JAIIT *(Journal of Advances in Information and Industrial Technology)*
Vol. 6, No. 1 May 2024, ISSN 2716-1935, E-ISSN 2716-1927

Design and Implementation of Tire Pressure and Temperature Monitoring System for Hatchback and Multi-Purpose Vehicle Based on IoT

Hendy Briantoro*1), Anang Budikarso2), Arifin3), Md. Mahbubur Rahman4)
1)Department of Computer Engineering, Telkom University, Surabaya, Indonesia
2,3)Department of Telecommunication Engineering, Politeknik Elektronika Negeri Surabaya, Surabaya, Indonesia
4)Department of Electrical and Electronic Engineering, Jatiya Kabi Kazi Nazrul Islam University Trishal, Mymensingh, Bangladesh
1*hendybr@telkomuniversity.ac.id, 2anang_bk@pens.ac.id, 3arifin@pens.ac.id, 4mahbubur@jkkniu.edu.bd

A R T I C L E I N F O

Article history:
Received 26 April 2024
Revised 30 April 2024
Accepted 06 June 2024
Available online 07 June 2024

Keywords:
Docker container
IoT
MQTT
TPMS

A B S T R A C T

Tire Pressure Monitoring Systems (TPMS) have developed into an essential element in vehicles to improve safety and the driving experience. In general, TPMS systems rely on special hardware to collect and transmit tire pressure data to the vehicle's on-board computer and this data can only be viewed by the driver and passengers in the vehicle. In this study, we developed a remote tire pressure and temperature monitoring system using IoT technology. The MQTT protocol facilitated communication between the cloud server and controller, while the system uses Docker container to simplify program integration. The results revealed the optimal standard deviation for tire pressure in hatchback vehicles to be 2.24, and for Multi-Purpose Vehicles (MPVs), it was 2.97. For tire temperature, the best standard deviation in hatchback vehicles was 1.93, compared to 1.05 in MPVs. This system effectively monitors tire pressure and temperature changes in real time, accessible remotely via smartphones and computers.

1. Introduction

The automobile sector has advanced significantly in recent years, especially when it comes to vehicle performance and safety. Tire pressure monitoring is a crucial component of car safety since low tire pressure can decrease fuel economy, interfere with comfort while driving, and raise the chance of collisions. Given this, the Tire Pressure Monitoring System (TPMS) has emerged as a critical element of contemporary automobiles, greatly enhancing road safety [1].

Advancements in vehicle electronic technology have brought forth the Tire Pressure Management System (TPMS), becoming a crucial safety feature in vehicles. Research papers [2]-[4] have extensively explored TPMS applications for four-wheeled vehicles. A unique method for identifying tire pressure loss in a range of operational scenarios is presented in paper [5]. Studies on TPMS applications have also been conducted in [6][7], with an emphasis on identifying torsional resonance frequency variations as a sign of tire pressure drop. Furthermore, the Anti-lock Braking System (ABS) tire speed signals can be used to improve tire pressure monitoring, providing a potential path toward accurate and dependable tire pressure monitoring. To further improve the accuracy and precision of the monitoring process, a study [8] examined a tire pressure and temperature monitoring system combined with ABS control signals. These studies highlight how important TPMS is for maximizing tire performance and safety, providing essential information about tire health, and facilitating preventative actions to lessen possible road dangers.

A solution to address the issue of tire blowouts involves implementing a vehicle tire pressure monitoring system (TPMS). In [9][10], researchers devised a TPMS that presents tire pressure information on a dot matrix Liquid-Crystal Display (LCD), with pressure data transmitted via a 433MHz radio frequency (RF) module, accessible solely to the driver locally. Similarly, in [10], wireless communication between tire sensors and TPMS modules was explored, with the author analyzing associated power consumption through simulation. In [11], experiments were conducted involving wireless transmission of data from tire sensors to TPMS modules operating at 433MHz, while data transmission from TPMS modules to a computer was examined using wired communication employing the universal synchronous/asynchronous receiver/transmitter (USART) protocol. If remote pressure monitoring is required, effective communication facilities are needed, effective communication facilities are vital to transmit vehicle data. Internet of Things (IoT) technology emerges as a potential solution for long-distance data transmission, enabling all devices to be connected online, thereby enhancing efficiency and productivity [13][14]. Numerous studies on IoT, such as those in [15][16], have been published, reflecting its widespread development and applicability.

In this study, we developed a remote tire pressure and temperature monitoring system for vehicles using IoT technology. The tire pressure and temperature data are transferred to the server via the Message Queueing Telemetry Transport (MQTT) protocol, while the system uses Docker container to simplify program integration. With this configuration, tire pressure and temperature data can be monitored remotely in real time using a computer or smartphone.

2. Methods

In this paper, we undertook in several crucial stages to develop a tire pressure and temperature monitoring system based on IoT. Figure 1 shows the flow of the research. These stages encompassed conducting literature reviews, designing the system, implementing the system, and rigorously testing its functionality. This chapter will provide an in-depth elucidation of each of these steps.

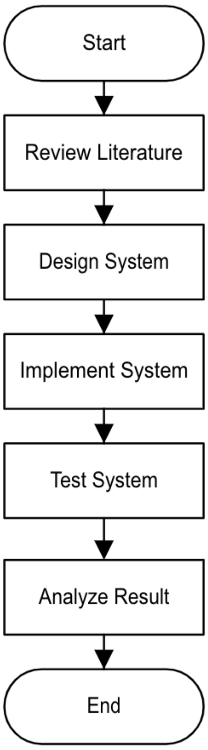

Figure 1. The Flow of the Research

2.1. Literature Review

In this chapter, we briefly explain the Tire Pressure Management System (TPMS), Internet of Things (IoT) and Docker container. There are two primary types of TPMS: direct systems and indirect systems. To achieve accurate tire pressure measurements, the direct systems need putting sensors on each tire of the vehicle separately [7]. On the other hand, the indirect systems estimate tire pressure using sensors that are already installed in the car. Tire pressure loss in this system is identified by closely

 DOI: https://doi.org/10.52435/jaiit.v6i1.545

observing changes in the recorded data [8][9]. While the indirect systems employ existing onboard sensors to estimate tire pressure indirectly, providing a more affordable option, but the direct systems provide exact real-time pressure data from each tire. By warning drivers of possible pressure abnormalities, TPMS systems significantly contribute to the improvement of vehicle safety, preventing dangerous circumstances and advancing general road safety.

The Internet of Things (IoT) is a network technology that permits industrial equipment and sensor devices to seamlessly connect and exchange data over the internet. Many studies investigating the potential uses of IoT technology have been spurred by its widespread use [12]–[15]. For example, the author of [2] looks into the application of IoT technology for a tire pressure monitoring system that makes use of the MPX5700AP sensor. Researchers used an Android smartphone and the Blynk application to show tire pressure data. In a similar vein, researchers used Internet of Things (IoT) in [15] to monitor tire pressure and temperature using independent sensors (MPX5D00AP tire pressure sensor and LM35 temperature sensor). Through smartphone integration of the Blynk app, data visualization was accomplished. One commonly used protocol for IoT is the Message Queueing Telemetry Transport (MQTT), which operates on TCP/IP and is open source [16].

A Docker container is a lightweight, standalone, and executable software package that includes everything needed to run a piece of software, including the code, runtime, system tools, libraries, and settings [17]. Docker containers enable users to install and manage programs effectively on a Raspberry Pi. They do this by creating an isolated environment that can execute multiple apps reliably across different development and production environments, making use of the Pi's limited resources [18].

2.2. System Design

This section outlines the system design for an Internet of Things-based tire pressure and temperature monitoring system for vehicles. The block diagram shows the parts and connections in the system, as shown in Figure 2. The Raspberry Pi 4B serves as the system's central controller. The controller has a Docker container installed, which makes managing software apps easier. The controller is equipped with an RTL-SDR radio signal receiver, which is intended to receive and decode temperature and pressure data signals sent by tire sensors. RTL-SDR is a type of Software Defined Radio (SDR) device. SDR is a contemporary radio communication system that differs from others in that it uses software implementations running on a computer or embedded system in place of conventional hardware components including mixers, filters, amplifiers, modulators/demodulators, and detectors [19]. With the RTL2832U chipset, RTL-SDR devices can receive signals at frequencies between 500kHz and 1.75GHz. Furthermore added for user convenience is a Liquid Crystal Display (LCD) that shows tire pressure and temperature data in real time.

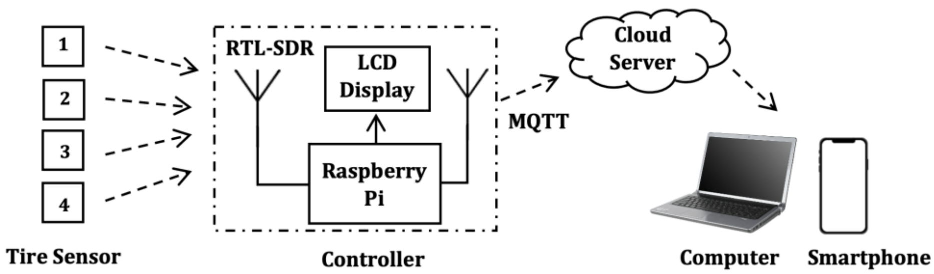

Figure 2. System Design

The system operates through the following process. Initially, the sensor transmits tire pressure and temperature data to the central controller. This data is encoded as a signal modulated with Frequency-Shift Keying (FSK) modulation and Manchester code [20][21]. FSK is a modulation technique employed in telecommunications, particularly radio transmission. This modulation alters the frequency of a carrier signal to transmit the data. In FSK modulation, distinct frequencies represent the data being transmitted. Manchester code is a type of line code that signifies each data bit through transitions or polarity changes in the signal. It is applied broadly in data communications, notably in Ethernet and certain wireless communication standards. Manchester code exhibits resilience against noise and distortion. Subsequently, the controller receives the data and decodes it into hexadecimal format, containing sensor ID data, pressure data and temperature data. The information that has been decoded is then shown on the LCD panel. In addition, the internet is used to send the data to cloud servers. The transmission from the controller to the cloud server utilizes the Message Queueing Telemetry Transport (MQTT) protocol, commonly employed for IoT purposes, running on TCP/IP and being open source. By using a browser program and the cloud server link, users may monitor tire pressure and temperature data from computers and smartphones. This method allows pressure and temperature readings to be shown in real-time on the dashboard's LCD screen as well as through computer and smartphone applications.

2.3. System Implementation

This section outlines the thorough implementation procedure for an IoT-based tire pressure and temperature monitoring system. This system employs hardware with specifications outlined in Table 1, while the physical appearance of the device is depicted in Figure 3. This system uses a Raspberry Pi 4B because the Docker container can be installed on it. We use RTL-SDR to receive data signals from the tire sensor.

Table 1. Device Specification

No	Device	Specification
1	Raspberry Pi 4B	Quadcore Cortex A-72
		Broadcom BCM2711
		2GB RAM
		IEEE 802.11ac Wireless
2	RTL-SDR	Realtek RTL2832U Chip
		Frequency Range 500kHz ~ 1,766MHz
3	Tire Sensor	Frequency 433MHz
		Pressure Value Range: 0 ~ 210 psi
		Temperature Value Range: -40º ~ 90º Celcius
4	Smartphone	MediaTek Helio G95 2.05 GHz
		6GB RAM
		Android 13
5	Computer	AMD Ryzen™ 5
		8 GB RAM
		512 GB SSD Hard drive
6	Powerbank	Battery 10Ah

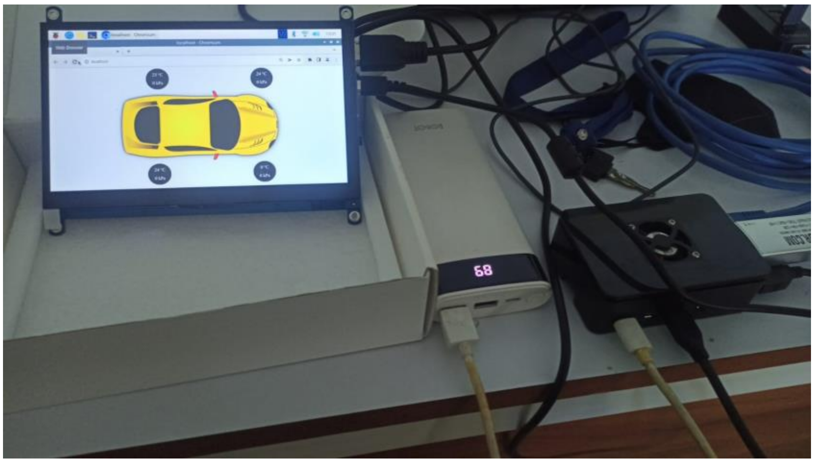

Figure 3. The Physical Appearance of The Device

 DOI: https://doi.org/10.52435/jaiit.v6i1.545

In this setup, tire sensors transmit tire pressure and temperature data via radio signals utilizing FSK modulation, with a transmission frequency of 433MHz. The controller then captures and decodes the transmitted data. This decoded data comprises sensor ID, tire pressure value and tire temperature value, all of which are showcased on the LCD screen. To achieve this visual representation, we employ the HTML programming language accessible through a browser application. The LCD display is shown in Figure 4, along with a picture of an automobile. It shows tire pressure data in kiloPascals (kPa) and tire temperature values in degrees Celsius (°C). Pascal (Pa) is the international unit for pressure values. The definition of Pascal (Pa) is the force of one Newton applied to one square meter (N/m2). By giving drivers immediate access to tire pressure and temperature measurements, this design improves driving convenience.

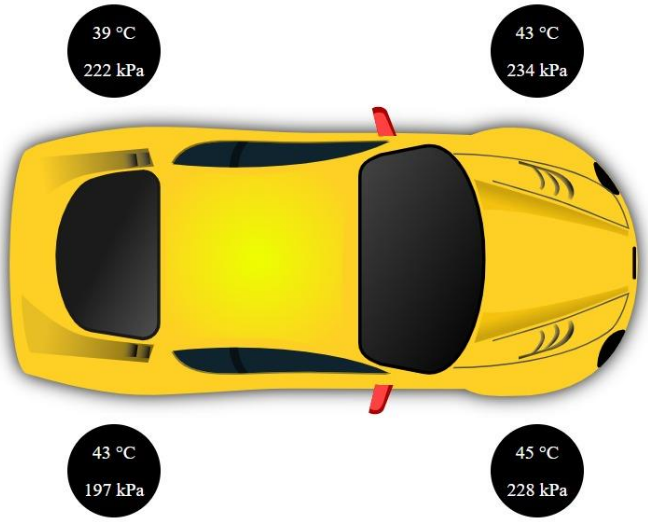

Figure 4. Display of LCD Screen

Data on temperature and tire pressure are sent to a cloud service in addition to being displayed on the LCD. Using the MQTT protocol, the controller sends this data to the cloud server. Because it uses cloud-based storage, users can obtain pressure and temperature data remotely from computers and cellphones by using the IP address associated with the cloud server. We create web browser-accessible HTML-based applications to make access easier from computers and smartphones. Tire pressure and temperature measurements in kPa and °C are displayed in Figure 5, which shows the user interface of the application for PCs and smartphones. This easy-to-use program guarantees smooth functioning and easy reading on PCs and cell phones.

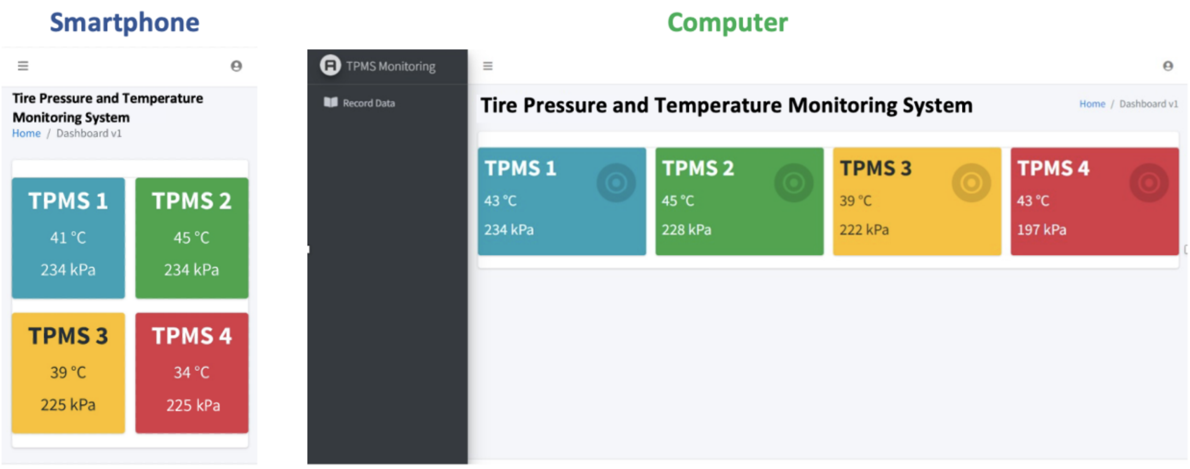

Figure 5. User Interface Application on Smartphone and Computer

3. Results and Discussions

To assess the system's performance, a 25km test drive was conducted during daylight hours. The evaluation involved two vehicle types: hatchback vehicle and multi-purpose vehicle (MPV), with their specifications outlined in Table 2. During the test, tire sensors were affixed to each tire of the vehicles. Figure 6 illustrates the positioning of the sensor on a car tire and provides a visual representation of the sensor's physical design.

Table 2. Specification of Vehicles

Parameters	Hatchback Vehicle	Multi-Purpose Vehicle
Dimensions	Length: 359.5 cm	Length: 439.5 cm
	Width: 159.5 cm	Width: 173.0 cm
	Height: 148.0 cm	Height: 166.5 cm
Engine Capacity	1250 cc	1,298 cc
Tire	185/55 R15	185/65 R15

Figure 6. Tire Sensor

3.1. Testing Results for Hatchback Vehicle

In the first test, we conducted the testing using a hatchback vehicle. From the test results, the system is capable of recording and displaying changes in pressure and temperature values. Figure 7 illustrates the monitoring results of tire pressure in kPa. The results indicate that the pressure values in all tires are quite fluctuating. These fluctuations could be due to varying road conditions, and measurements were also taken while the vehicle was in motion. From the results, the average pressure values for each tire were found to be 233.4 kPa for the first tire, 231 kPa for the second tire, 222.5 kPa for the third tire, and 193.4 kPa for the fourth tire. Additionally, we calculated the standard deviation values for each tire's pressure data. The standard deviation value for the first tire is 2.08, for the second tire is 4.39, for the third tire is 2.24, and for the fourth tire is 5.92. From these results, the best standard deviation value is 2.24.

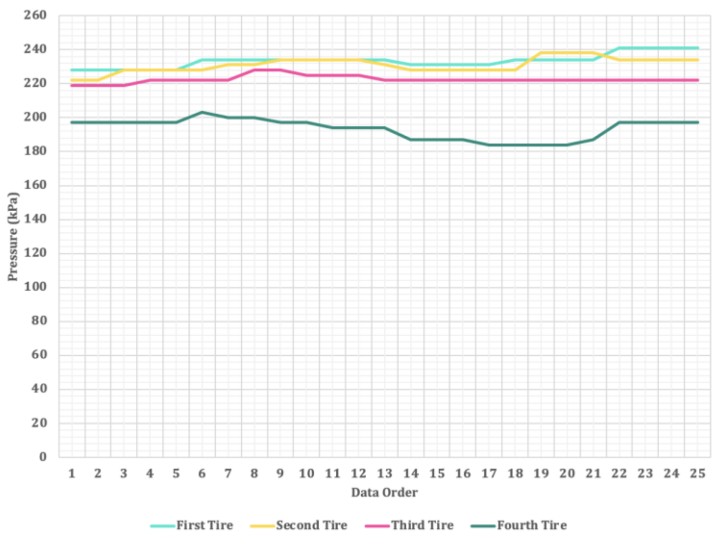

Figure 7. Tire Pressure Results for Hatchback Vehicle

DOI: https://doi.org/10.52435/jaiit.v6i1.545

In addition to pressure values, we also conducted tire temperature monitoring tests. The results of the tire temperature monitoring are shown in Figure 8. The tire temperature data is displayed in degrees Celsius (°C). The test results indicate that tire temperatures fluctuate. From the testing, the first and second tires have higher temperatures compared to the others because tires 1 and 2 are positioned closer to the car's engine. Thus, tire temperatures are influenced not only by environmental temperatures but also by engine heat. Additionally, we calculated the average and standard deviation values of tire temperatures. From the test results, the average tire temperatures are 41°C for the first tire, 43.8°C for the second tire, 38.4°C for the third tire, and 37.9°C for the fourth tire.

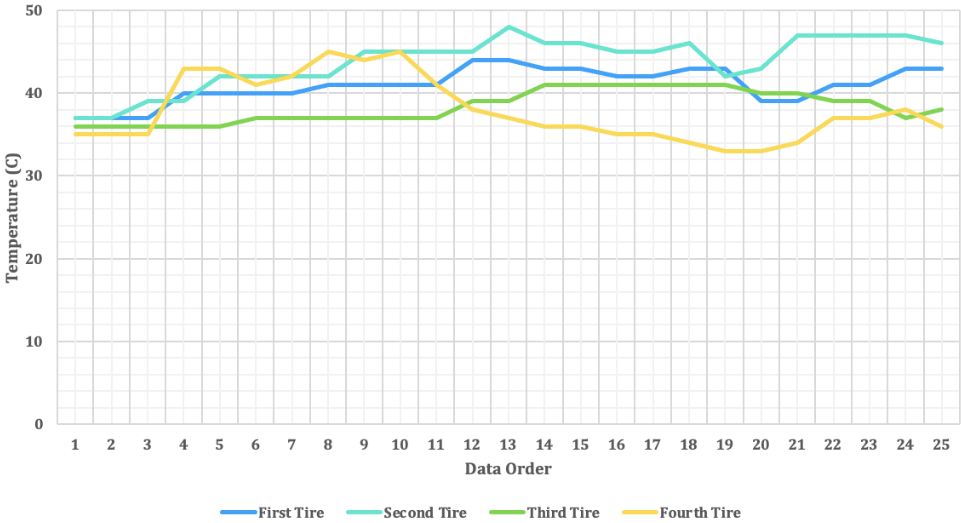

Figure 8. Tire Temperature Results for Hatchback Vehicle

The standard deviation of temperature value for the first tire is 2.08, for the second tire is 3.18, for the third tire is 1.93, and for the fourth tire is 3.87. The best standard deviation value is 1.93. This indicates that third tire relatively low variability in temperature value.

3.2. Testing Results for Multi-Purpose Vehicle

In another test, we conducted the experiment using a multi-purpose vehicle. According to the results, the system effectively records and presents real-time changes in pressure and temperature values.

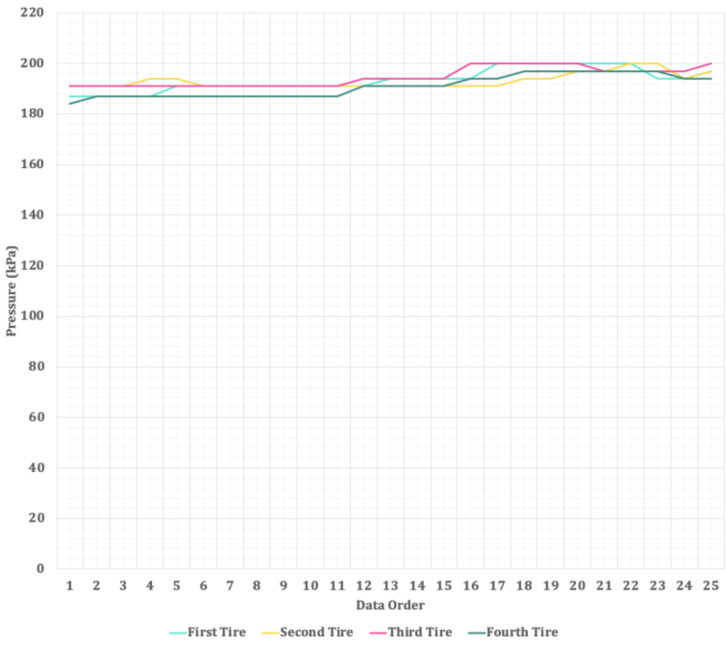

Figure 9. Tire Pressure Results for Multi-Purpose Vehicle

Figure 9 depicts the monitoring outcomes of tire pressure measured in kPa. The results reveal that pressure values in all tires quite fluctuations, likely attributable to varying road conditions, with measurements taken while the vehicle was in motion. The average pressure values for each tire were determined as follows: 193.5 kPa for the first tire, 193 kPa for the second tire, 194.6 kPa for the third tire, and 191 kPa for the fourth tire. Moreover, standard deviation values were computed for each tire's pressure data, resulting in 4.5 for the first tire, 2.97 for the second tire, 3.78 for the third tire, and 4.38 for the fourth tire. Among these, the most favorable standard deviation value is 2.97.

Furthermore, tire temperature monitoring tests were conducted. The results of these tests are depicted in Figure 10, with tire temperature data presented in degrees Celsius (°C). The findings indicate fluctuations in tire temperature. Interestingly, the temperature is relatively consistent across all tires. This uniformity can be attributed to the vehicle under test utilizing a rear-wheel drive system, resulting in similar temperatures between the front and rear tires. Additionally, we computed the mean and standard deviation of tire temperatures. According to the test results, the average tire temperatures were as follows: 29.8°C for the first tire, 27.9°C for the second tire, 28.6°C for the third tire, and 31.8°C for the fourth tire. The standard deviation values were determined as 1.05 for the first tire, 0.76 for the second tire, 1.19 for the third tire, and 1.05 for the fourth tire. Among these, the most favorable standard deviation value is 1.05. This indicates that third tire relatively low variability in temperature value.

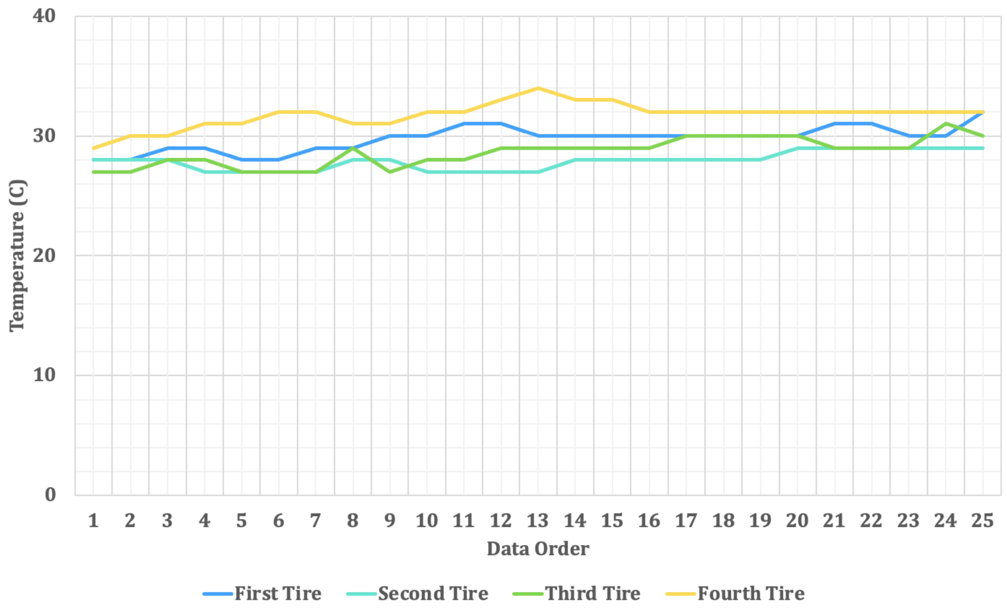

Figure 10. Tire Temperature Results for Multi-Purpose Vehicle

Based on the results, the system can monitor a vehicle's tire pressure and temperature data in real-time. This data is accessible remotely, allowing users to check it from a computer. Additionally, the information can be monitored via a smartphone. This ensures that users can keep track of their vehicle's condition from anywhere.

4. Conclusion

Vehicle accidents resulting from burst tires are common occurrences. Often, these accidents happen because drivers continue to operate their vehicles despite tire pressure and temperature exceeding safe thresholds. To address this issue, this paper presents a solution in the form of a vehicle tire pressure and temperature monitoring system, leveraging Internet of Things (IoT) technology. This system displays tire pressure and temperature information on various platforms, including LCD screen, computer, smartphone. It efficiently monitors variations in tire pressure and temperature through real-time tracking. The tests were conducted on both hatchback and MPV cars. The best standard deviation for

 DOI: https://doi.org/10.52435/jaiit.v6i1.545

tire pressure levels in hatchback cars is 2.24, while it is 2.97 for MPV cars, according to the results. The best standard deviation for tire temperature values in hatchback car is 1.93, while for MPV car, it is 1.05. This indicates relatively low variability in tire pressure and temperature. This system plays a vital role in enhancing vehicle safety and mitigating accidents stemming from tire conditions. In future studies, researchers aim to develop a system for monitoring tire pressure and temperature and tracking position of vehicle.

References

[1] A. Abbi and T. Ramakrishnaiah, "Tyre Pressure Monitoring System," *IOP Conference Series: Materials Science and Engineering,* vol. 1024, pp. 1-7, 2020.

[2] J. M. S. Waworundeng, D. F. Tiwow and L. M. Tulangi, "Air Pressure Detection System on Motorized Vehicle Tires Based on IoT Platform," in *2019 1st International Conference on Cybernetics and Intelligent System (ICORIS)*, Denpasar, Indonesia, 2019.

[3] N. N. Hasan, A. Arif, M. Hassam, S. S. U. Husnain and U. Pervez, "Implementation of Tire Pressure Monitoring System with wireless communication," in *2011 International Conference on Communications, Computing and Control Applications (CCCA)* , Hammamet, Tunisia, 2011.

[4] J. Zhang, Z.-H. Zhang, T. Chen, X.-M. Kong, T.-L. Ren and L.-T. Liu, "A Tire Pressure Monitoring System Based on MEMS Sensor," *Key Engineering Materials,* vol. 483, pp. 370-373, 2011.

[5] Z. Fuqiang, W. Shaohong, W. Yintao and X. Zhichao, "Indirect Tire Pressure Monitoring System Based on Tire Vertical Stiffness," in *2015 12th IEEE International Conference on Electronic Measurement & Instruments (ICEMI),* Qingdao, China, 2015.

[6] J. Zhao, J. Su, B. Zhu and J. Shan, "An Indirect TPMS Algorithm Based on Tire Resonance Frequency Estimated by AR Model," *SAE International Journal of Passenger Cars - Mechanical Systems,* vol. 9, no. 1, pp. 99-106, 2016.

[7] Q. Xin, G. Jingfeng, G. Junjie, B. ri, Y. Mingxing1 and Z. Pian, "Automobile Tire Pressure Monitoring Technology and Development Trend," *Journal of Physics: Conference Series,* vol. 1314, pp. 1-6, 2019.

[8] G. Phade, A. Kulkarni, O. Vaidya and S. Gandh, "Wireless Communication Based Effective Tire Pressure Monitoring System," *International Journal of Advanced Research in Engineering and Technology (IJARET),* vol. 11, no. 11, pp. 1282-1291, 2020.

[9] S.-s. Hwang, S.-m. Kim, J.-Y. Pyun and G.-R. Kwon, "Low-power TPMS Data Transmission Technique Based on Optimal Tire Condition," in *VEHICULAR 2013, The Second International Conference on Advances in Vehicular Systems, Technologies and Applications,* Nice, France, 2013.

[10] S. Grys, "An Experimental Test Bench for the Tire Pressure Monitoring System – Discussion of Measurement and Communication Issues," *International Journal of Electronics and Telecommunications,* vol. 65, no. 1, pp. 51-56, 2019.

[11] S. Kumar, P. Tiwari and M. Zymbler, "Internet of Things is A Revolutionary Approach for Future Technology Enhancement: A Review," *Journal of Big Data,* vol. 6, no. 111, pp. 1-21, 2019.

[12] A. Al-Fuqaha, M. Guizani, M. Mohammadi, M. Aledhari and M. Ayyash, "Internet of Things: A Survey on Enabling Technologies, Protocols, and Applications," *IEEE Communications Surveys & Tutorials,* vol. 17, no. 4, pp. 2347 - 2376, 2015.

[13] I. Yaqoob, E. Ahmed, I. A. T. Hashem, A. I. A. Ahmed, A. Gani, M. Imran and M. Guizani, "Internet of Things Architecture: Recent Advances, Taxonomy, Requirements, and Open Challenges," *IEEE Wireless Communications* , vol. 24, no. 3, pp. 10-16, 2017.

[14] Y.-P. E. Wang, X. Lin, A. Adhikary, A. Grovlen, Y. Sui, Y. Blankenship, J. Bergman and H. S. Razaghi, "A Primer on 3GPP Narrowband Internet of Things," *IEEE Communications Magazine,* vol. 55, no. 3, pp. 117 - 123, 2017.

[15] D. Manickam and K. B. Bhaskar, "IOT Based Real Time Measurement of Temperature for Inverter Using Low Cost Node Microcontroller," *nternational Journal of Advanced Research in Science, Communication and Technology (IJARSCT),* vol. 9, no. 5, pp. 150-158, 2020.

[16] J. D. d. Paiva, C. R. d. S. Junior and A. L. d. Silva, "IoT Application for Monitoring and Storage of Temperature History in Electric Motors," in *the 11th International Conference on Sensor Networks (SENSORNETS 2022),* 2022.

[17] C. Tipantuna, A. Yazan and J. Carvajal, "Containers-Based Network Services Deployment: A Practical Approach," *Enfoque UTE,* vol. 15, no. 1, pp. 36-44, 2024.

[18] H. Knoche and H. Eichelberger, "Using the Raspberry Pi and Docker for Replicable Performance Experiments: Experience Paper," in *The 2018 ACM/SPEC International Conference on Performance Engineering,* Berlin, Germany, 2018.

[19] A. Aboltins, "Software-Defined Radio Implementation and Performance Evaluation of Frequency-Modulated Antipodal Chaos Shift Keying Communication System," *Electronics,* vol. 12, no. 5, pp. 1240-1260, 2023.

[20] R. W. Middlestead, Frequency Shift Keying (FSK) Modulation, Demodulation, and Performance, Wiley Telecom, 2017.

[21] L. W. Jameel, "Manchester Coding and Decoding Generation Theoretical and Experimental Design," *American Scientific Research Journal for Engineering, Technology, and Sciences (ASRJETS),* vol. 42, no. 1, pp. 130-138, 2019.

 DOI: https://doi.org/10.52435/jaiit.v6i1.545