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Design and Implementation of a Wearable IoT System Based on Time of Flight (ToF) Sensor for Personal Safety Support in Commuter Line Transportation

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ABSTRACTS

The development of Internet of Things (IoT) technology has enabled the implementation of intelligent systems to enhance personal safety in various environments, including public transportation. Commuter Line (KRL) transportation often experiences high passenger density, which may increase the risk of physical collisions and unsafe proximity between passengers. This study aims to design and implement a wearable IoT-based system utilizing a Time of Flight (ToF) sensor for real-time object proximity detection. The proposed system integrates a VL53L0X ToF sensor, an ESP32 microcontroller, a vibration motor, a buzzer, and the Blynk platform for monitoring and notification purposes. A threshold-based detection method combined with time-duration analysis was applied to identify potentially unsafe proximity conditions. Experimental results show that the VL53L0X sensor was able to detect objects within a distance range of 20–60 cm with measurement errors ranging from 0% to 8%, depending on the object characteristics. The system successfully activated warning notifications when objects were detected within the predefined threshold distance, achieving an average response time of 2.02 seconds. False alarm testing demonstrated stable system performance without unintended notification activation when objects were outside the detection threshold. Furthermore, environmental noise testing indicated that sensor performance remained stable under noise levels of 70–90 dB. These results demonstrate that the proposed wearable IoT system can serve as a practical personal safety support solution for users in crowded and dynamic commuter transportation environments.

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1. INTRODUCTION

Public transportation plays an essential role in supporting urban mobility. The Commuter Line (KRL) is one of the most widely used transportation modes in Indonesia due to its high passenger capacity and time efficiency. However, the increasing number of passengers, particularly during peak hours, creates crowded and dynamic environments that may increase the risk of physical collisions and unsafe proximity between passengers. According to public transportation reports, the daily number of KRL passengers exceeded one million users, indicating the high density of commuter transportation environments [1]. Furthermore, KAI Commuter reported that more than 166 million passengers used KRL services during the first semester of 2025, highlighting the increasing demand for commuter rail transportation in Indonesia [2].

The rapid development of Internet of Things (IoT) technology has enabled the implementation of intelligent monitoring systems capable of collecting, processing, and transmitting data in real time [3]. One of the emerging applications of IoT is wearable technology, which allows users to continuously monitor environmental conditions without interrupting daily activities [4]. Wearable devices integrated with sensors can provide immediate feedback and improve user awareness in potentially hazardous situations [5].

Among various distance measurement technologies, the Time of Flight (ToF) sensor has gained significant attention due to its ability to measure object distance accurately by calculating the travel time of infrared light signals. Compared with conventional distance sensors, ToF sensors offer higher accuracy, faster response times, and better stability in dynamic environments. These characteristics make them suitable for proximity monitoring applications in crowded public spaces [6].

Several previous studies have explored the use of ToF sensors in safety and monitoring systems. Wei et al. developed a ToF-based fall detection system for elderly monitoring, while Hsu et al. proposed a spatial-temporal correlation approach to improve detection reliability in dynamic environments [7], [8]. Other studies have applied proximity detection systems in industrial safety applications [9]. However, most previous research has focused on healthcare and industrial environments rather than personal safety support systems in public transportation settings.

Therefore, this study proposes a wearable IoT-based proximity detection system utilizing a VL53L0X Time of Flight sensor, an ESP32 microcontroller, vibration and audible warning actuators, and the Blynk platform for real-time monitoring. The system employs a threshold-based detection method combined with duration analysis to identify potentially unsafe proximity conditions. The proposed system is expected to support personal safety and increase user awareness in crowded and dynamic commuter transportation environments.

2. MATERIALS AND METHODS

2.1 System Design

The proposed wearable IoT system consists of a VL53L0X Time of Flight (ToF) sensor, an ESP32 microcontroller, a vibration motor, a buzzer, a Li-Po battery, and the Blynk application. The system is designed to detect the proximity of surrounding objects in real time and provide warning notifications to the user when potentially unsafe conditions are detected [6].

The VL53L0X sensor continuously measures the distance between the user and nearby objects. The measured data are transmitted to the ESP32 microcontroller for processing using a threshold-based detection method combined with time-duration analysis. The system employs a threshold distance of 30 cm and a minimum detection duration of 2 seconds to determine whether a proximity condition should be classified as a warning event.

When an object is detected within the predefined threshold distance for at least 2 seconds, the ESP32 activates the vibration motor and buzzer as warning actuators. At the same time, distance data and system status information are transmitted to the Blynk platform through Wi-Fi communication, enabling real-time monitoring via a smartphone application [10].

The overall architecture of the proposed wearable IoT system is illustrated in Figure 1.

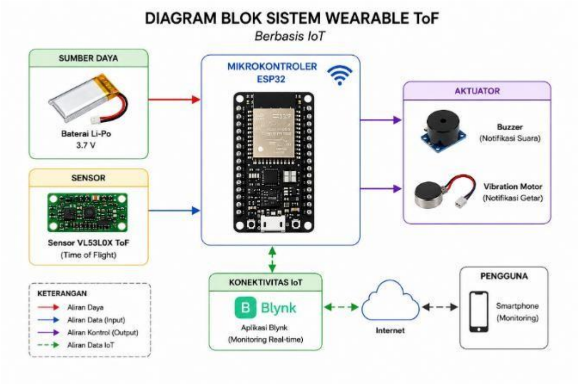

Figure 1. System Architecture of the Proposed Wearable IoT System

2.2 Testing Procedure

Several testing scenarios were conducted to evaluate the performance and reliability of the proposed wearable IoT system. The tests focused on sensor accuracy, response time, false alarm performance, and environmental noise resistance.

Sensor accuracy testing was performed by placing various objects at distances of 20 cm, 30 cm, 40 cm, 50 cm, and 60 cm from the VL53L0X sensor. The measured distances were compared with the actual distances to determine the measurement error.

Threshold and response time testing were conducted using a threshold distance of 30 cm and a minimum detection duration of 2 seconds. The objective of this test was to evaluate the system's ability to activate warning notifications and determine the response time between object detection and actuator activation.

False alarm testing was performed by positioning objects beyond the predefined threshold distance. The purpose of this test was to verify that the system did not activate warning notifications under normal conditions.

Environmental noise testing was carried out under two different conditions: a normal environment with noise levels of 55–60 dB and a noisy environment with noise levels of 70–90 dB. This test aimed to evaluate the stability of sensor measurements and notification performance in conditions that simulate crowded public transportation environments.

3. RESULTS AND DISCUSSION

3.1 System Implementation

The proposed wearable IoT system was successfully implemented using an ESP32 microcontroller, a VL53L0X Time of Flight sensor, a vibration motor, a buzzer, and a Li-Po battery. The hardware prototype of the developed wearable device is shown in Figure 2.

The VL53L0X sensor continuously measures the distance between the user and surrounding objects. Distance data are processed by the ESP32 and transmitted to the Blynk platform via Wi-Fi communication. When the measured distance remains below the predefined threshold of 30 cm for at least 2 seconds, the system activates the vibration motor and buzzer as warning mechanisms.

The monitoring interface developed using the Blynk platform is presented in Figure 3. The application displays real-time distance measurements and system status notifications, allowing users to monitor proximity conditions remotely through a smartphone.

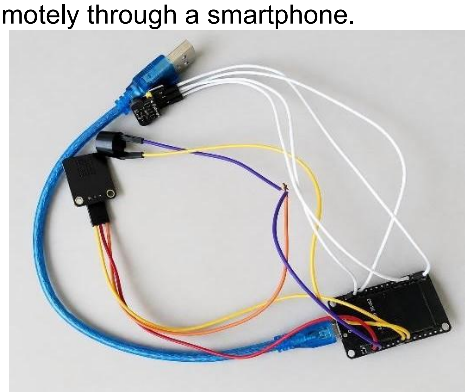

Figure 2. Implementation of the Proposed Wearable IoT System

Figure 3. Real-Time Monitoring Interface on the Blynk Application

3.2 Sensor Accuracy Testing

Sensor accuracy testing was conducted to evaluate the performance of the VL53L0X Time of Flight sensor in measuring object distances under different conditions. The experiments were performed at distances of 20 cm, 30 cm, 40 cm, 50 cm, and 60 cm using three different object materials, namely a bag, clothing, and hand skin.

The experimental results indicate that the sensor was able to measure object distances with satisfactory accuracy throughout the tested range. As presented in Table 1, the measurement error varied depending on the object characteristics. The lowest error was observed for bag objects, while clothing generally produced larger errors due to differences in infrared light reflectivity.

At a distance of 40 cm, the sensor demonstrated stable performance with measurement errors ranging from 0% to 4%. Furthermore, the sensor remained capable of detecting objects at distances up to 60 cm, where the maximum recorded error was 6%. These results indicate that the VL53L0X sensor provides sufficient accuracy and stability for real-time proximity monitoring applications in wearable IoT systems.

The variation in measurement error can be attributed to differences in material properties that affect the reflection of infrared signals emitted by the sensor. Nevertheless, all tested objects were successfully detected within acceptable error limits, demonstrating the suitability of the sensor for proximity detection in crowded public transportation environments.

Table 1. Average Measurement Error of the VL53L0X Sensor at Different Distances

Distance (cm)	Average Error (%)
20	8.0
30	5.3
40	2.0
50	3.0
60	2.7

As shown in Table 1, the average measurement error ranged from 2.0% to 8.0% across the tested distances. The lowest error was observed at 40 cm, while the highest error occurred at 20 cm. Overall, the VL53L0X sensor demonstrated stable and reliable performance within the 20–60 cm measurement range, indicating its suitability for wearable proximity detection applications.

3.3 Threshold and Response Time Testing

Threshold and response time testing was conducted using a threshold distance of 30 cm and a minimum detection duration of 2 seconds. The summarized results are presented in Table 2. The system successfully activated the vibration motor and buzzer in all testing trials when an object remained within the specified threshold. The average response time was 2.02 seconds, with values ranging from 2.00 to 2.04 seconds. These results indicate that the proposed system is capable of providing consistent and timely warning notifications while maintaining stable proximity detection performance.

Table 2. Threshold and Response Time Testing Results

Parameter	Value
Threshold Distance	30 cm
Detection Duration	2 s
Average Response Time	2.02 s
Response Time Range	2.00–2.04 s
Notification Success Rate	100 %

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3.4 False Alarm Analysis

False alarm testing was conducted by positioning objects beyond the predefined threshold distance of 30 cm. The results of the false alarm testing are presented in Table 3. During all testing trials, the system did not activate the vibration motor or buzzer when objects were located outside the detection area. These results indicate that the proposed system is capable of maintaining stable operation and effectively preventing false alarm events under normal conditions.

Table 3. False Alarm Testing Results

Parameter	Value
Number of Trials	10
Object Distance	> 30 cm
Notification Activation	No
False Alarm Occurrence	0

3.5 Environmental Noise Testing

Environmental noise testing was conducted to evaluate the stability of the proposed system under different noise conditions. The testing results are presented in Table 4. The VL53L0X sensor produced consistent distance measurements under both normal (55–60 dB) and noisy (70–90 dB) environments. In addition, the warning notification system operated according to the predefined threshold conditions in all testing scenarios. These results indicate that environmental noise does not significantly affect the performance of the proposed wearable IoT system.

Table 4. Environmental Noise Testing Results

Noise Condition	Noise Level (dB)	Sensor Performance	System Status
Normal	55–60	Stable	Operated Normally
Noisy	70–90	Stable	Operated Normally

4. Discussion

The experimental results demonstrate that the proposed wearable IoT system is capable of providing reliable proximity detection in crowded transportation environments. The VL53L0X sensor exhibited stable measurement performance within the tested range, with measurement errors remaining within acceptable limits for wearable safety applications.

The implementation of a threshold-based detection method combined with a 2-second duration parameter improved the reliability of the system by preventing warning notifications from being triggered by temporary object movements. This behavior was further confirmed through false alarm testing, where no unintended notification activation was observed.

In addition, environmental noise testing showed that the performance of the VL53L0X sensor remained stable under noise levels of up to 90 dB. Since the sensor operates using infrared light rather than acoustic waves, its performance is not significantly affected by surrounding noise conditions. This characteristic makes the proposed system suitable for use in public transportation environments such as commuter trains, where high noise levels are commonly encountered.

Overall, the integration of IoT monitoring, wearable technology, and ToF-based proximity detection provides a practical solution for improving personal safety awareness in crowded and dynamic transportation environments.

5. CONCLUSION

This study successfully designed and implemented a wearable IoT-based proximity detection system utilizing a VL53L0X Time of Flight sensor, an ESP32 microcontroller, a vibration motor, a buzzer, and the Blynk platform for real-time monitoring. Experimental results showed that the sensor was capable of detecting objects within a distance range of 20–60 cm with acceptable measurement accuracy. The proposed system successfully activated warning notifications when objects were detected within the predefined threshold distance of 30 cm for at least 2 seconds, achieving an average response time of 2.02 seconds. In addition, false alarm testing demonstrated stable system performance without unintended notification activation, while environmental noise testing confirmed that the sensor remained stable under noise levels of up to 90 dB. These results indicate that the proposed wearable IoT system can serve as a practical solution for supporting personal safety awareness in crowded public transportation environments.

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