Vicinity Monitoring of Military Vehicle Cabin to Improve Passenger Comfort with Fusion Sensors and LoRa RFM95W

Wildan Muhammad Yasin Fadillah [1], Giva Andriana Mutiara [2*], Periyadi [3], Muhammad Rizqy Alfarisi [4], Lisda Meisaroh [5]
[1, 2, 3, 4, 5] Department of Applied Science, Universitas Telkom, Bandung, Indonesia
Email: [1] wildanmyf@student.telkomuniversity.ac.id, [2] givamz@telkomuniversity.ac.id, [3] periyadi@telkomunivesity.ac.id, [4] mrizkyalfarisi@telkomuniversity.ac.id, [5] lisdameisaroh@telkomuniversity.ac.id
*Corresponding Author

Abstract—**The application and utilization of technology to measure the level of comfort in mass-produced vehicles, including military vehicles, is constantly evolving. Currently, the testing of comfort parameters is carried out manually through human-driven test drives. Thus, the range of variability in measurements is extensive as it depends on the subjective experiential indications of experts. This research utilizes KY-037 sensor to measure noise level and BME280 sensor fusion to detect temperature, air pressure, humidity, and altitude. These parameters have a significant impact on passenger comfort inside the passenger cabin of military vehicles. This project included involves the development of LoRa-based communication medium using RFM95W technology. The system has extensive performance testing inside the passenger cabin of a military vehicle on various test area tracks. The test results indicate that the system is capable of accurately reading the KY-037 sensor, with a range of 80 - 141 dB depending on the tracks. The BME280 sensor consistently measures a temperature of 36,98°C, altitude readings ranging from 667-677 meter above sea level, maintaining a stable air pressure of 955.35 hPa, and measuring the lowest humidity level in the vehicle cabin at 24.34%. The LoRa technology possesses remarkable to extend the communication range, even in challenging environments, reaching distances over 2 kilometers. The response time for data sent in web-based applications consistently remains below 1 second. Thus, this system can assist experts in enhancing cabin passenger comfort standards by narrowing the range and making it more measurable.**

Keywords—BME280; Military Vehicle; Long-Range RFM95W; Real-Time; Vicinity Detection; Vehicle Cabin; Web-Based Application; Humidity; Air Pressure; Altitude; Communication.

I. INTRODUCTION

The application and utilization of comfort level measurement technology in a vehicle is crucial for both public vehicles and military vehicles made of steel that provides protection and is equipped with weapons [1]. These military vehicles are designed to be as robust as possible while still providing certain human comfort parameters, even when used in hazardous terrain.

Prior to deployment, military vehicles undergo a series of rigorous testing procedures. In addition to rigorous external testing to assess the durability of the armored vehicle, it is also crucial to evaluate internal factors that impact the safety and comfort of the passengers and drivers. Testing various parameters is necessary, including sound, temperature, humidity, altitude, and pressure [2]-[4].

Currently, the evaluation of military vehicle vehicles has been conducted by highly knowledgeable experts who possess extensive experience in assessing the internal aspects of military vehicles. However, this testing has challenges due to the diverse measurement resulting from differences in experiential factors and institutions backgrounds of various experts. Therefore, in order to enhance the measurement of parameters within these internal factors, it is crucial to utilize measuring instruments in the form of sensors that can assist experts in assessing and ensuring the value of parameters derived from internal factors, thereby improving measurement accuracy and consistency [5], [6].

Evaluating the noise levels in a military vehicle is an important criterion to assess the sound intensity in decibels. This testing is necessary because it is crucial to ensure that the level of noise in military vehicles remains below acceptable limit. Failure to do so can result in a potential decrease in auditory ability, either temporary or permanent [7]-[10]. It is essential to conduct tests on the temperature, pressure, and humidity parameters since the internal factors of the vehicle must be within the normal range of body temperature $20^0 – 25^0$ C [11]. It is important to maintain the humidity level of a vehicle within the range of 30%-50% to ensure ideal conditions [12]. It is also crucial to measure the elevation or altitude, and the gradient of military vehicles to determine their orientation. It is important for ensuring that passengers do not experience confusion when riding the vehicles [13].

To enhance the reliance of military vehicle operations based on test results, it is crucial to develop a real-time data system. This will enable accurate monitoring and storage of data results [14]. The previous documentation and data retrieval process could only be performed manually and lacked real-time capabilities. Data retrieval can only be performed after the completion of testing, similar to blackbox [15]. Therefore, the achieved results are not effective. Furthermore, after the completion is finished, it is possible to process new data that cannot be directly observed and processed for data retrieval.

Currently, there are various wireless data transmission devices available, including Wi-Fi [16], [17], Z-Wave [18], Zigbee [19], NB-IoT [20], and LoRa [21]. LoRa provides a very efficient and extensive data transmission range, resulting in significant cost savings [22], [23]. LoRa can also be utilized in challenging environments, including situations with thick walls and steel obstacles [24]-[26].

Based on the information provided above, there is a gap in the lack of a device to measure passenger comfort based on internal factors of military vehicles. Therefore, this research is developed to assist professionals in evaluating internal factors of military vehicle. This research aims to create a device that can function to measure comfort parameters automatically, such as noise level detection, temperature, humidity, air pressure, and altitude. This system can provide a measurable comfort range, minimize the testing range for experts, and offering the benefit of a reference range of comfort values when dealing with experts. Furthermore, the monitoring process and test results can be conveniently stored in the cloud, allowing for easy access and future reference. This research also has practical contributions in testing the internal factors of military vehicles to provide information for decision-making regarding the safety and comfort of military vehicles according to standards [1], [27], [28] while minimizing associated risks.

The device used for this research is the LoRa RFM95W, which will function as a communication medium to transmit data from various types of sensors. LoRa is recommended to address the limitations of using WIFI in military vehicles that are mostly armored and cause limited signal transmission rates. The sound sensor utilized for detecting loud sounds in military vehicles is the KY-037 [29]. In addition, a sound meter detector is employed to calibrate and compare the measurements obtained from the KY-037. Meanwhile, BME280 sensors [30], [31] is utilized to facilitate temperature, humidity, pressure, and altitude measurements. All measurement values will be calibrated according to the provided reference standards in the literature review section. The monitoring system that will be obtained on the monitoring dashboard will be presented through a web-based interface. This will facilitate experts in analyzing real-time testing data.

In addition, this research will be presented as follows. In chapter two, the author delves into the related work and research methodology, providing a comprehensive overview and focuses on the intricate details of the system design. Chapter three provides a comprehensive analysis of the test results, while chapter four presents the conclusions and future works.

II. Research Methodology

A. Methodology

This research was conducted using a collaborative research and development methodology to create a prototype. The process entailed doing comprehensive literature reviews, designing and developing a prototype, constructing prototypes and an integrated system, performing tests and analysis, and drawing conclusions based on the results of the analysis as depicted in Fig. 1. All stages are explained in detail in each subsequent subsection.

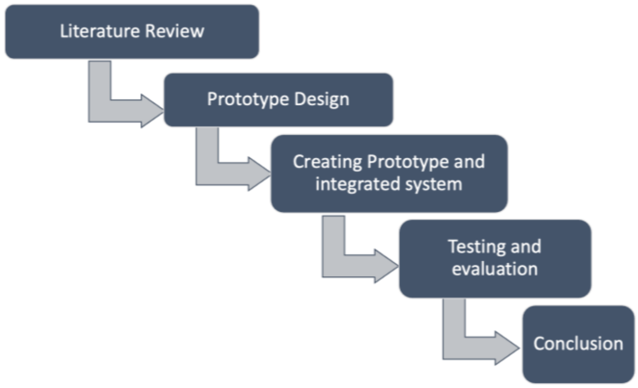

Fig. 1. Research methodology

B. Methodology

Prior to delving into the proposed system modeling in this research, it is crucial to conduct a comprehensive review of the existing literature and relevant studies. Literature study would explore the research conducted by previous scholars in the same field. The findings from the literature review will serve as the foundation for the innovation and development of the system created in this research.

The literature study encompasses various aspects of the fundamental framework of the proposed system. This encompasses research on the utilization of sound sensors for noise detection, integration of sound sensors, temperature, humidity, altitude, and pressure detection, as well as the implementation of LoRaWAN as a cost-effective, energy-efficient, and versatile communication medium for data transmission. Furthermore, a comprehensive review is conducted on relevant research in the field of military vehicles, specifically focusing on the internal factors of the passenger cabin.

Sound sensors are commonly used to detect noise. The sound sensor plays a crucial role in detecting and measuring noise levels inside military vehicles. A sound sensor is capable of detecting sound signals and converting them into decibels (dB) [32]. In sound level detection, there is a threshold of volume that is considered comfortable for the human ear to perceive [33], [34], as illustrated in Fig. 2.

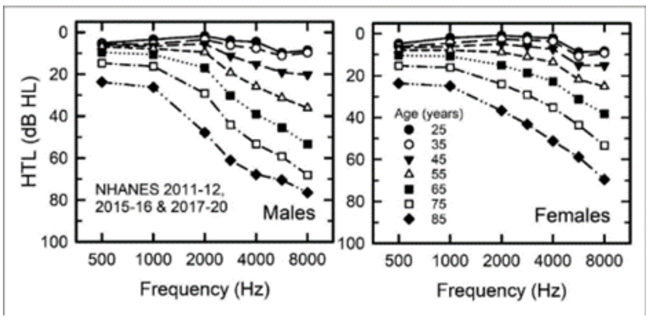

Fig. 2. Hearing threshold level range

According to Fig. 2, it is proven that the permissible noise level is approximately 80dB [35]. Therefore, this sensor has potential to prevent hearing impairments either temporarily or permanently [36]. The commonly used sound sensor is the KY-037 sensor. This sensor is also utilized to measure aircraft noise in residential areas [37], resulting in a 5%

discrepancy compared to measurements obtained with a sound sensor [38], [39]. Furthermore, this sensor was utilized to assess the level of noise in the library of a university in Panama [40]. In this study, five sound sensors were compared using the LM393 mic. The results indicate that the KY-037 sensor outperforms the others in detecting sound.

To identify additional internal factors like temperature, humidity, pressure, and altitude, a single integrated sensor can be used is the BME280 sensor. By incorporating the BME280 sensor, it becomes possible to measure temperature and humidity levels, which are crucial factors in monitoring the internal environment of a vehicle [41]-[43]. If the temperature is excessively high and the humidity falls within the dry or humid range in military vehicles, it can lead to discomfort and negatively impact the health of users, particularly in terms of virus transmission [44], [45], [46]. Humidity measurements can have an impact on the interior of the car, potentially leading to damage or disruption [47]-[49].

Measuring altitude parameters while driving is crucial for optimizing fuel efficiency and ensuring compatibility with new vehicle systems [50], [51]. The calculation of air pressure within a vehicle is crucial to provide appropriate air circulation and overall comfort [52], [53].

There are numerous studies that support the utilization of the BME280 sensor. One example is the implementation of a weather station to monitor air quality and compare it to BMKG measurements [54]-[57], or the utilization of temperature prediction in conjunction with IoT [58]. Furthermore, BME sensors have the capability to detect airflow by analyzing the ambient environmental variables [59]. The utilization of the BME 280 integrated sensor simplifies the circuit implementation by eliminating the need to use sensors from numerous modules.

In addition, it is essential to comply with precise criteria standards when conducting military vehicle testing. The continuous monitoring of the vehicle in real-time involves the acquisition of current data [60]. Thus, a device is required to transmit all data to the control center using IoT technology.

The data communication media utilized for monitoring all testing metrics leverages LoRaWAN technology. LoRaWAN technology is extensively utilized in rural areas that lack WIFI network coverage [61]-[63]. Considering the extensive data range and diverse terrain, including areas with restricted signal connectivity availability [64]. LoRaWAN technology provides considerable gain in terms of data transmission and power efficiency [65]-[67].

LoRaWAN technology is commonly utilized for Internet of Things (IoT) devices like smart homes [68]-[70]. Agricultural monitors have using LoRa to monitor the progress of agricultural produce [71]. The LoRa RF95W was employed to monitor microclimate variables in the environment, effectively transmitting data for a duration of more than two years [72]-[75].

Based on the literature review analysis this research proposes the development of a system that can assist experts in assessing the internal comfort parameters of the passenger cabin particularly for military vehicles. This system would involve embedded sensors that are integrated with a monitoring system, providing a realistic scientific contribution that may be implemented in a real environment.

C. Design and Proposed System

After doing a comprehensive literature review, the next step is to proceed with the design of the proposed system. Fig. 3 displays the block diagram of the proposed system.

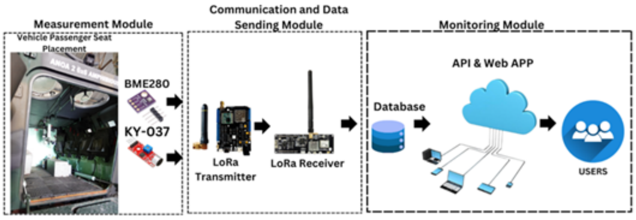

Fig. 3. Block diagram of the proposed system

Fig. 3 presents the block diagram of the proposed system, consisting of three modules: measurement module, data transmission/communication module, and monitoring module. The measurement module is designed to detect and analyze the internal parameters of the passenger cabin environment. As previously mentioned, the measurement module incorporates the KY037 and BME280 sensors, which are creating a fusion sensor to detect the five comfort factors in military vehicles.

The KY037 sensor is chosen for its ability to detect the noise levels inside military vehicles, while the BME 280 sensor is preferred for its powerful sensing capabilities. The sensor is utilized to detect temperature, humidity, air pressure, and altitude from within the military vehicle.

At the implementation stage, the measurement module is then integrated into a military vehicle and positioned in the passenger cabin at a height of 120 cm from the vehicle floor. The device is positioned at height that is precisely calibrated to match the typical hearing level of a person seated in a passenger cabin. This guarantees enhanced precision I carrying out tests that accurately reflect real environmental conditions.

Furthermore, the data communication module is positioned at both the transmitter and receiver side. This module serves as an intermediary between the measurement module and the monitoring module. The selected module is the LORA RFM95W module. This module is used as a communication medium as a transmitter to deliver data that has been successfully sensed in the measurement module area, and as a receiver to receive and interpret sensing data in the monitoring module. As previously mentioned, the LORA RFM95W was selected for its durability, robustness and resilience in transmitting radio frequency signals in the steel-covered areas, or remote locations beyond the range of WIFI signals that challenge data transmission.

Fig. 4 illustrates the module responsible for data transmission and communication. Fig. 3 depicts the peer-to-peer (P2P) LoRa data transmission where the receiver is installed outside the military vehicle. The system installed in the passenger cabin of a military vehicle features a microcontroller connected to a sensor, as well as a LoRa device that enables the transmission of sensor data on a Peer-to-Peer basis [76].

By utilizing peer-to-peer technology, the efficiency of data transfer in the remote testing range can be enhanced. This is achieved through the utilization of the LoRa Transmitter module device in the passenger cabin, which is connected to various sensors on the microcontroller. The data is subsequently received by the LoRa Receiver module in the testing area.

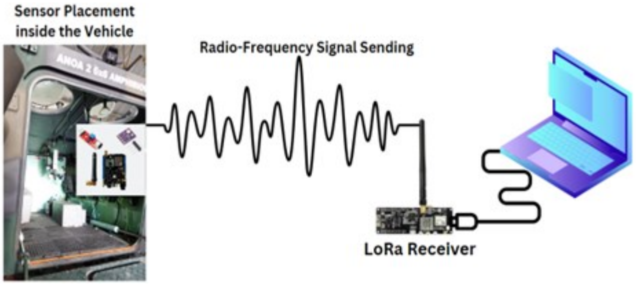

Fig. 4. P2P communication module

The final module is the monitoring module, which is an application accessible through a web interface. The display in this monitoring module is web-based and linked to a SQL database and a specialized API for translating data acquired from the measurement module. Fig. 5 depicts the design of the monitoring module, which allows the monitoring center to observe alterations in the data. Real-time monitoring includes parameters such as temperature, humidity, noise, pressure, and altitude. The web interface has the capability to display data in either numerical or graphical form, facilitating in the comprehension and analysis of the information.

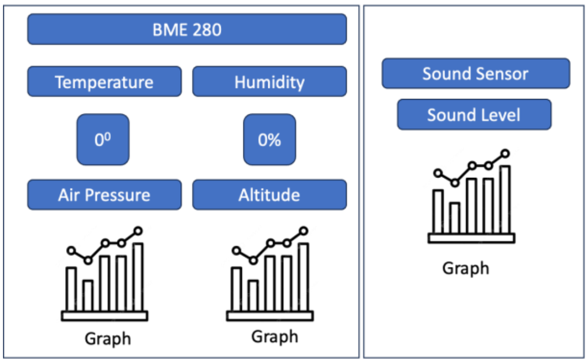

Fig. 5. Design of monitoring system module

After the block diagram has been explained, the subsequent task is to provide a detailed description of the functioning of the proposed system. The functionality of the proposed system is illustrated in Fig. 6.

The system initiates its operation when electricity is supplied to the microcontroller. The initial LoRa configuration is considered finished once it is successfully connected and ready for operation. Afterwards, the system continues with the sensor initialization. If the sensor is detected, the sensor reading loop will be activated from task core 0 to begin detecting the sound level. If the sound level exceeds 85 dB, the buzzer will emit a sound, and the speed of the sound range will escalate. Subsequently, the primary loop will initiate the reading of the BME280 sensor. After acquiring the measurement data, the task data will be transmitted over the LoRa module using a peer-to-peer method. The loop procedure will be terminated when power is no longer supplied to the microcontroller. All data recorded by the Lora receiver can be accessed on the monitoring dashboard, accessible through a web-based application.

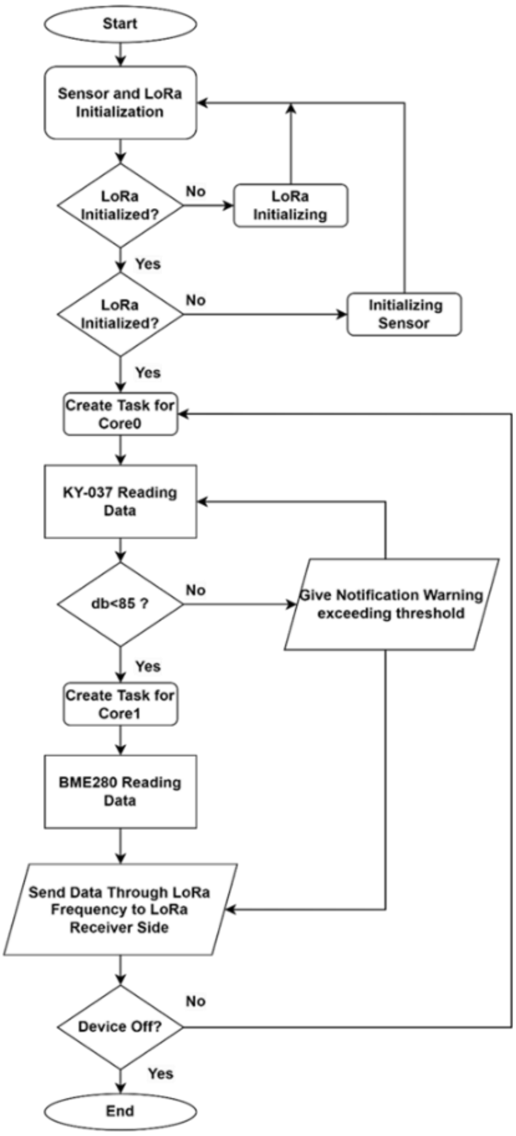

Fig. 6. Flowchart of the proposed system

III. RESULT AND DISCUSSION

Following the prototyping section, the subsequent step is to perform testing on the system prototype. The proposed system will be subjected to testing with various scenarios to assess the performance of the measurement system module, LoRa RFM95W communication media module, and monitoring system module.

Testing is conducted in a dedicated battle training track area that provides several tracks for military vehicle travel. The measurement system is positioned in the passenger cabin, elevated 1.2 meters above the floor of the military vehicle. The monitoring receiver is installed in the supervisory control room, which is 100 meters away from the battle training track area. It has the capability to cover a distance of more than 2 kilometers, as shown in Fig. 7. The testing situation is depicted in Fig. 7 below.

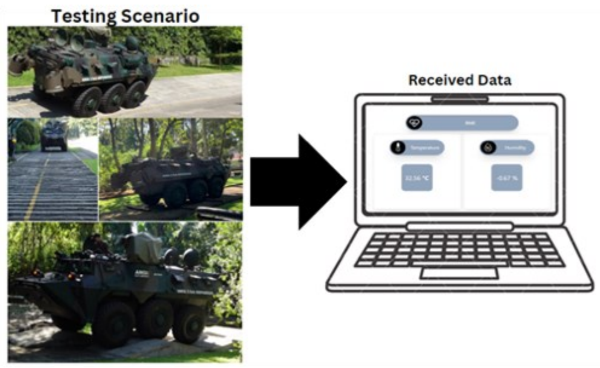

Fig. 7. Testing scenario

The initial test conducted aimed to assess the efficacy of LoRa communication medium. This experiment was carried out to determine the maximum distance across which data may be transmitted between the LoRa transmitter and receiver. The purpose of this experiment was to assess the data transmission performance of the system in several terrains, including parallel beam, sine wave type 1, sine wave type 2, and a slope of 30^0. The proposed detection system is then placed in the passenger cabin of a military vehicle, as previously explained. The enclosed armored military vehicle departs the control center and travels at varying speeds ranging from 10 km/h and 40 km/h along specified warfare training routes.

Fig. 8 displays the graph represents the results of the LoRa performance test carried out along the track, covering distances from 100 meters to 2000 meters. The test was conducted using the line-of-sight (LOS) and non-line-of-sight (non-LOS) methods on the military training track area. LOS testing is performed by systematically opening all the windows and door of military vehicles. In contrast, all the military vehicle's windows and access doors are closed during non-LOSS situations. Therefore, the vehicle's armor layer will block the signal.

During the testing phase, the results may vary based on factors such as the terrain, obstacles, and range. Challenges arise from various structures in the training track vicinity and the fortified steel wall of the military vehicle. In line-of-sight (LOS) settings, the monitoring center receives a consistent, robust, and reliable RSSI signal intensity, which varies depending on the distance. The signal strength remains consistently excellent, with the lowest value of -115 dB seen for distances more than 2000 m.

However, in non-line-of-sight (non-LOS) the test findings indicate that, over distances more than 2000 meters, the detection system data may still be properly received at the control center even in the presence of an RSSI signal strength as low as -120 dB. Therefore, in this test, it can be stated that the signal on the LoRa is not greatly affected even though all doors and windows on military vehicles are closed. The tests of the transmitter and receiver were only discontinued after the distance exceeding 2200 m for non-LOS, and 3000 m for LOS environment. According to this analysis, loRa can address the issue of transmitting data that is restricted by WIFI signals. This capability can assist the control center in monitoring the passenger cabin environment. To expand the observation range, it is possible to deploy gateway points strategically as relays to enhance the radio frequency signal transmitted by LoRa.

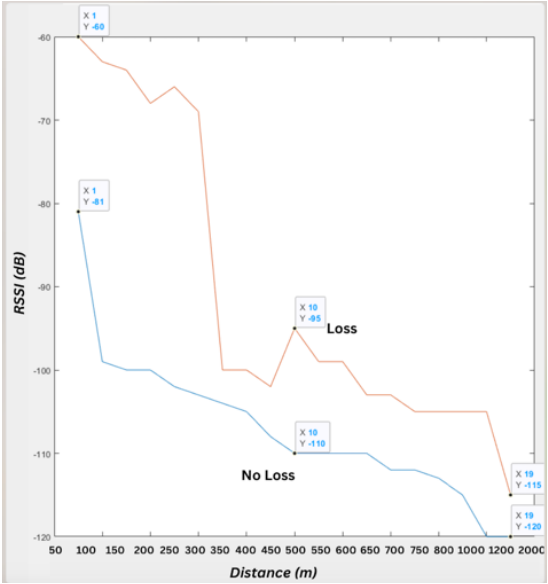

Fig. 8. LoRa RSSI experiment result

Afterward, the test proceeded to evaluate the efficacy of the KY-037 sound sensor. During this test, the military vehicle was operated at speeds ranging from 10km/h to 40km/h on various tracks within the warfare training test area, as depicted in Fig. 8 earlier. The graph in Fig. 9 depicts the test results obtained from the KY-037 sensor.

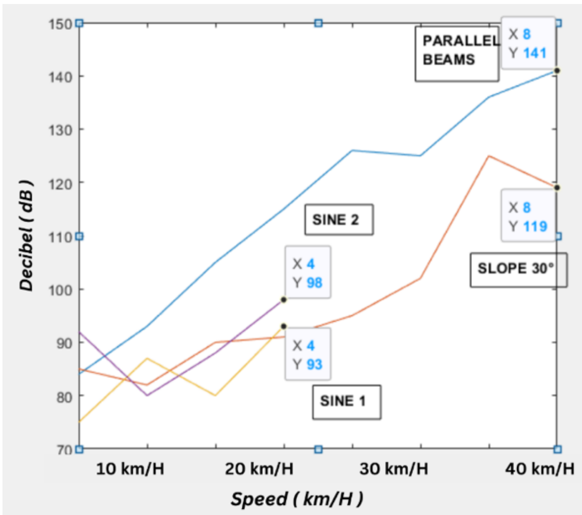

Fig. 9. KY-037 experiment result

The graph in Fig. 9 illustrates demonstrates the proficiency of the KY-037 sensor in detecting sound and converting it into decibel (dB) unit. The sensor is strategically positioned at a height of 120 cm from the vehicle's floor, ensuring that noise data is collected in alignment with the passenger's ear level when seated in the cabin. The sensor is capable of detecting noise levels ranging from 60 dB to 141 dB in the passenger cabin. The parallel beam track exhibits the highest degree of noise due to the ability of military vehicles to achieve speeds of up to 40 km/h. This results in elevated engine noise and noise levels reaching up to 141 dB.

Regarding sine routes 1 and 2, the level of noise generated is relatively insignificant. This is due to the varying heights of the track, which necessitates military vehicles to operate at slower speeds of 10-20 km/hour. The source of noise in military vehicles arises from the engine and the sounds generated by passengers. However, the excessive noise and high decibel levels within military environment can potentially cause a decrease in passengers' hearing sensitivity if it continues and potentially leading to future hearing loss. Tracks exhibiting significant vibration waves might experience an extreme rise in sound vibration.

According to the test results, it can be inferred that detecting noise in military vehicles can offer valuable information to experts for analysis and decision-making. This information can guide the development of measures to reduce the noise level, ensuring that it remains below the necessary threshold.

The subsequent examination entailed the utilization of the BME-280 sensor. The BME-280 Sensor is tested on military vehicles operating at speeds ranging from 10 km/h to 40 km/h on various tracks within the war exercise test area, similar to the testing of the KY-037 sensor. The BME-280 testing will be demonstrated for each parameter identified by the BME-280. A comprehensive analysis will be presented for each parameter measured by the BME-280, including temperature, humidity, altitude, and air pressure. Fig. 10 illustrates the results of the temperature parameter experiment.

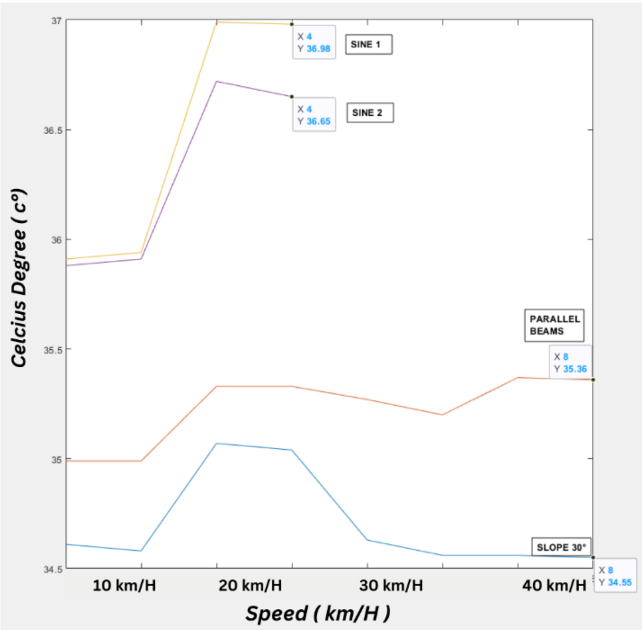

Fig. 10. Temperature experiment result

The graph depicted in Fig. 10 illustrates the variability of temperature parameters on military vehicles, which can be attributed to a multitude of influencing factors. An important consideration is the working temperature of the engine in military vehicles. The graph displays the maximum temperature recorded, which varies between 34.6 °C and 37.0 °C. The measurements were conducted indoors and are not directly comparable to the external air temperature readings taken throughout the testing period. Nevertheless, the temperature inside the passenger cabin can be influenced by the external air temperature, especially when all windows are tightly closed.

The temperature parameter greatly influences the comfort of military vehicle passengers, especially during extended journeys in dangerous terrain. The upper limit of temperature that humans can endure is 38^0 degrees Celsius [77]. Extended periods of being exposed to and/or engaging in physical activity in a consistent temperature of 38^0 C can lead to heat cramps or heat exhaustion, and there is a potential risk for heat stroke [78]. During the test, it can be observed that the cabin temperature readings were taken under tolerance conditions. This included the combination of engine heat, body heat from the passengers, and the heat generated by the device itself.

The following test outcome represents the result of assessing the pressure parameter as shown in Fig. 11. According to Fig. 11, the air pressure measured within the passenger cabin of the military vehicle ranges from 934.68 hPa to 955.35 hPa. This is caused by the significant oscillation that occurs during the journey, which changes the wind and passenger movement pattern. Consequently, this affects the air pressure within the cabin. However, this range is acceptable since it indicates that the pressure inside the military vehicle is within the standard range, below 1 atmosphere (atm), which is equivalent to 1013.25 hectopascals (hPa).

Therefore, it will cause any detrimental impacts on human breathing or the stability of vehicles. The graph also illustrates the impact of pressure variation on speed. It is observed that when the engine performance exceeds 30 km/h to 40 km/h, there is a noticeable decrease in air pressure measurements. This occurred because all the vents on the test journey were closed, which had an impact on respiration. Pressure changes can also lead to structural damage, which is often observed in military vehicles. Therefore, it can serve as a useful parameter for assessing the resilience of military vehicles to pressure fluctuations in the passenger cabin.

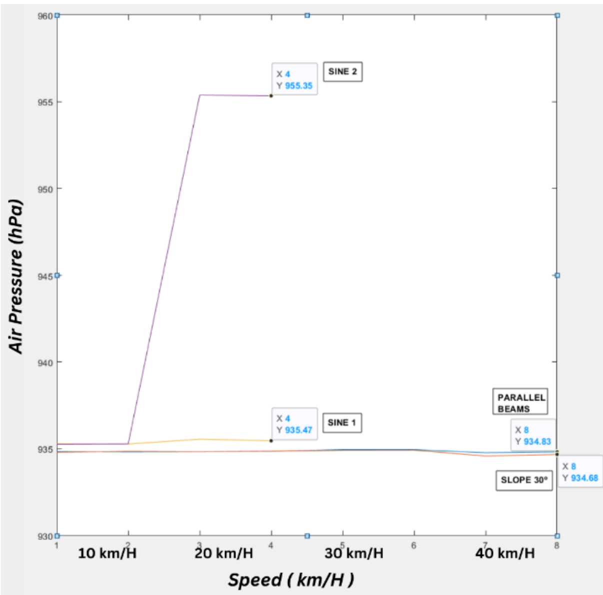

Fig. 11. Air-pressure experiment result

In addition, Fig. 12 displays the result of the altitude parameter testing. The altitude parameter in the passenger cabin of the military vehicle maintains a constant level within the range of 667-677 meter above sea level (mdpl) during the test. The potential variation in movement of 10 mdpl can be attributed to the incline of the terrain and the unpredictable nature of the military vehicle's performance on different track surfaces. The highest and most noticeable altitude is observed when military vehicles pass the 30^0-gradient track. On this route, the altitude reaches a maximum of 677 meters above sea level. However, it remains within the permissible range.

The air temperature and pressure can be influenced by the altitude and slope of the terrain. As elevation increases, air pressure decreases. It is a well-known fact that cold air has a greater density compared to warm air. When the air pressure is high, dry weather is typically formed in low areas, whereas low air pressure tends to result in cooler temperatures in higher areas [79]. Based on the test results, there are no exceptional circumstances in which altitude has an impact on variations in temperature and air pressure.

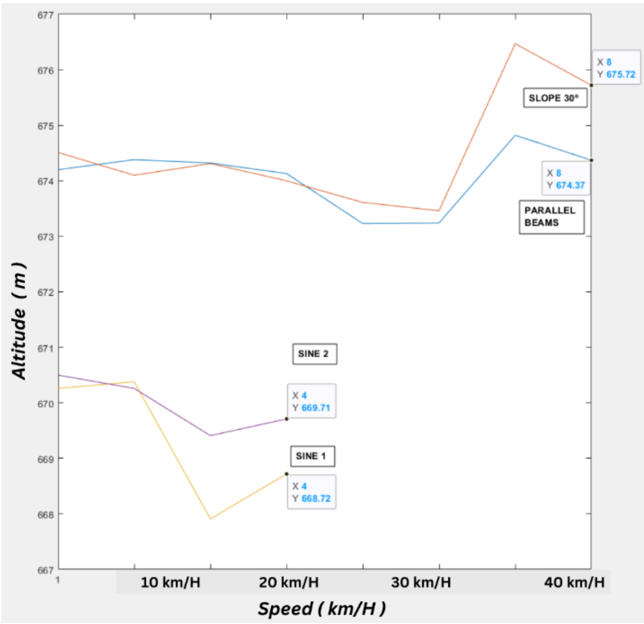

Fig. 12. Altitude experiment result

The final parameter to be assessed in the measurement module is the evaluation of the humidity parameter. Fig. 13 displays the test results. According to the test result, the humidity level detected in the military vehicle car falls within the range of 24.34% - 30.05%. This indicates that the humidity level within the military vehicle is not elevated, but rather the surrounding environment is dry. The ideal humidity level for a vehicle is typically between 30% and 50% [4]. This has a detrimental impact on both the user and the interior of the vehicle. Insufficient humidity levels can lead to dry air, which can affect the respiratory system and impact the skin. Insufficient humidity levels may not be a major issue for the interiors of military vehicles. However, it is important to consider that the use of synthetic materials in military vehicles may result in accelerated degradation.

The air humidity in a place is influenced by six factors: temperature, quality and quantity of irradiation, wind movement, air pressure, vegetation, and availability of groundwater in the area [80]. According to the given information, the humidity level in the vehicle is still within the allowable limit for human comfort. Conversely, when the humidity is below 10%, it can cause dehydration, leading to the development of dry and irritated skin, as well as dry eyes and nosebleeds. Individuals suffering from eczema or acne will have heightened instances of inflammation due to decreased humidity levels. Inadequate tear production can lead to pain in the eyes, reduced clarity of vision, and increased vulnerability to eye infections [81]. Hence, it is imperative to control humidity levels in a military vehicle through meticulous observation of wind patterns and air pressure.

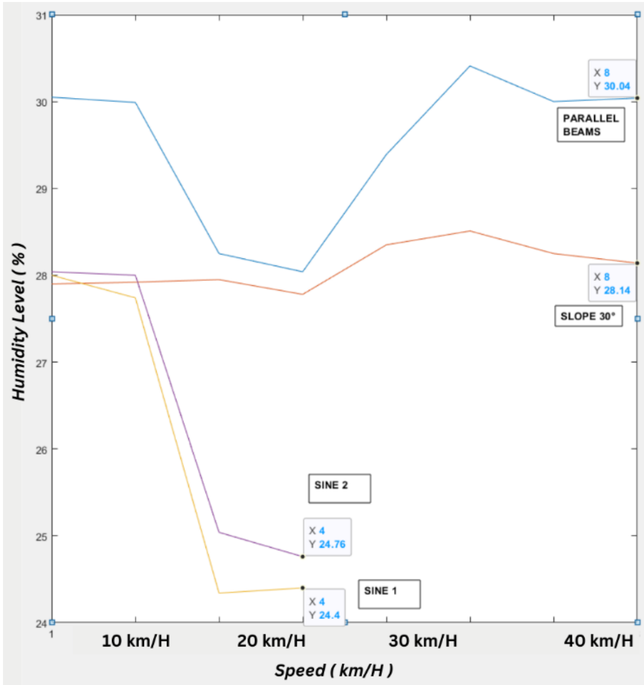

Fig. 13. Humidity experiment result

The test findings of the BME280 sensor indicate that it is crucial to utilize this equipment for the detection of temperature, humidity, air pressure, and altitude. Due of its ability to offer useful data for experts to analyze and make informed decisions. This information can provide guidance for developing measures to enhance the comfort of the military vehicle passenger compartment, in accordance with established measuring standards.

The final assessment is the test for the monitoring module. This test aims to assess the efficacy of delivering data from the detection module to the monitoring module using the LoRa communication module. Fig. 14 displays the test results. It illustrates the response time comparison between the KY037 sensor and the BME280 sensor. The KY037 sensor exhibits a response time ranging from 0.461 ms to 0.8 ms, whereas the BME280 sensor has a considerably longer response time of 6,830 ms. This is because the BME280 sensor promptly transmits a comprehensive set of data, including temperature, humidity, air pressure, and altitude parameters, during testing. According to this test, it can be concluded that the data can be transmitted to web monitoring in real time, as it takes less than a second. In the event of an unsuccessful transmission, it is possible to monitor the data by accessing the database file containing the test data saved on the cloud server.

Fig. 14. Response time

If all the sensors connected to the LoRa transmitter encounter an error while transmitting data to the API, one possible solution is to capture the screen on the LoRa transmitter serial monitor. This can be tracked and stored the values of each sensor for test result data. During the testing phase, the inability to transmit data to the display was solely caused by a loss of connection between the transmitter and receiver due to the distance between them. The terrain type and presence of obstacles did not cause any substantial inaccuracy in transmitting data from the transmitter to the receiver.

Fig. 15 depicts a visual representation of the monitoring display during the test. The online display dashboard presents five measurement metrics that are measured by the device. The display can be represented by a parameter value, which can be either a numerical value or a dynamic graphical representation of a test operation. During the test, temperature and humidity are represented numerically as these two variables are often consistent and infrequently fluctuate once a measurement is recorded. Graphs are utilized to visually represent measurements for noise, pressure, and altitude parameters because they allow for easy adjustment of detection levels within a short period of time. Therefore, it is expected that this technology will assist experts in assessing the internal comfort aspects of newly developed military vehicles and analyzing the collected data to facilitate decision-making.

Fig. 15. Web display

IV. CONCLUSIONS

A proposed model for the development of military vehicle cabin comfort involves the use of sound sensors (KY-037), BME280 sensors for measuring temperature, humidity, air pressure, and altitude, and an RFM95W LoRa module for real-time data transmission. Through the integration of these technologies, this research has successfully developed a unique alternative system that can accurately provide information on vehicle comfort parameters. The system can be tested with a range of military vehicle models, as it possesses quantifiable parameters and does not rely on the professionalism of an experienced expert. This system can be implemented to enhance the expertise of individuals in assessing the comfort and safety of a vehicle, particularly military vehicles.

The utilization of LoRa as a communication medium enables data transmission over long distances while consuming minimal power. This technology offers a solution to address challenges faced by military vehicles in enclosed spaces or areas where Wi-Fi signals are not accessible. The test results indicate that this system is capable of functioning effectively within the passenger cabin of an armored military vehicle, even under challenging conditions such as fluctuating speeds and enclosed environments.

By utilizing the BME280 sensor and KY-037 sensor, we can effectively analyze various parameters such as sound, temperature, air pressure, altitude, and humidity. The sound sensor, for instance, has demonstrated its capability by detecting a maximum of 141 db. Inside military vehicles, the temperature remains within a range of 34.55 to 36.98 °C. Meanwhile, the air pressure readings fluctuate between 934.68 hPa and 955.35 hPa. As for altitude, the track elevations vary from 667 to 677 above sea level. Lastly, the humidity levels inside the vehicle range from 24.34% to 30.05%. The detection results can assist specialists in conducting analytical investigations to identify areas that want improvement and choose appropriate measures to enhance them.

The LoRa test results demonstrate the system's ability to operate effectively in diverse terrain conditions, even in the presence of obstacles like buildings and steel-wall vehicle. The maximum distance achievable by LoRa exceeds 2 km, with an RSSI of -120 dB. Furthermore, real-time testing of the detection system's response time to web monitoring is possible.

Due to the implementation of the detection model, professionals can now conduct internal vehicle testing with greater accuracy and efficiency. Furthermore, the data generated can be seamlessly stored in real-time in the cloud, facilitating effortless monitoring and analysis of the data. This technology is anticipated to elevate the benchmark of military vehicle testing and provide a tangible contribution to the safety and comfort of its users.

This research offers fresh perspectives on military Vehicle Manufacturing and Production. Although there has been notable progress in identifying the outcomes of the research, there are still various aspects that can be further explored to enhance understanding in this area. In the future, expanding the dataset can be seen as a crucial step in enhancing the applicability of these findings. Further research and experimentation are necessary to validate and expand the research framework.

In the future, it is possible to incorporate and enhance the parameters of the measurement system. For instance, this system can be applied in the passenger cabin of a military vehicle that is equipped with a system like an Inertia Measurement Unit (IMU) capable of measuring the vehicle's orientation in 9 degrees of freedom.

Exploring additional enhancements to the models or techniques employed and assessing the influence of specific variables may be the primary focus in the future. The inclusion of an integrated camera within the cabin of the armored military vehicle allows passengers to gain awareness of the external surroundings of the vehicle.

Furthermore, the range between transmitters and receivers can be expanded by employing wireless sensor network technology and implementing supplementary gateways as relays at surveillance sites. Similarly, it is crucial to apply these findings in practical situations and conduct sustainability testing to assess their potential impact. It could potentially be applied and enhanced to military vehicle tracking processes. Overall, this research paves the way for additional exploration and future contributions, laying a solid groundwork for further advancements in innovation.

ACKNOWLEDGMENT

We extend our gratitude to the Directorate General of Vocational Education, Ministry of Education, Research and Technology of the Republic of Indonesia. We would like to express our gratitude to the Directorate of Research and Community Service (PPM) Telkom University and the Applied Science Laboratory of Sustainable Technology (STAS) Telkom University, Bandung, Indonesia for their invaluable support in this research endeavor. This research was supported by the Directorate of Research and Community Service (PPM) for the superior applied research scheme of higher.

REFERENCES

[1] P. S. Beran, D. Bryson, A. S. Thelen, M. Diez, and A. Serani, "Comparison of Multi-Fidelity Approaches for Military Vehicle Design," in *AIAA AVIATION 2020 FORUM*, p. 3158, Jun. 2020, doi: 10.2514/6.2020-3158.

[2] L. Tian, J. Li, and Y. Li, "Analysis of Driving Fatigue Characteristics in Cold and Hypoxia Environment of High-Altitude Areas," *Big Data*, vol. 11, no. 4, pp. 255–267, Aug. 2023, doi: 10.1089/big.2021.0464.

[3] S. Wang, H. Li, P. Zhang, J. Tao, H. Zou, and X. Qiu, "An experimental study on the upper limit frequency of global active noise control in car cabins," *Mech. Syst. Signal Process*, vol. 201, p. 110672, Oct. 2023, doi: 10.1016/j.ymssp.2023.110672.

[4] M. K. A. M. Zali and S. A. Sulaiman, "Study on Air-Circulation Practices in Car Cabin," in *2022 7th International Conference on Electric Vehicular Technology (ICEVT)*, pp. 205–209, Sep. 2022, doi: 10.1109/ICEVT55516.2022.9924780.

[5] S. G. Rajamani, S. A. Neelavara, and A. Thangamani, "Custom Wireless Sensing System for Evaluation of Automotive Cabin Thermal Comfort Metrics," in *2022 International Conference on Electrical, Computer and Energy Technologies (ICECET)*, pp. 1–6, Jul. 2022, doi: 10.1109/ICECET55527.2022.9872664.

[6] M.-H. Lu, M. U. Jen, and D. de Klerk, "Case study: Separating source contributions of vehicle interior noise by operational transfer path analysis," *Noise Control Eng. J.*, vol. 69, no. 1, pp. 39–52, Jan. 2021, doi: 10.3397/1/37694.

[7] M. M. Maassen *et al.*, "Safe and reliable sound threshold measures with direct vibration of the ossicular chain," *Laryngoscope*, vol. 114, no. 11 I, pp. 2012–2020, 2004, doi: 10.1097/01.mlg.0000147938.52132.4b.

[8] J. T. McDaniel *et al.*, "Spatiotemporal Trends in Vision Impairment, Hearing Loss, and Executive Dysfunction Among Active-Duty Military Personnel, United States, 2015-2019," *Mil. Med.*, vol. 188, no. 7–8, pp. e1408–e1415, Jul. 2023, doi: 10.1093/milmed/usab483.

[9] B. C. J. Moore, "Diagnosis and quantification of military noise-induced hearing loss," *J. Acoust. Soc. Am.*, vol. 148, no. 2, pp. 884–894, Aug. 2020, doi: 10.1121/10.0001789.

[10] J. E. Melzer, A. A. Scharine, and B. E. Amrein, "Soldier Auditory Situation Awareness: The Effects of Hearing Protection, Communications Headsets, and Headgear," in *Designing Soldier Systems*, pp. 173–195, 2018, doi: 10.1201/9781315576756-9.

[11] C. Li, F. Yang, and Z. Wang, "Experimental study on high-speed endurance of electric vehicle at normal temperature (25)," *E3S Web of Conferences*, vol. 268, 2021, doi: 10.1051/e3sconf/202126801032.

[12] K. Gładyszewska-Fiedoruk and T. J. Teleszewski, "Experimental research on the humidity in a passenger car cabin equipped with an air cooling system-development of a simplified model," *Applied Thermal Engineering*, vol. 220, p. 119783, 2023, doi: 10.2139/ssrn.4148567.

[13] Z. Liu and J. Liu, "Effect of altitude conditions on combustion and performance of a turbocharged direct-injection diesel engine," *Proceedings of the Institution of Mechanical Engineers, Part D: Journal of Automobile Engineering*, vol. 236, no. 4, pp. 582–593, 2022, doi: 10.1177/09544070211026204.

[14] C. Yuan, Y. Li, H. Huang, S. Wang, Z. Sun, and H. Wang, "Application of explainable machine learning for real-time safety analysis toward a connected vehicle environment," *Accid. Anal. Prev.*, vol. 171, p. 106681, Jun. 2022, doi: 10.1016/j.aap.2022.106681.

[15] S. Nidhra, "Black Box and White Box Testing Techniques - A Literature Review," *International Journal of Embedded Systems and Applications*, vol. 2, no. 2, pp. 29–50, 2012, doi: 10.5121/ijesa.2012.2204.

[16] S. R. Pokhrel and C. Williamson, "Modeling Compound TCP over WiFi for IoT," *IEEE/ACM Transactions on Networking*, vol. 26, no. 2, pp. 864–878, 2018, doi: 10.1109/TNET.2018.2806352.

[17] G. A. Mutiara *et al.*, "Integrated Sensor-Based Smart Mannequin for Injury Detection in Armored Vehicle," *International Journal of Safety and Security Engineering*, vol. 13, no. 4, pp. 625–633, 2023, doi: 10.18280/ijsse.130404.

[18] C. Vattheuer, C. Liu, A. Abedi, and O. Abari, "Is Z -Wave Reliable for IoT Sensors?," *IEEE Sens. J.*, vol. 23, no. 24, pp. 31297–31306, Dec. 2023, doi: 10.1109/JSEN.2023.3328014.

[19] A. Fathima, M. Kavipriya, B. Preethi, S. Azhageshwari, B. Manikandan, and S. Prathap, "Virtual Wearable Band Using Zigbee for Iot Application," *ECS Trans.*, vol. 107, no. 1, pp. 14889–14899, Apr. 2022, doi: 10.1149/10701.14889ecst.

[20] T. Inthasuth, P. Uarchoojitt, W. Boonsong, and N. Kaewthong, "Time-Based Performance Analysis of Narrowband Internet of Things (NB-IoT) for Particulate Matter Monitoring System," in *2023 International Conference on Electronics, Information, and Communication (ICEIC)*, pp. 1–4, 2023, doi: 10.1109/ICEIC57457.2023.10049930.

[21] V. K. Sarker, J. P. Queralta, T. N. Gia, H. Tenhunen, and T. Westerlund, "A Survey on LoRa for IoT: Integrating Edge Computing," in *2019 Fourth International Conference on Fog and Mobile Edge Computing (FMEC)*, pp. 295–300, 2019, doi: 10.1109/FMEC.2019.8795313.

[22] D. Wu and J. Liebeherr, "A Low-Cost Low-Power LoRa Mesh Network for Large-Scale Environmental Sensing," *IEEE Internet Things J*, vol. 10, no. 19, pp. 16700–16714, Oct. 2023, doi: 10.1109/JIOT.2023.3270237.

[23] B. Xie, M. Cui, D. Ganesan, X. Chen, and J. Xiong, "Boosting the Long Range Sensing Potential of LoRa," in *Proceedings of the 21st Annual International Conference on Mobile Systems, Applications and Services*, pp. 177–190, 2023, doi: 10.1145/3581791.3596847.

[24] Z. Sun *et al.*, "Low-power wide area network construction method based on lora technology for agricultural science and technology parks," *J. Phys. Conf. Ser.*, vol. 1673, no. 1, pp. 1–6, 2020, doi: 10.1088/1742-6596/1673/1/012066.

[25] B. Xie, M. Cui, D. Ganesan, and J. Xiong, "Wall Matters: Rethinking the Effect ofWall for Wireless Sensing," *Proc. ACM Interact. Mob. Wearable Ubiquitous Technol.*, vol. 7, no. 4, 2024, doi: 10.1145/3631417.

[26] X. Zhang, Z. Bao, Y. Yin, X. Yang, X. Xu, and Q. Niu, "LoFall: LoRa-Based Long-Range Through-Wall Fall Detection," in *2023 IEEE Symposium on Computers and Communications (ISCC)*, pp. 831–836, 2023, doi: 10.1109/ISCC58397.2023.10218222.

[27] E. C. Tsirogiannis, E. Daskalakis, M. H. Hassan, A. M. Omar, and P. Bartolo, "Ballistic design and testing of a composite armour reinforced by CNTs suitable for armoured vehicles," *Defence Technology*, vol. 32, pp. 173-195, 2024, doi: 10.1016/j.dt.2023.04.013.

[28] D. Voicu *et al.*, "Frequency Analysis of Vibrations in Terms of Human Exposure While Driving Military Armoured Personnel Carriers and Logistic Transportation Vehicles," *Electronics (Switzerland)*, vol. 12, no. 14, Jul. 2023, doi: 10.3390/electronics12143152.

[29] L. Wen, S. Dong, C. Gu, and J.-F. Mao, "A Compact Non-Contact Heart Sound Sensor Based on Millimeter-Wave Radar," in *2022 IEEE MTT-S International Microwave Biomedical Conference (IMBioC)*, pp. 305–307, 2022, doi: 10.1109/IMBioC52515.2022.9790257.

[30] M. Stojkov, G. Delija, I. Đuračić, and T. Alinjak, "Air Quality Supervision System using the IoT Platform," *Tehnicki Glasnik*, vol. 17, no. 4, pp. 605–613, 2023, doi: 10.31803/TG-20230226194209.

[31] I. P. Sari, A. A. N. Gunawan, I. M. S. Wibawa, I. K. Putra, and M. Yusuf, "Design and Manufacture of Radiosonde Based on Arduino Pro Mini Using BME280 Sensor," *Journal of Engineering Research and Reports*, vol. 23, no. 12, pp. 1–9, 2022, doi: 10.9734/jerr/2022/v23i12758.

[32] P. M. Dinesh, B. Y. Bala, S. M. Kumar, R. S. Sabeenian, M. E. Paramasivam, and A. Manjunathan, "Noise Level Notifier," *E3S Web of Conferences*, vol. 399, pp. 1–14, 2023, doi: 10.1051/e3sconf/202339904011.

[33] L. E. Humes, "Hearing Thresholds for Unscreened U.S. Adults: Data From the National Health and Nutrition Examination Survey, 2011–2012, 2015–2016, and 2017–2020," *Trends Hear.*, vol. 27, 2023, doi: 10.1177/23312165231162727.

[34] R. A. N. Rifqah, S. W. Suciyati, A. Surtono, and G. A. Pauzi, "Design of a Classroom Noise Monitoring Tool Using a KY-037 Sound Sensor Based on Wemos D1R1," *Journal of Energy, Material, and Instrumentation Technology*, vol. 4, no. 4, pp. 125–135, 2023, doi: 10.23960/jemit.v4i4.118.

[35] "Hearing Threshold," in *Encyclopedia of Autism Spectrum Disorders*, Cham: Springer International Publishing, pp. 2325–2325, 2021, doi: 10.1007/978-3-319-91280-6_300781.

[36] S. K. Mishra, U. Saxena, and H. Rodrigo, "Extended High-frequency Hearing Impairment Despite a Normal Audiogram: Relation to Early Aging, Speech-in-noise Perception, Cochlear Function, and Routine Earphone Use," *Ear Hear*, vol. 43, no. 3, pp. 822–835, May 2022, doi: 10.1097/AUD.0000000000001140.

[37] A. Ridwan and T. Pangaribowo, "Design of Prototype Aircraft Noise Monitoring System Using Microcontroller," *International Journal of Advanced Technology in Mechanical, Mechatronics and Materials*, vol. 2, no. 2, pp. 87–92, 2021, doi: 10.37869/ijatec.v2i2.49.

[38] S. G. Curhan, C. Halpin, M. Wang, R. D. Eavey, and G. C. Curhan, "Prospective Study of Dietary Patterns and Hearing Threshold Elevation," *Am J Epidemiol*, vol. 189, no. 3, pp. 204–214, Mar. 2020, doi: 10.1093/aje/kwz223.

[39] E. H. Berger, "Active noise reduction (ANR) in hearing protection: Does it make sense for industrial applications," in *27th Conference of the National Hearing Conservation Association*, 2002.

[40] J. J. Saldana-Barrios, E. Aguilar, W. Ng, and R. Orocu, "Designing an IoT-Based System for Monitoring Noise Levels in the Computer Science Faculty and Library of the Technological University of Panama," *Sensors*, vol. 23, no. 22, 2023, doi: 10.3390/s23229083.

[41] E. Levenberg *et al.*, "Live road condition assessment with internal vehicle sensors," *Transp. Res. Rec.*, vol. 2675, no. 10, pp. 1442–1452, 2021, doi: 10.1177/03611981211016852.

[42] K. Gładyszewska-Fiedoruk and T. J. Teleszewski, "Modeling of Humidity in Passenger Cars Equipped with Mechanical Ventilation," *Energies (Basel)*, vol. 13, no. 11, p. 2987, Jun. 2020, doi: 10.3390/en13112987.

[43] A. Wadhwa and M. Kalsia, "A Critical Review on Occupant's Thermal Comfort Inside Electric Vehicle Car Cabin," in *2023 2nd Edition of IEEE Delhi Section Flagship Conference (DELCON)*, pp. 1–7, 2023, doi: 10.1109/DELCON57910.2023.10127397.

[44] I. Panfilov, A. N. Beskopylny, and B. Meskhi, "Numerical Simulation of Heat Transfer and Spread of Virus Particles in the Car Interior," *Mathematics*, vol. 11, no. 3, 2023, doi: 10.3390/math11030784.

[45] R. Andarini and M. Widjaja, "Monitoring Indoor Air Quality for Thermal Comfort using Internet of Things," in *2022 Seventh International Conference on Informatics and Computing (ICIC)*, pp. 1–6, 2022, doi: 10.1109/ICIC56845.2022.10006955.

[46] F. Alanazi, "The spread of COVID-19 at Hot-Temperature Places With Different Curfew Situations Using Copula Models," in *2021 1st International Conference on Artificial Intelligence and Data Analytics (CAIDA)*, pp. 268–270, 2021, doi: 10.1109/CAIDA51941.2021.9425301.

[47] J. B. Kim and M. S. Kang, "The monitoring system of temperature and humidity on vehicle for HACCP," *Journal of Advanced Navigation Technology*, vol. 22, no. 2, pp. 168-172, 2018.

[48] R. A. Angelova, D. G. Markov, I. Simova, R. Velichkova, and P. Stankov, "Accumulation of metabolic carbon dioxide (CO_2) in a vehicle cabin," *IOP Conf. Ser. Mater. Sci. Eng.*, vol. 664, no. 1, p. 012010, Oct. 2019, doi: 10.1088/1757-899X/664/1/012010.

[49] V. Perez-Gracia, S. Santos-Assuncao, V. Sossa, and M. Solla, "Assessment of humidity damage in cultural heritage," in *2021 11th International Workshop on Advanced Ground Penetrating Radar (IWAGPR)*, pp. 1–6, 2021, doi: 10.1109/IWAGPR50767.2021.9843177.

[50] P. Li, J. Liu, M. Chen, F. Wang, R. Yuen, and J. Wang, "Experimental study of high altitude effect on heat release rates of pool fires using calorimeters," *J. Therm. Anal. Calorim.*, vol. 131, no. 2, pp. 1597–1603, Feb. 2018, doi: 10.1007/s10973-017-6637-1.

[51] Y. Xu, G. Yu, Y. Wang, X. Wu, and Y. Ma, "Car detection from low-altitude UAV imagery with the faster R-CNN," *J. Adv. Transp.*, vol. 2017, 2017, doi: 10.1155/2017/2823617.

[52] M. Bertone *et al.*, "Experimental Characterization of the Airflow within a Car Cabin," *J. Phys. Conf. Ser.*, vol. 2509, no. 1, 2023, doi: 10.1088/1742-6596/2509/1/012024.

[53] L. Qiu, H. Zhou, Z. Wang, S. Zhang, L. Zhang, and W. Lou, "High-speed elevator car air pressure compensation method based on coupling analysis of internal and external flow fields," *Applied Sciences (Switzerland)*, vol. 11, no. 4, pp. 1–26, 2021, doi: 10.3390/app11041700.

[54] W. Suparta, A. Warsita, and Ircham, "A low-cost development of automatic weather station based on Arduino for monitoring precipitable water vapor," *Indonesian Journal of Electrical Engineering and Computer Science*, vol. 24, no. 2, pp. 744–753, 2021, doi: 10.11591/ijeecs.v24.i2.pp744-753.

[55] D. H. Effendi, L. Kamelia, A. Faroqi, and M. I. Z. Ulhaq, "Pepper Greenhouse Condition Control System Using the Proportional Integral Derivative (PID) Methods," in *2022 8th International Conference on Wireless and Telematics (ICWT)*, pp. 1–5, 2022, doi: 10.1109/ICWT55831.2022.9935345.

[56] M. D. Djordjevic, J. M. Vracar, and A. S. Stojkovic, "Supervision and Monitoring System of the Power Line Poles Using IIoT Technology," in *2020 55th International Scientific Conference on Information, Communication and Energy Systems and Technologies (ICEST)*, pp. 58–61, 2020, doi: 10.1109/ICEST49890.2020.9232909.

[57] S. Srilakshmipathy, R. Abhishek, and Deepa, "Temperature and Humidity Monitoring in Silo," in *2021 International Conference on Recent Trends on Electronics, Information, Communication & Technology (RTEICT)*, pp. 55–59, 2021, doi: 10.1109/RTEICT52294.2021.9573918.

[58] W. S. B, A. Setiawan, A. Budiarto, and Y. Suprapto, *Proceedings of the International Conference on Advance Transportation, Engineering, and Applied Science (ICATEAS 2022)*, vol. 1, 2023, doi: 10.2991/978-94-6463-092-3.

[59] G. V. Shevchenko, N. A. Glubokov, A. V. Yupashevsky, and A. S. Kazmina, "Air flow sensor based on environmental sensor BME280," *International Conference of Young Specialists on Micro/Nanotechnologies and Electron Devices, EDM*, vol. 2020, pp. 432–435, 2020, doi: 10.1109/EDM49804.2020.9153474.

[60] S. Deniziak, M. Płaza, and Ł. Arcab, "Approach for Designing Real-Time IoT Systems," *Electronics (Switzerland)*, vol. 11, no. 24, 2022, doi: 10.3390/electronics11244120.

[61] G. A. Mutiara, N. Suryana, and O. Bin Mohd, "Wireless sensor network for illegal logging application: A systematic literature review," *J. Theor. Appl. Inf. Technol.*, vol. 97, no. 1, pp. 302–313, 2019.

[62] B. Veerasamy, B. G. Durga, T. H. M. Kumaran, I. V. Devika, and M. J. Akshaya, "Soldier Health Detection and Position Tracking System using LoRaWAN Sensor for Low Power and Long-Range Access," in *2023 7th International Conference on Trends in Electronics and Informatics (ICOEI)*, pp. 9–13, 2023, doi: 10.1109/ICOEI56765.2023.10125644.

[63] H. A. H. Alobaidy *et al.*, “Low-Altitude-Platform-Based Airborne IoT Network (LAP-AIN) for Water Quality Monitoring in Harsh Tropical Environment,” *IEEE Internet Things J.*, vol. 9, no. 20, pp. 20034–20054, Oct. 2022, doi: 10.1109/JIOT.2022.3171294.

[64] M. Rademacher, H. Linka, T. Horstmann, and M. Henze, “Path Loss in Urban LoRa Networks: A Large-Scale Measurement Study,” *2021 IEEE 94th Vehicular Technology Conference (VTC2021-Fall)*, pp. 1-6, 2021, doi: 10.1109/VTC2021-Fall52928.2021.9625531.

[65] G. A. Mutiara, O. Mohd, N. Suryana, and A. N. C. Pee, “Weights-Based Energy-Efficient Wireless Sensor Network Protocol with Firefly Synchronization for Illegal Logging,” *International Journal of Intelligent Engineering and Systems*, vol. 14, no. 3, pp. 374–387, 2021, doi: 10.22266/ijies2021.0630.31.

[66] I. Francis and S. Mohd Shah, “Cost-Effective Arduino-Based RFID Automated Cage Door and Pet Tagging with GPS Tracker using Peer-to-Peer LoRa WAN,” *Journal of Electronic Voltage and Application*, vol. 3, no. 2, pp. 47–58, 2022, doi: 10.30880/jeva.2022.03.02.005.

[67] P. D. P. Adi and A. Kitagawa, “Performance Evaluation of Low Power Wide Area (LPWA) LoRa 920 MHz Sensor Node to Medical Monitoring IoT Based,” in *2020 10th Electrical Power, Electronics, Communications, Controls and Informatics Seminar (EECCIS)*, pp. 278–283, 2020, doi: 10.1109/EECCIS49483.2020.9263418.

[68] X. Xianyu, “Application of Lora technology in smart home of Internet of Things,” in *3rd International Conference on Internet of Things and Smart City (IoTSC 2023*, p. 95, 2023, doi: 10.1117/12.2684023.

[69] J. Souifi, Y. Bouslimani, M. Ghribi, A. Kaddouri, T. Boutot, and H. H. Abdallah, “Smart Home Architecture based on LoRa Wireless Connectivity and LoRaWAN® Networking Protocol,” in *020 1st International Conference on Communications, Control Systems and Signal Processing (CCSSP)*, pp. 95–99, 2020, doi: 10.1109/CCSSP49278.2020.9151815.

[70] Md. Shahjalal, Moh. K. Hasan, Md. M. Islam, Md. M. Alam, Md. F. Ahmed, and Y. M. Jang, “An Overview of AI-Enabled Remote Smart-Home Monitoring System Using LoRa,” in *2020 International Conference on Artificial Intelligence in Information and Communication (ICAIIC)*, pp. 510–513, 2020, doi: 10.1109/ICAIIC48513.2020.9065199.

[71] A. Pagano, D. Croce, I. Tinnirello, and G. Vitale, “A Survey on LoRa for Smart Agriculture: Current Trends and Future Perspectives,” *IEEE Internet Things J.*, vol. 10, no. 4, pp. 3664–3679, 2023, doi: 10.1109/JIOT.2022.3230505.

[72] F. Rebaudo *et al.*, “A low-cost IoT network to monitor microclimate variables in ecosystems,” *Methods Ecol. Evol.*, vol. 14, no. 4, pp. 1025–1034, 2023, doi: 10.1111/2041-210X.14062.

[73] S. Khriji, O. K. Gunyeli, D. El Houssaini, and O. Kanoun, “Energy-Efficient Short-Long Range Communication Network Combining LoRa and Low-Power Radio for Large-Scale IoT Applications,” in *2022 IEEE 9th International Conference on Computational Intelligence and Virtual Environments for Measurement Systems and Applications (CIVEMSA)*, pp. 1–6, 2022, doi: 10.1109/CIVEMSA53371.2022.9853705.

[74] J. Breitegger, C. Raffelsberger, S. S. Borkotoky, I. Rogler, and C. Bettstetter, “Long-Term LoRa Experiments in a Chemical Plant,” in *2021 22nd IEEE International Conference on Industrial Technology (ICIT)*, pp. 1–6, 2021, doi: 10.1109/ICIT46573.2021.9453474.

[75] P. Mayer, M. Magno, T. Brunner, and L. Benini, “LoRa vs. LoRa: In-Field Evaluation and Comparison For Long-Lifetime Sensor Nodes,” in *2019 IEEE 8th International Workshop on Advances in Sensors and Interfaces (IWASI)*, pp. 307–311, 2019, doi: 10.1109/IWASI.2019.8791362.

[76] R. Berto, P. Napoletano, and M. Savi, “A LoRa-Based Mesh Network for Peer-to-Peer Long-Range Communication,” *Sensors*, vol. 21, no. 13, p. 4314, 2021.

[77] S. Khatoon and M. H. Kim, “Human thermal comfort and heat removal efficiency for ventilation variants in passenger cars,” *Energies (Basel)*, vol. 10, no. 11, Nov. 2017, doi: 10.3390/en10111710.

[78] C. Feng, F. Ma, R. Wang, W. Li, and J. Gao, “A thermal comfort evaluation on vehicular environments based on local human body thermal sensations,” *Results in Engineering*, vol. 17, Mar. 2023, doi: 10.1016/j.rineng.2023.100907.

[79] B. Salahi, A. Kashani, and V. Safarianzengir, “Investigation and analysis of climate change and siberian high-pressure system during drought and wet periods in the Iranian plateau,” *Modeling Earth Systems and Environment*, vol. 6, pp. 1695-1706, 2020.

[80] C. H. Huang, H. H. Tsai, and H. C. Chen, “Influence of weather factors on thermal comfort in subtropical urban environments,” *Sustainability (Switzerland)*, vol. 12, no. 5, Mar. 2020, doi: 10.3390/su12052001.

[81] J. Li, X. Wu, S. K. W. Chow, Q. Zhuang, and G. Habert, “Thermal Comfort Comparison and Cause Analysis of Low-Temperature High-Humidity Indoor Environments of Rural Houses in Gansu Province, China,” *Sustainability*, vol. 15, no. 23, p. 16428, Nov. 2023, doi: 10.3390/su152316428.