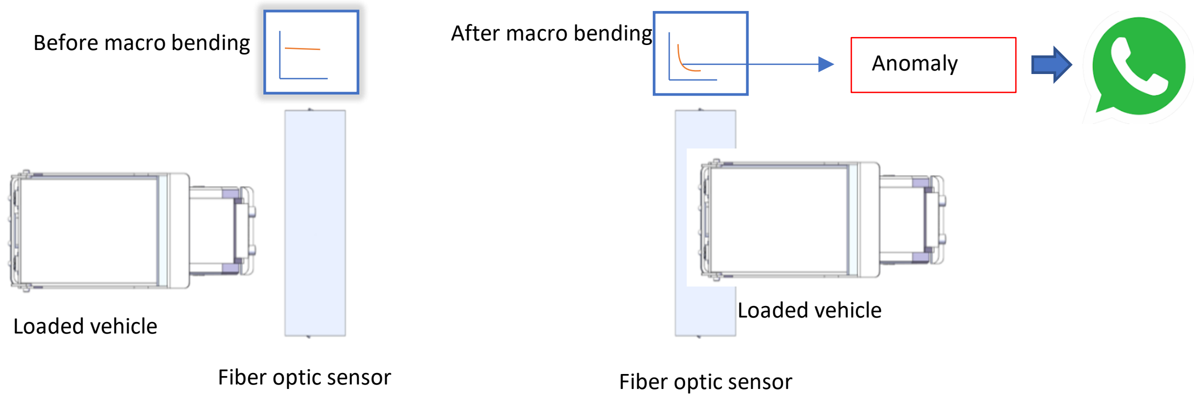


Figure 2. Integration concept of optoelectronic technology and WhatsApp gateway in real-time WIM monitoring system

The programming aspect uses Arduino and Virtual Basic (VB) to support the hardware system for real-time detection by the optoelectronic components. The rationale for platform selection is Arduino and VB. Arduino was chosen for its simplicity, affordability, and adaptability, making it ideal for rapid prototyping and proof-of-concept development. It provides an accessible hardware interface that enables quick implementation and testing of control systems. VB was selected for its ability to simulate real-world environments efficiently, facilitating system visualization and testing without requiring physical setups, thereby saving time and cost.

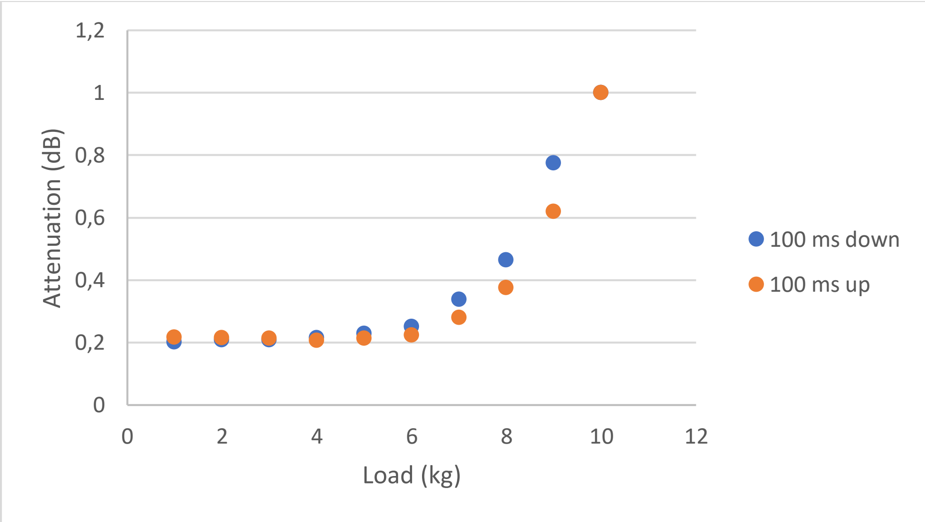
Limitations for Large-Scale Systems were selected. Arduino is excellent for small to medium-scale applications but has limited processing power and memory, which can be a constraint in complex or resource-intensive systems. It may lack the advanced features required for industrial-scale deployments, such as robust networking capabilities and multi-threading. VB is primarily designed for visualization and simulation, which may not fully represent real-time performance in large-scale environments.

RESULTS AND DISCUSSION

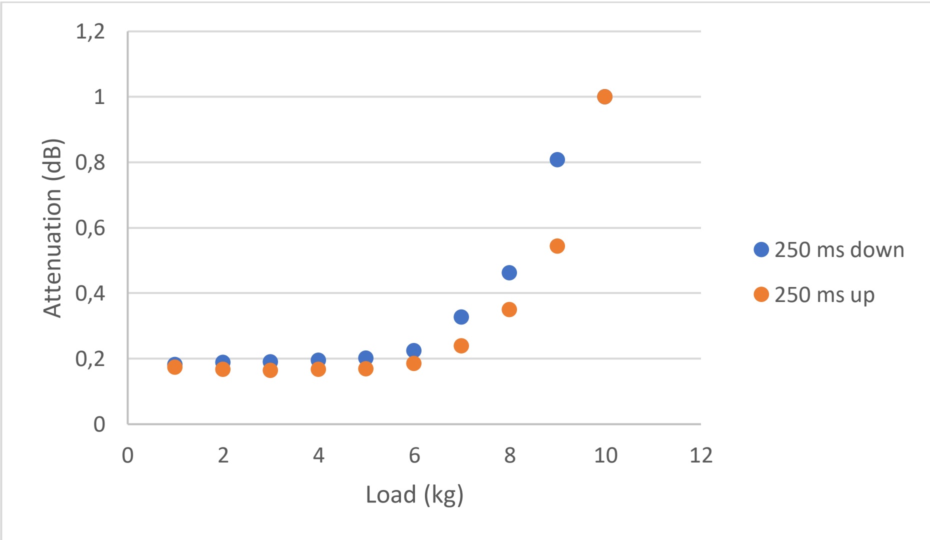
The decrease in voltage data on the WIM system means increased attenuation data on the optical fiber. Testing the research system is a critical stage that must be carried out before data collection. System testing is divided into two parts: load up-down and rapid test. The explanation of each part is described.

The load-up-down system test is carried out by placing the scale load on the fiber optic sensor base. The scale load used is 1 kg up to 10 kg. When in the up condition, the scale load starts from 1 kg to 10 kg, while the scale load used in the down condition starts from 10 kg to 1 kg. The variation used in this test is time in ms units. The time variations are 100 ms, 250 ms, 500 ms, 750 ms, and 1000 ms.

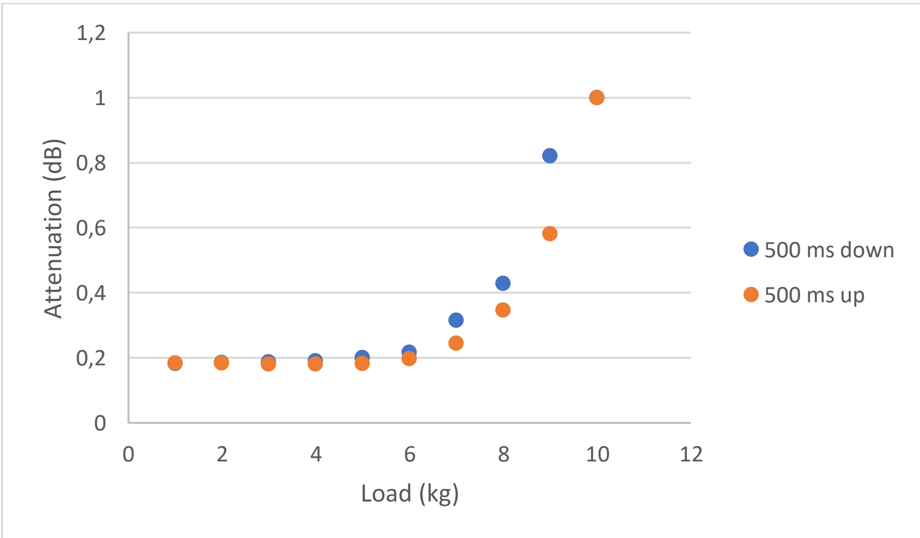
This load-up-down test determines the performance of the fiber optic sensor when subjected to loading by a moving vehicle. The ideal condition for good fiber optic sensor performance is when the up-down data shows the same results. The results of this system test can be seen in Figure 3.


Attenuation (dB)
Load (kg)
100 ms down
100 ms up

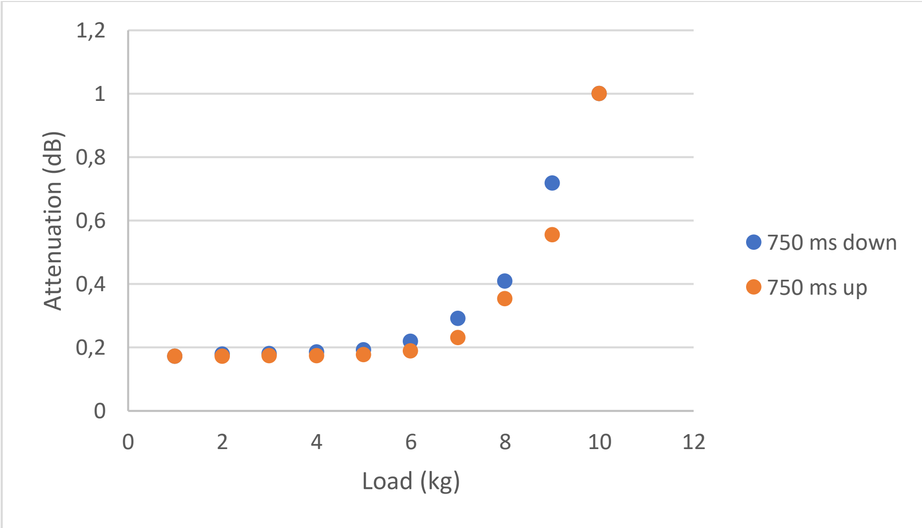
(a)


Attenuation (dB)
Load (kg)
250 ms down
250 ms up

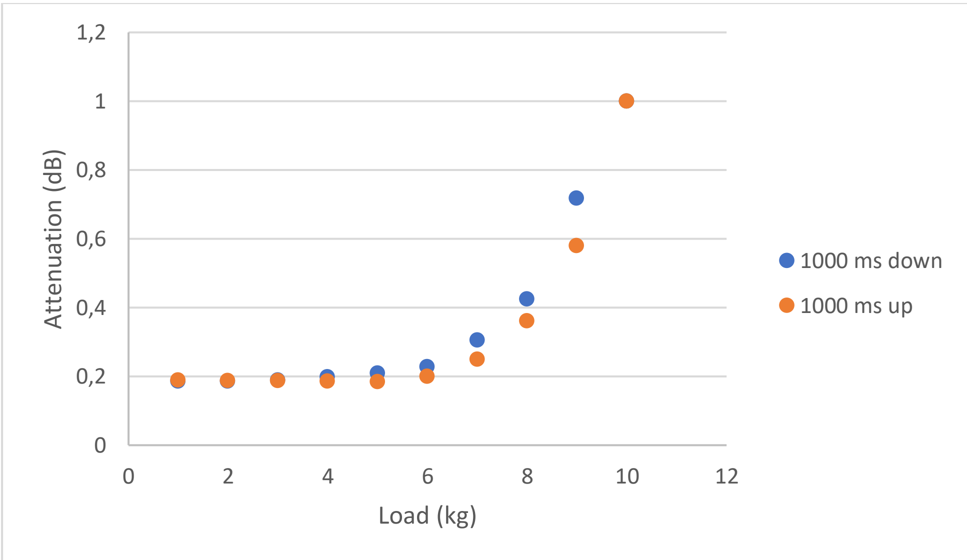
(b)


Attenuation (dB)
Load (kg)
500 ms down
500 ms up

(c)



(d)



(e)

Figure 3. Results of up-down load system testing at time variations: (a) 100 ms; (b) 250 ms; (c) 500 ms; (d) 750 ms; and (e) 1000 ms

Figure 6 shows the results of the up-down load system test at each specified time variation. At time variations of 100 ms and 250 ms, the results show that when the loading conditions are up and down, none of the data are at the same point. Furthermore, at time variations of 500 ms and 750 ms, the trendline graph when the up and down conditions are at the same point is indicated by a load of 1 kg. At time variations of 1000 ms, the up and down conditions at the same point are indicated by loads of 1 kg, 2 kg, and 3 kg.

Up-down data that are not at the same point indicate a correction in the WIM monitoring system. This can occur because the spring's return deflection is not fast enough. Another thing that indicates a correction in the system is the interface, which is less stable when reading the load. Meanwhile, data that shows the same point during up-down conditions indicates that the fiber optic sensor testing system can be used properly. The trendline graph in Figure 6 shows the best performance of the fiber optic sensor system at 1000 ms variation. This is indicated by the presence of the same points during up-down conditions.

The rapid test testing system is a data collection that is carried out quickly. This rapid test is carried out to determine the consistency of data readings from loads carried out repeatedly and quickly. The loads used are 5 kg and 8 kg. The results of the rapid test system testing can be seen in Figure 4.

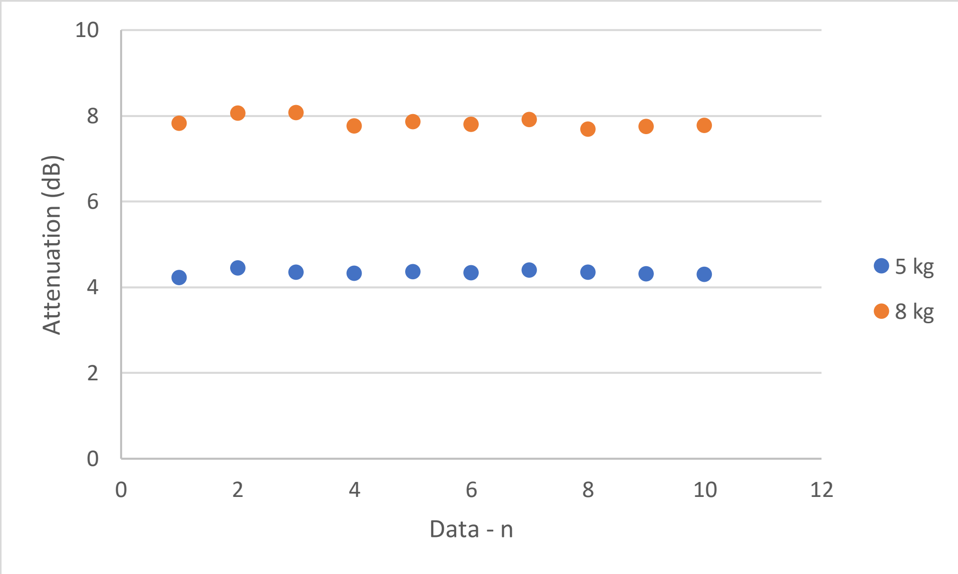


Figure 4. Rapid test results of fiber optic sensor

Figure 4 shows that the 5 kg and 8 kg loads have a stable data consistency trendline. This indicates that the fiber optic sensor system can work well. In addition, 8 kg loading has higher attenuation data than 5 kg loading. This event indicates that the system's fiber optic bending can detect loads with optimal performance.

Our prototype demonstrates efficacy for loads between 1 kg and 10 kg. To address scalability concerns for heavier vehicles are technical enhancements and real-world considerations. Things that are done to improve technical enhancements include high-capacity sensors for implementing industrial-grade fiber optic sensors with increased sensitivity and dynamic range. The second is advanced signal processing for developing algorithms to filter noise, compensate for non-linear responses, and accurately calculate weights. Then, sensor array configurations are used to deploy multiple sensors strategically. The last is robust materials to utilize high-strength materials for sensor housing and road embedding.

Conversely, developing real-world considerations includes field testing to conduct trials with varied vehicle types and weights. Calibration and validation for establishing standardized procedures. Next, integration with existing infrastructure to collaborate with transportation agencies. The last is durability and maintenance to investigate strategies for minimizing maintenance.

By addressing scalability concerns and outlining strategies for real-world implementation, our system can effectively transition from prototype to practical solution for heavy vehicle weight measurement. Future research will focus on refining scalability, accuracy, and durability.

Next is the Anomaly Data Capture sent to the WhatsApp Gateway. The way this system works is that DAQ continuously captures data. Then, the data will be sent to the Internet of Things (IoT) service, namely Blynk and If This Then That (IFTTT). Blynk plays a role in presenting data in visual form, or this case, it is called the web User Interface (UI). This web UI is built using a widget provided by Blynk called a gauge. The function of the gauge is to display historical data in the form of real-time data and graphs. Another service used is IFTTT, the benefit of which is to activate the WhatsApp notification service and connect to a Google spreadsheet. This is useful for storing data sent by the DAQ device. By determining the voltage threshold data, when the voltage received by the DAQ passes the anomalous data criteria, IFTTT requests to send a warning system notification via WhatsApp to the user. This can be seen in Figure 5.

The threshold data in this study was when the load was 6 kg. Figure 3 shows that when there was a load of 6 kg, there was an initial increase in the attenuation value. When the initial increase in attenuation occurs, the system provides a warning in the form of a WhatsApp notification to the user.

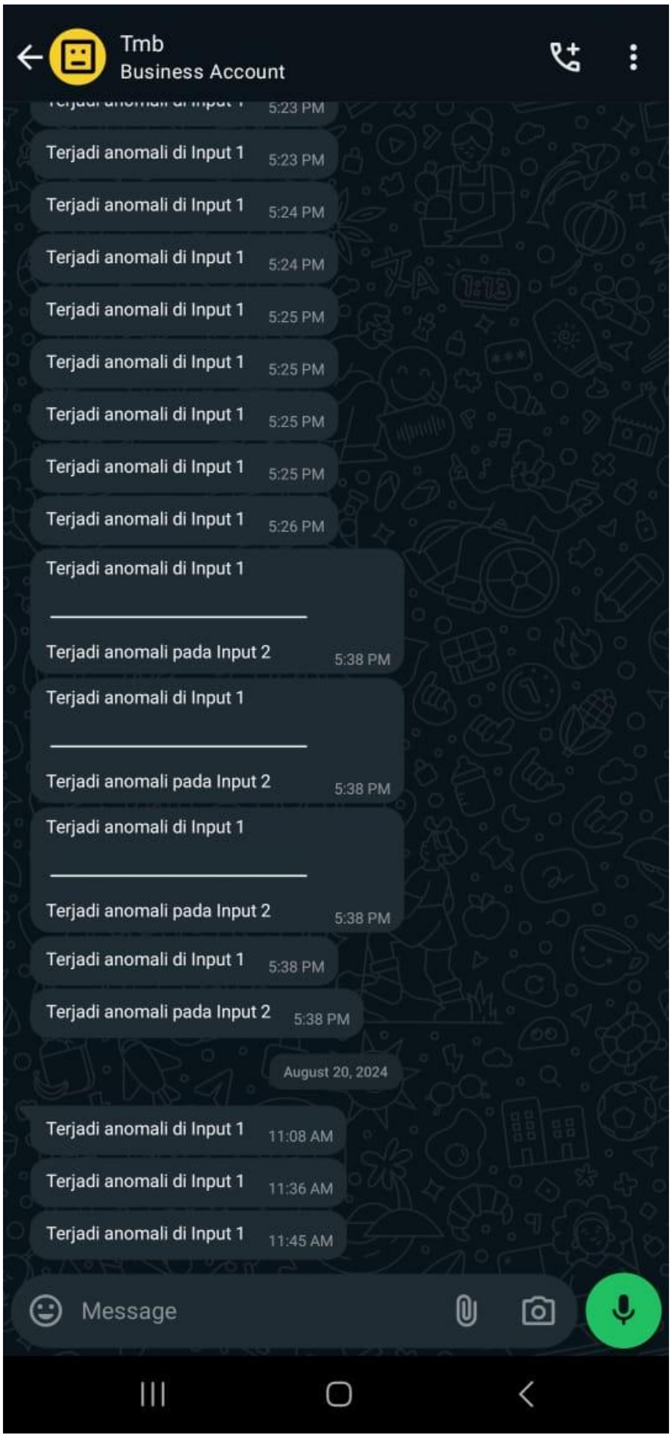


Figure 5. WhatsApp notification indicating that the system detected anomalous data

WhatsApp was selected due to its widespread adoption, user familiarity, real-time message delivery, and cost efficiency. It ensures quick communication without requiring users to adopt new technologies.

Reliability and Safeguards by message delivery and redundancy. Message Delivery Assurance to WhatsApp’s delivery status (sent, delivered, and read receipts) ensures transparency in communication. Redundancy to address potential outages and implement fall back mechanisms such as SMS and email notifications to maintain continuity.

Data privacy and security include the security of WhatsApp messages with end-to-end encryption, ensuring only intended recipients can access the notifications. User data is handled in compliance with data protection standards (e.g., GDPR) and is neither stored unnecessarily nor shared with third parties.

It is important to clarify the system's integration scope, particularly whether it is designed to complement existing road infrastructure, such as traffic lights, road sensors, or communication networks, or to function independently as a standalone solution. This distinction significantly influences adoption strategies and cost considerations. Furthermore, detailed information on the system's installation and operation in real-world conditions should be provided. This includes outlining the installation process, such as the steps for deploying the system, sensor placement, software integration, and required equipment. Compatibility issues should also be addressed, particularly the requirements or challenges of retrofitting existing infrastructure.

Additionally, details on maintenance, such as how the system will be sustained and updated over time, are crucial. Performance in diverse conditions, including urban, rural, or extreme weather scenarios, must be considered to ensure robust functionality. Lastly, if the system leverages existing infrastructure, it is essential to highlight its cost and resource efficiency, demonstrating the benefits of utilizing established frameworks rather than starting from scratch. Integrating these details would enhance the research's practicality and make it more appealing to stakeholders interested in implementation.

Previous studies have indicated that an increase in the loading value on the WIM sensor corresponds to a higher attenuation value [21]. This phenomenon occurs due to disturbances in the light path within the fiber optic core, specifically in the form of macro bending. During macro bending, the angle of light reflection within the fiber optic falls below 90 degrees. As a result, the amount of light captured by the receiving sensor is significantly reduced.

The light sensor utilized in this study is a photodiode, which is integrated into the DAQ device. According to Pires et al., the principle of photodiode light detection involves the photon current received by the photodiode-generating electron-hole pairs. Electrons are directed toward the positive source, while holes migrate to the negative source. This process produces a voltage pulse generated by the photodiode. The greater the photon current (ΣE) received by the photodiode, the higher the number of voltage pulses (ΣV) produced [22]. Consequently, when the light pulses captured by the receiving sensor decrease, the voltage pulses produced also diminish. Conversely, the same principle applies in the opposite scenario.

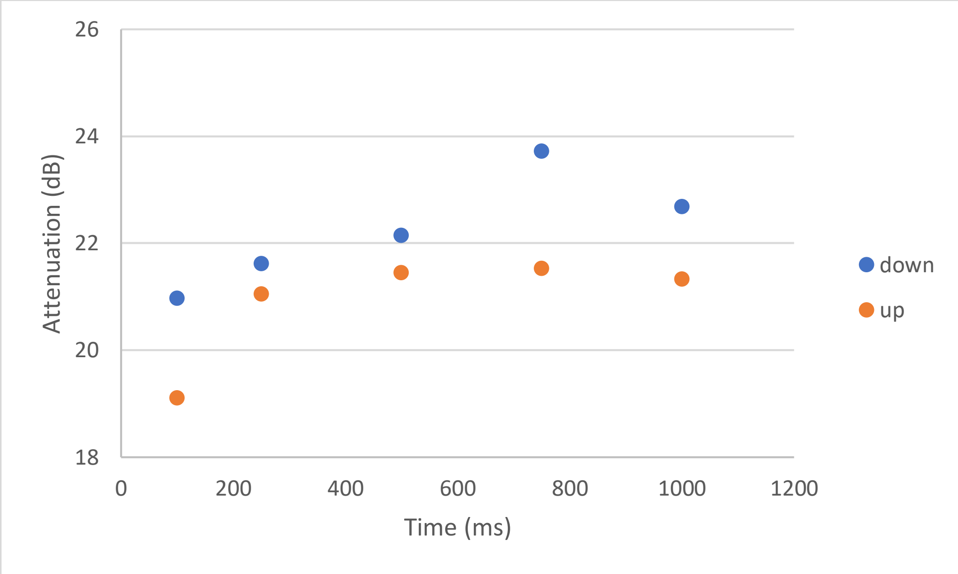


Figure 6. The trendline in scale 10 kg

Figure 6 shows that the longer the loading time crosses the WIM plane, the greater the attenuation value. This case occurs because the longer the loading time on the WIM plane, the longer the macro bending event in the fiber optic. The loading time affects the number of photon pulses received by the photodiode; the fewer photon pulses, the lower the voltage pulse intensity. Based on Equation (1), the light transmittance value is also smaller when the modulation voltage pulse value is small. When the light transmittance is small, the attenuation value is enormous.

CONCLUSION

The real-time WIM monitoring system uses optoelectronic devices, and the WhatsApp gateway communication system can run well. This is indicated by the existence of a system that can detect anomaly data, which can then provide WhatsApp notifications to users. This is evidenced by the data trendline, which shows alignment at the same point during both ascending and descending conditions. Additionally, the threshold data at a load of 6 kg when passing over the fiber optic sensor system can trigger a warning to the user, delivered as a notification on WhatsApp.

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