

TYRE PRESSURE MONITORING SYSTEM

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Abstract:The Internet of Things (IoT)-based Tyre Pressure Management System also known as TPMS uses an ESP8266 microcontroller with a BMP280 pressure sensor to measure tyre pressure and send alerts when required. The system monitors tyre pressure continuously, displays the data on an I2C based LCD, provides visual, audible and/or vibrating alerts based on pre-set levels for normal, low and critical tyre pressure conditions, and allows for remote monitoring of the device through Wi-Fi from the ESP8266 microcontroller by sending emails based upon abnormal conditions. TPMS will improve vehicle safety, fuel economy and maintenance management by implementing an efficient, low-cost, scalable system. The performance results of experiments performed by users indicate accurate and repeatable performance as well as a fast response time when pressure changes occur. Therefore, it is a viable system for use on personal vehicles, fleet vehicles and smart automotive monitoring systems.

Index Terms- Tyre Pressure Monitoring System (TPMS), ESP8266, BMP280 Sensor, Internet of Things (IoT), Real-Time Monitoring, Vehicle Safety, Embedded Systems, Wireless Communication, Alert System, Smart Automotive System.

I. INTRODUCTION

Tyre pressure is an important aspect of vehicle safety and dramatically influences many aspects of vehicle performance including fuel efficiency, braking ability, and tyre life. When tyre pressure is too low (under-inflated) or too high (over-inflated), it can affect how stable your vehicle is, how uniformly your tyres will wear, how much fuel you will use, and the likelihood that you will be involved in an accident. As a result, your tyre pressure must be monitored continuously to enable your vehicle to operate safely and efficiently.

Traditionally, tyre pressure monitoring has been completed through manual checks using a pressure gauge; however, due to the reliance on driver knowledge and the regularity of routine maintenance practices, these processes can be very unreliable, time-consuming, and generally poor at recognising changes in tyre pressure. Many drivers typically do not check their tyres regularly; therefore, they may not know if their tyres have lost air pressure until it is too late or their tyres experience a catastrophic failure. While many modern vehicles come with TPMS (Tyre Pressure Monitoring Systems), the cost of TPMS limits the use of these systems on more conventional or lower-cost vehicles.

Due to continuous advancements in IoT Technology it has enabled the possibility to create intelligent, automatic monitoring systems for automotive use. An IoT system can deliver real-time data collection, allows for wireless communication and provides users with remote monitoring capabilities. Because of the capabilities of IoT technology, we can also create new types of applications for tire pressure monitoring that are considered to be safety-critical and provide real-time alerts and notifications to users whenever there are any changes in the tire conditions outside of the norm.

This research illustrates the development of an IoT-based Tire Pressure Monitoring System that utilizes the ESP8266 microcontroller and BMP280 pressure sensor as a tire pressure monitoring system. Continuous tire pressure monitoring and real-time display of the tire pressure measurement on an LCD display will occur using the system. LED lamps will indicate whether the tire pressure is within normal limits, below normal limits or whether the tire pressure is at a critical level and a buzzer alert will sound whenever a tire is at a critical level. In addition to providing real-time alerts and notifications, the ESP8266 module will provide a Wi-Fi connection which monitors and sends email notifications to the user when the tire pressure is at critical levels.

The design includes an affordable system, is compatible with vehicle systems, and is simple to implement; however, the implementation will improve road safety, reduce cost associated with maintenance of vehicles, and be better fuel economy. In addition, the proposal offers a foundation for future development of scalable solutions (for example, cloud-based and mobile applications) as well as predictive maintenance capability for smart automotive systems in vehicle operations.

II. LITERATURE SURVEY

In their article, Li et al. introduced a real-time tyre wear monitoring algorithm that is intelligent, based on an understanding of finite element modal analysis, and has an approach that includes neural network technology. In this instance, the authors used the ABAQUS software to create a finite element model of a radial tyre (205/55/R16) and performed Finite Element Analysis to show how the tyre vibration frequency is influenced by inflation pressure, load (weight placed on the tyre), wear and road speed. They concluded that wear and inflation pressure significantly influence the characteristics of the vibrations of the tyre. In addition, the model was used to develop a neural network model to accurately predict the amount of wear on the tyre [1]. The researchers conducted an experimental study that compared the predicted values of the neural network with the actual values of tyre wear. The average error of the predicted, compared to the actual, amount of tyre wear was 0.0874 mm and the average error percentage was 2.78%. The authors of the article highlighted the use of intelligent tyre technology and the adoption of machine learning in developing advanced tyre condition monitoring systems that offer real-time monitoring options in automotive applications. Tong et al. presented a new intelligent tyre wear detection system driven by machine learning that is capable of accurately and rapidly determining tyre wear conditions from multiple environmental settings. In creating their system, Tong and his colleagues developed a multi-sensor intelligent tyre module composed of accelerometers and polyvinylidene fluoride (PVDF) sensors to capture both vibration signals and deformation signals associated with tyre wear [2], due to different tyre pressures, loads, speeds, and degrees of wear, respectively. The collected data were analyzed in both time and frequency domains, in order to detect specific characteristics indicative of tyre wear conditions. Additionally, to classify the type of wear detected, they performed signal preprocessing on the collected data and used deep learning techniques that employed convolutional neural networks to classify the detected wear type. The experimental results revealed that the proposed intelligent tyre wear detection system achieved a remarkable 99.99% accuracy for the successful detection of tyre wear, thus demonstrating its operationally robust, reliable, and practical capability for intelligent automotive monitoring systems. The authors concluded that the combination of multi-sensor data acquisition and machine learning techniques represents a powerful approach to improving the accuracy and reliability of advanced tyre condition monitoring and predictive maintenance systems. The Driver Fatigue and Alcohol Detection System proposed by Swathi-Rama Krishna to reduce vehicle collisions that result from driver drowsiness and alcohol consumption consists of an eye-blink sensing device for detecting signs of driver drowsiness and an alcohol sensor that detects whether or not the driver has consumed alcohol based on the level of alcohol that he/she breathes out. The proposed real-time monitoring system is microcontroller and sensor-based and continuously collects and monitors the driver's state in real time. When signs of driver drowsiness or alcohol consumption are detected, the proposed system issues warnings both visually (on a display screen) and audibly (using a loud beeping sound) while at the same time taking control of vehicle operation in order to prevent accidents from occurring [3]. The experimental findings showed that the proposed driver monitoring system is able to detect potential abnormal driver conditions with significantly greater response time and reliability than previously developed driver monitoring systems; moreover, the authors concluded that integrating intelligent vehicle safety monitoring systems with the vehicles themselves will increase road safety and reduce vehicle crashes caused by negligent drivers.

III. PROPOSED SYSTEM

An IoT-based tyre pressure monitoring system (TPMS) will continuously monitor the tyre pressure of a vehicle in real-time and provide an alert if there are any abnormal readings for the tyre pressure. The proposed TPMS utilises an ESP8266 (NodeMCU) microcontroller with the BMP280 pressure sensor as the data-acquisition, processing, and communication hardware to achieve an efficient solution for acquiring tyre pressure data and transmitting it via the Internet of Things (IoT) to a cloud-based application. The main focus of this system is to increase the safety of the vehicle, reduce the fuel required for powering the vehicle, and decrease the maintenance cost by continuously monitoring the condition of the tyre. This will allow those who own or manage both commercial and personal vehicles to know the status of the tyres at all times.

The BMP280 pressure sensor will continuously measure the tyre pressure and send the data to the ESP8266 microcontroller using I2C protocol. The ESP8266 will act as the processing unit for the TPMS's data. The data sent to the microcontroller will be processed and assessed against predetermined threshold values to ascertain the tyre's condition. The system will use the detected tyre pressure data to classify the tyre condition into three classifications; normal, low, or critical.

The system in this proposal includes integration of an I2C LCD display onto the system for real-time display of tyre pressure readings and for display of system-wide information. The system has also implemented a visual alert mechanism by way of LEDs will provide visual indicators for multi-tier alerts to the user for current tyre pressure conditions; these will include: green=normal conditions; orange=low pressure; red=critical pressure. To warn the user that there is a critical condition, during a critical condition, there will also be an audible alert in the form of a buzzer to the user as well. The system will also support IoT functionality through the Wi-Fi capabilities of the ESP8266 module. When the critical conditions for tyre pressure are identified, the system will send an email to the user to amplify the efficiency of monitoring the tyre pressure remotely, optimising response time and facilitation of corrective action, thereby increasing the awareness of the driver and ultimately reducing the potential for tyre failure and/or tyre-related accidents.

IV. SYSTEM ARCHITECTURE

The proposed IoT Tyre Pressure Monitoring System (TPMS) uses a layered architecture to efficiently detect, analyse, and notify of tyre pressure issues. This architecture combines the systems for detection, analysis, notification and communication allowing for continuous real time monitoring of tyre pressure along with an intelligent notification system. Modular design allows for seamless transfer of data between hardware elements while ensuring simplicity, expandability and reliability.

4.1 Sensors Layer

The sensors layer of the system includes the BMP280 pressure sensor that is responsible for continuous monitoring of tyre pressure values via an ESP8266 microcontroller using the I2C communication standard, which provides an accurate real time acquisition of tyre pressure values with a low amount of required wiring. The pressure values measured by the sensor are used as the most critical and primary data for the system.

4.2 Processing Layer

The Processing Layer will be developed using an ESP8266 (NodeMCU) Microcontroller, which acts as the central control for the system. The ESP8266 receives pressure data from a BMP280 Pressure Sensor and converts it to usable units of pressure (ex. PSI or Bar) as per customer requirements. The controller continually compares actual vs expected values against predefined thresholds to identify if a tire is categorized as either normal, low (loss of pressure) or critical (severe loss of pressure). Based on the analysis of the reported data, the controller will activate a related output (i.e. light, buzzer, etc.) and communication (i.e. text message) mechanism for reporting to the owner or authorized representative.

4.2 Output Layer

The output layer consists of an I2C LCD display, an LED indicator and a buzzer that will provide real-time user feedback on tyre pressure and system status messages. The LCD will continuously display tyre pressure values and system status information. The visual indication feature will use a multi-level mechanism to indicate the pressure level with an LED; green is for normal pressure, orange represents low pressure and red indicates critical pressure. The buzzer will also sound when critical pressure is detected to warn the user.

The sequencing of data in the proposed system from the BMP280 pressure sensor (which collects tyre pressure) through to the ESP8266 controller, which processes the data, and then displays that data on an LCD screen, generates alerts via LEDs and a Buzzer, and, in the case of critical conditions, provides email notifications via WIFI communication module, is representative of the overall architecture design of the proposed system; therefore, it provides a means to monitor, respond in real time to, and remotely alert users of critical conditions.

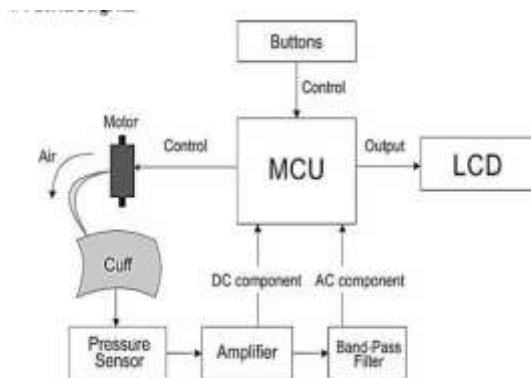


Fig.1. Block Diagram

Fig.1. The overall system structure of a pressure measuring application is outlined through a block diagram, with all major functions and components identified. The MCU is the main processing and control unit of the pressure measuring system, which consists of a cuff, motor, pressure sensor, amplifier, band pass filter and an LCD display, as well as button for user inputs. The cuff has a motor to inflate with the appropriate amount of air as instructed by the MCU. The pressure sensor is located inside the cuff, and upon deflation of the cuff the pressure change within the cuff is registered by the pressure sensor and converted to an electrical signal. The electrical signal is then amplified and filtered to remove unwanted noise from the electrical signal prior to being processed by the MCU. The MCU processes the information obtained from the processing of the pressure signals and makes decisions regarding how to operate the system based on user inputs from the buttons. After processing, the signals are used to indicate the current pressure level on the LCD display. An executable signal measurement and processing system can be achieved using the integrated architecture and its ability to measure signal levels, process data and provide real-time monitoring of pressure measuring systems to ensure accurate results.

The block diagram illustrates the architecture of the proposed IoT-based Tyre Pressure Monitoring System (TPMS) developed using the BMP280 pressure sensor and ESP8266 microcontroller. The BMP280 sensor continuously measures tyre pressure and transmits the sensed data to the ESP8266, which acts as the central processing and control unit of the system. The ESP8266 processes the received pressure data and determines the tyre condition based on predefined threshold values. The processed information is displayed in real time on the LCD module, while LED indicators provide visual alerts for different pressure levels. In critical pressure conditions, the buzzer generates an audible warning to immediately alert the user. Additionally, the ESP8266 utilizes Wi-Fi connectivity to send email notifications for remote monitoring and alert generation. The proposed architecture ensures efficient real-time pressure monitoring, fast response to abnormal conditions, and reliable IoT-based communication for improved vehicle safety and maintenance.

V. RESULTS

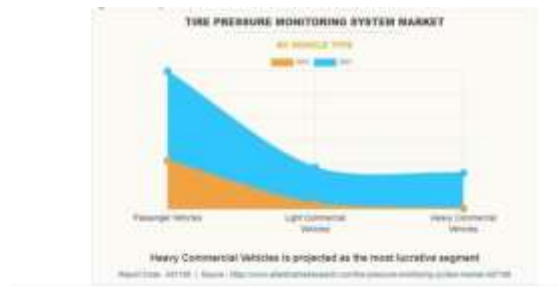


Fig. 2. Tire Pressure Monitoring System (TPMS) Market Analysis by Vehicle Type (2021–2031)

Fig.2. illustrates the projected growth of the Tire Pressure Monitoring System (TPMS) market across different vehicle categories, including passenger vehicles, light commercial vehicles, and heavy commercial vehicles, from 2021 to 2031. The analysis indicates a significant increase in TPMS adoption, particularly in passenger and heavy commercial vehicles, driven by the growing demand for vehicle safety, fuel efficiency, and intelligent automotive monitoring systems. The rising market trend highlights the importance of advanced TPMS technologies and supports the development of IoT-based real-time tyre pressure monitoring solutions for modern transportation systems.

Table 1. Performance Evaluation

Parameter	Performance
Accuracy	High
Response Time	Fast
Reliability	Stable
Communication	Efficient
Cost	Low

Table 1. The IoT-based tyre pressure monitoring system's performance evaluation showed a high level of accuracy in relation to measuring tire pressures, with reliable tyre condition monitoring. The system provides a fast response time to detect variations in pressure and sends out alerts to indicate when there is something wrong. It has reliable system stability due to continuous real-time monitoring and efficient alternate data processing. Furthermore, because the ESP8266 enables quick wireless communication (utilizing Wi-Fi) to provide remote alerts, the entire system is low cost and easy to implement, making it a viable option for real world automotive monitoring solutions.

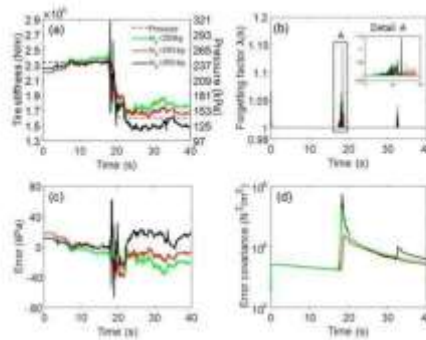


Fig. 3. Performance analysis of tyre stiffness estimation under varying load conditions

Fig .3. presents the performance evaluation of tyre stiffness estimation and error analysis under different vehicle load conditions. Figure (a) illustrates the variation of tyre stiffness with respect to time for different masses, showing that the system effectively tracks pressure-related stiffness changes during operation. A noticeable transient response is observed around 18–20 seconds due to sudden pressure variation, after which the system stabilizes and continues monitoring accurately. Figure (b) represents the forgetting factor variation used in the adaptive estimation process, indicating stable parameter adaptation with minor fluctuations during transient conditions. Figure (c) shows the estimation error analysis, where the error remains within acceptable limits after the transient response, demonstrating reliable estimation performance. Figure (d) illustrates the error covariance response, highlighting the stability and convergence characteristics of the estimation algorithm. Overall, the results demonstrate that the proposed monitoring and estimation approach provides stable, accurate, and reliable tyre condition analysis under varying operational conditions, making it suitable for real-time automotive monitoring applications.

VI. CONCLUSION

The proposed IoT based tyre pressure monitoring system (TPMS) illustrates both a very efficient and reliable way of achieving real-time tyre pressure monitoring along with providing alerts in terms of abnormal tyre pressure situation. The combination of the BMP280 pressure sensor with the ESP8266 microcontroller continuously monitors the tyre's current condition and will immediately give visual, audible and remote alerts in regard to tyre pressures that are outside of acceptable parameters. The use of IoT technology with Wi-Fi communications provides the added advantage of allowing remote monitoring, increasing user awareness, improving vehicle safety, and thereby decreasing the chances of failure due to tyre problems. The TPMS will have several additional advantages including; real-time monitoring; low power consumption; ease of installation; reduced maintenance costs; increased fuel economy; longer tyre life. The advanced flexibility and scalability offered by the TPMS allows the system to be expanded in the future for use with cloud platforms, mobile applications, GPS systems and predictive maintenance systems. These advantages make the TPMS technology applicable in many industries including automobiles; commercial trucks; fleet management; industrial machinery; logistics; agriculture equipment; and smart transportation systems, thus being an excellent solution for the present-day automotive and IoT safety system.

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