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Automobile Tyre Health Monitoring System

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ABSTRACT
Automotive Tyre Health Monitoring Systems (ATHMS) play a key role in keeping a vehicle safe and in good working order. The Tyre Pressure Monitoring System (TPMS) research paper explores the technology, advantages, challenges, and future advancements of TPMS. Flats are a major cause of frequent accidents and crashes because even a small, sharp object can cause serious damage to Tyres.The system uses image processing to detect flats in each Tyre and automatically monitors them to minimize manual work. The findings highlighted how TPMS can improve vehicle safety, prevent accidents and increase fuel efficiency.

1. INTRODUCTION

A Tyre Pressure Monitoring System (TPMS) is a safety feature designed to monitor tyre pressure, detect significant under-inflation, and alert the driver accordingly.
Tyres are among the most vital safety components of a vehicle, yet they are often overlooked. On average, there is one flat tyre for every 50,000 km driven, with over half caused by under-inflation. Additionally, three-fourths of all tyre issues result from a gradual loss of pressure due to slow leaks or under-inflation.
Automobiles are an integral part of daily life, serving as a means to transport goods and people. However, in remote areas, repairing a punctured tyre can be quite challenging. Over the years, inventors have developed various tyre designs, many of which are now widely adopted by major automakers.
India has one of the highest rates of road accidents and unintentional fatalities globally. Poor road infrastructure, especially in hilly regions, plateaus, and areas with inadequate road services, contributes significantly to the high accident and fatality rates.
Overinflating tube-type tyres can cause excessive stretching at the joints, weakening them. Worn tyres are particularly vulnerable, as even small objects can easily puncture them. Overinflation also generates excessive heat due to increased friction, further raising the risk of punctures. Additionally, factors such as rim bending, weak sidewalls, broken cords, and rust buildup in tubeless tyres can make them susceptible to punctures caused by external objects.
Image processing plays a vital role in analyzing tyre density. In a TPMS study, various methods for monitoring and detecting punctures were reviewed and compared, focusing on image acquisition and processing techniques. The aim to enhance pressure monitoring and automate puncture detection, minimizing the need for manual intervention. One such innovation involves using MATLAB-based image processing for automatic puncture detection.

TPMS seeks to evaluate the feasibility of leveraging automotive sensors to deliver real-time tyre pressure and puncture monitoring via a digital platform, offering a potential solution to the challenges.

2. LITERATURE SURVEY

The Automobile Tyre Health Monitoring System has been proposed by various method from the following literature survey given below:

Elsasser Devin et al, proposed an idea of [9] where evaluating tyre through two main methods Wheel based TPMS and Pressure sensor based TPMS. The proposed method enables to achieve TPMS alerts drivers to underinflated tyres, reducing the risk of tyre blowouts and accidents. However, a significant drawback was High initial cost that is Implementing TPMS can be expensive, especially for fleet vehicles.

Akshay Vishnoi et al. suggested a method [10] for monitoring tyres using a honking alarm and LCD display. TPMS system enhances fuel efficiency by maintaining optimal tyre pressure and extending tyre lifespan, though it has a drawback of potential security risks associated with wireless communication.

Stella Banou et al. proposed a method [11] utilizing an amplifying receiver to read signals and decode data, allowing for flexibility in frequency and protocol adjustments. However, its reliability is constrained in harsh environments.

Jennifer Drain et al. introduced a system [12] that periodically measures tyre pressure and adjusts it to the desired level. TPMS approach improved fuel efficiency and traction but required regular maintenance to replace battery-powered sensors.

Odafe Ojenikoh designed a TPMS [13] powered by sensors with transmitters embedded in the tyre rim, using Zigbee for wireless communication. While TPMS ensured low power consumption and extended sensor battery life, Zigbee signals were susceptible to interference from nearby wireless devices.

T. Xiangjun proposed a method [14] to measure tyre pressure in both stationary and moving vehicles using a long-lasting battery. TPMS method reduced rolling resistance and improved fuel efficiency but faced technical challenges in sensor accuracy and reliability.

Hua et al. focused on tyre design and post-manufacturing processes [15] to enhance tensile strength and toughness using RTSC and RTSF. However, the presence of fibers and cords reduced compressive strength and workability.

Varghese demonstrated [16] that increasing tyre pressure from 2 to 3 bars could reduce fuel consumption by 5%, improving handling and stability. However, over-inflation posed risks such as reduced traction, increased rolling resistance, and poor ride quality.

Jansen S et al. highlighted [17] that poor tyre maintenance accounts for 30% of road accidents. Regular tyre checks can identify issues like underinflation, uneven wear, and damage. However, here recommendations might not be universally applicable due to regional differences in tyre use.

Toma M et al. explained [18] that under-inflated tyres exhibit unusual wear patterns, potentially misinterpreted as brake or suspension issues. Proper inflation ensures accurate diagnosis, but TPMS adds complexity to maintenance.

Kasprzak et al. proposed a method demonstrating that increasing inflation pressure reduces aligning torque, which, when applied to a vehicle, decreases steering effort and rigid body aligning torque [19]. This approach helps optimize inflation pressure for enhanced tyre performance and fuel efficiency. However, it falls short in fully addressing tyre dynamics and the underlying physics needed to comprehensively interpret the results.

Godlewska J described [20] tyre recycling methods in Poland, emphasizing energy recovery and rubber reuse to minimize environmental harm. Yet, the high initial cost of setting up recycling facilities is a significant challenge.

Torretta et al. discussed [21] the European Union's strategies for sustainable tyre waste management, such as ELT recycling and multi-material packaging. The approaches are primarily EU-centric, limiting its applicability elsewhere.

Wadmare A.V et al. introduced an automatic system [22] for maintaining optimal tyre pressure, enhancing safety and reducing tyre wear. However, the system's reliance on electronic components makes it prone to failure.

A.K.Arshad et al, proposed the Proper tyre inflation can significantly impact the contact pressure and footprint area of a tyre on a flexible pavement surface[23].By this process, it enables to execute reduced wear and tear on pavement surfaces in enhancing road safety due to better traction and braking performance but has flaws in over-inflation, leading to reduced comfort and increased risk of tyre blowouts.

Anton Albinsson et al. stressed [24] the importance of calibration for accurate testing of vehicles and tyres. While TPMS ensures real-world representation, results can be influenced by factors like road conditions and driver behaviour.

Zain Anwar Ali et al. described [25] the use of EAGs for accurate tyre pressure readings, with real-time monitoring. Despite its benefits, The systems depend on power sources and connectivity, leading to potential malfunctions.

Sebaaly et al[26], designed the theory where Tyre type affects rolling resistance, traction, and braking performance, with different types suited to specific applications. By this practice, it enables to execute offering insights into the effects of tyre pressure, axle loads, and vehicle configurations on pavement wear but limited scope on focusing on a specific aspect of pavement damage.

Caban J et al, proposed the method where Temperature, for instance, affects tyre pressure significantly [27]. By this process, it enables to achieve in providing insights into the relationship between tyre pressure and various factors such as temperature, speed, and tyre type but lacks in focusing on a specific set of factors, which might not be comprehensive.

3. METHODOLOGY

It follows that the fleet's pressure and punctures in all vehicles are monitored at real time, even when they are running, and not only after returning to the home base. Additionally, by this system, there can be immediate responses to changes in any of the parameters, where both the driver and the management center are alarmed to take appropriate prompt actions and make the correct decision.

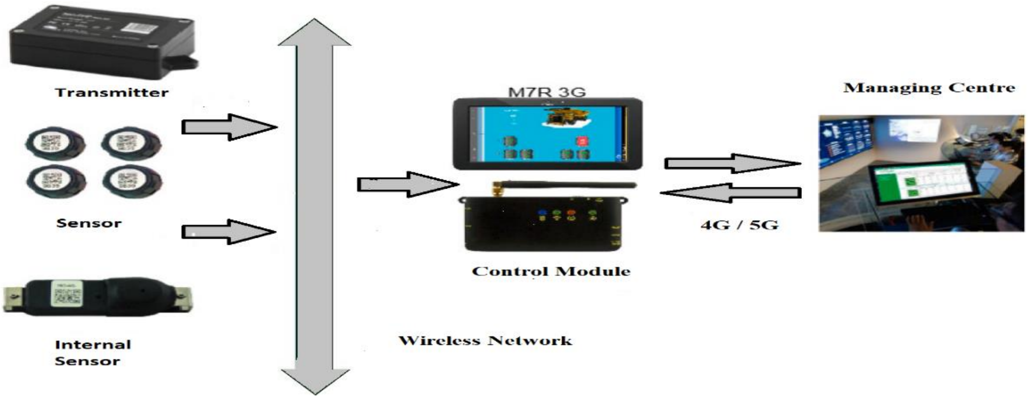


Fig.1 Components involved in monitoring system

It was anticipated that implementing the system would improve tire performance, extend their lifespan, and reduce the amount of waste generated annually by the company. The system's structure is outlined as follows: a TPMS sensor installed inside the tires measures air pressure and detects punctures. The collected data is wirelessly transmitted to a display in the driver's cabin via a mobile device running the Android system. The monitored information is presented on the screen in chart form.

Commercial components, such as sensors and antennas, were used to build the system, with the primary innovation being the creation of a platform with appropriate sampling rates and communication, along with the development of dedicated tools to support centralized decision-making. Pressure is measured in bars [bar], and temperature is measured in degrees Celsius [°C].

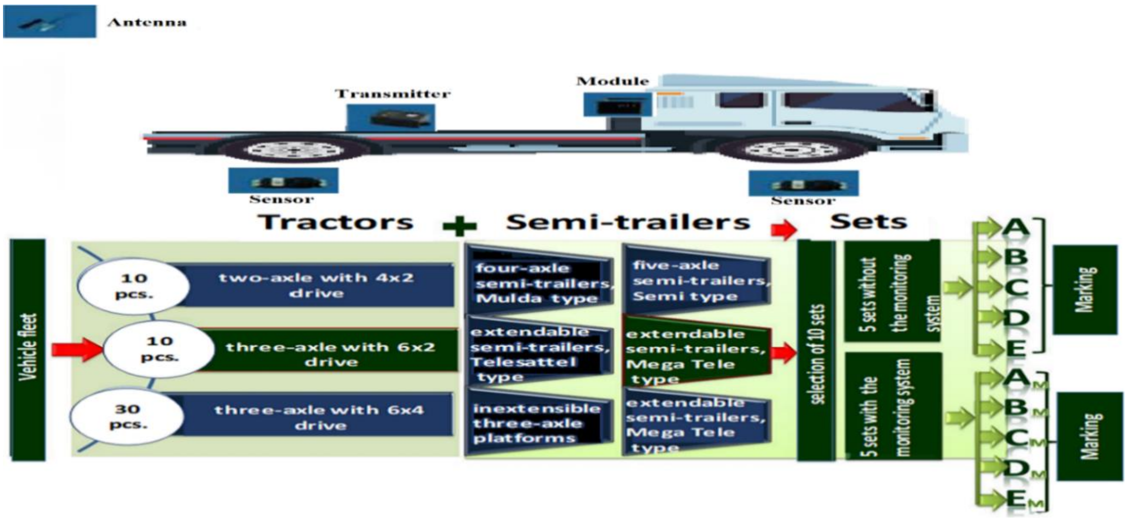


Fig 2. elements arranged in vehicle for monitoring

During the tests, undamaged tires on both monitored and unmonitored vehicles were neither replaced nor moved to different axles. The tires were inflated, with some also undergoing tread deepening. Each tire was labeled using a specific marking system. For instance, "vehicle A, tire A4" refers to tire C on the first axle of vehicle A. If an alert is triggered, the driver of a monitored vehicle stops at the next scheduled stop or the first available motorway exit to adjust the tire pressure. Moreover, the system detects issues before significant pressure loss occurs.

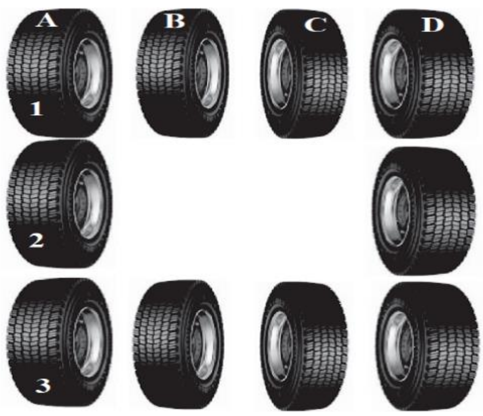


Fig 3. Tyre format in large fleet vehicles

Furthermore, the system can identify faults before the pressure falls below the lower tolerance limit. During the analysis period, a gradual decrease in tire pressure was noted due to a leak. The system enabled early detection of the issue during the vehicle's initial operation, preventing further damage.

3.1 FLOWCHART

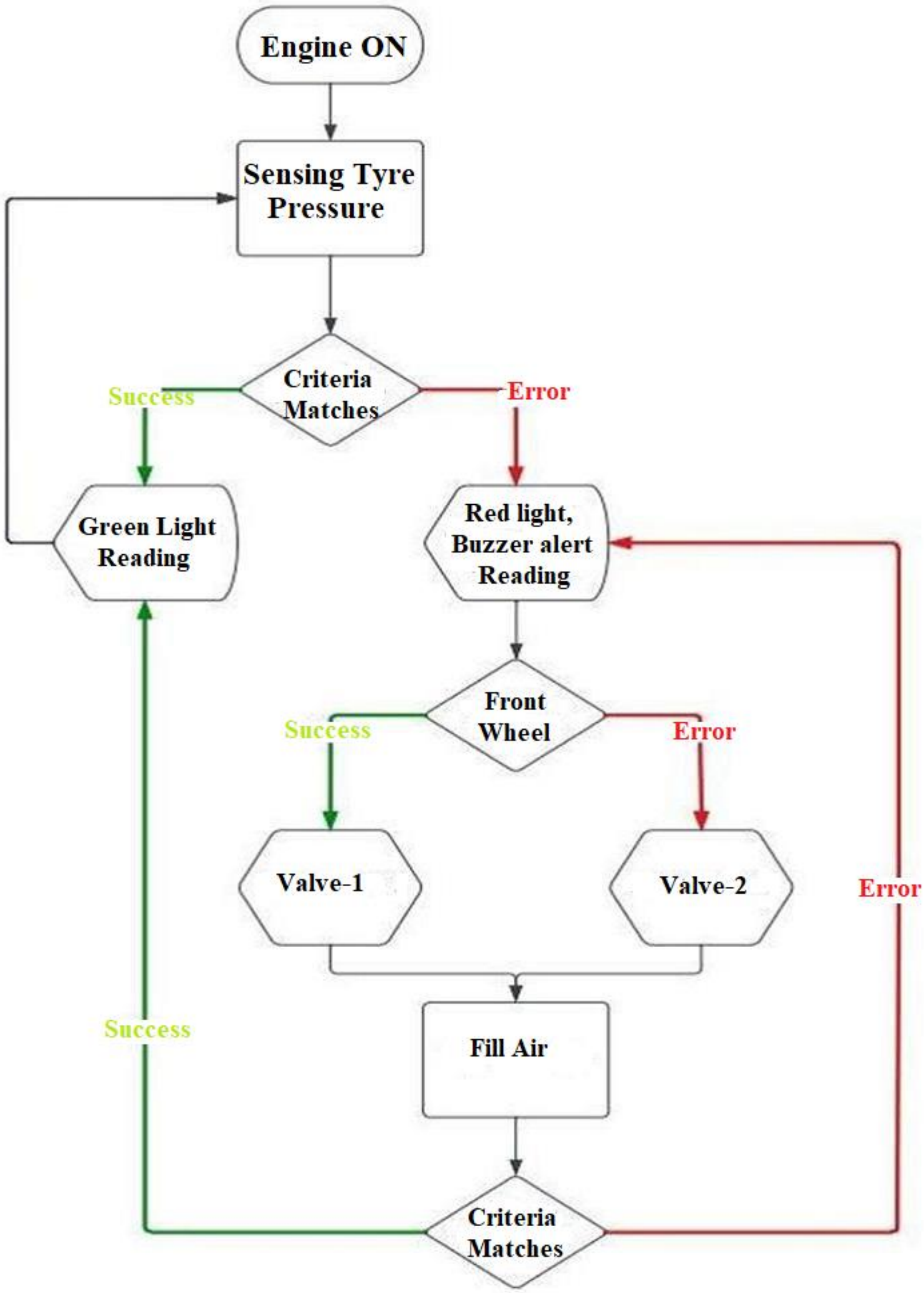


Fig.4 Flowchart for Automobile tyre health monitoring system

3.2 BLOCK DIAGRAM

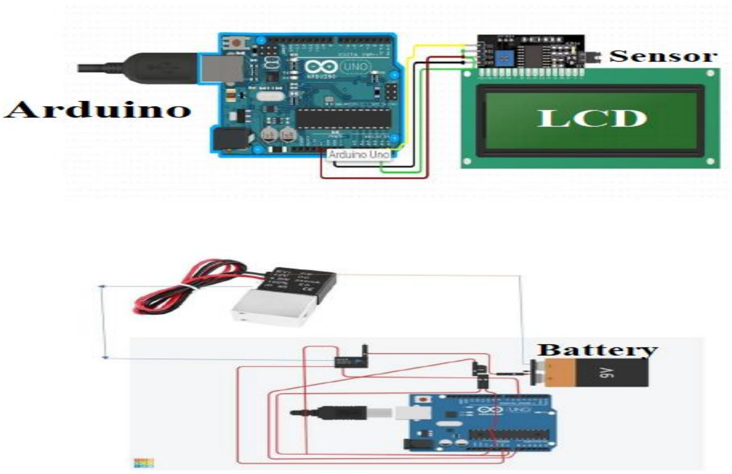


Fig 5. Block illustration of Automobile tyre health monitoring system

4. IMPLEMENTATION

Implementing a Automobile tyre health monitoring system in the real world involves a combination of sensor technology, wireless communication, data processing, and user interface integration. The process typically starts with embedding sensors within the tyres or wheel assembly of vehicles during manufacturing or as an aftermarket installation. The sensors track major parameters like tyre pressure, temperature, and then transmit data wirelessly to the vehicle's onboard system.

In real-world applications, the most commonly used type of Tyre Health Monitoring System (THMS) is the Tyre Pressure Monitoring System (TPMS), which is required by law in many areas, including the U.S. and the EU, for all new vehicles. The TPMS utilizes pressure sensors installed inside each Tyre or valve stem to monitor inflation levels. If a Tyre's pressure drops below a set threshold, the system activates an alert on the vehicle's dashboard, notifying the driver to take appropriate action.

Advanced Tyre Health Monitoring systems, especially in commercial fleets, integrate not only pressure sensors but also temperature and tread wear monitoring. The systems are connected to cloud-based platforms, where data from multiple vehicles is aggregated and analyzed using predictive analytics. TPMS allows fleet managers to monitor tyre health remotely, optimizing maintenance schedules and preventing costly blowouts.

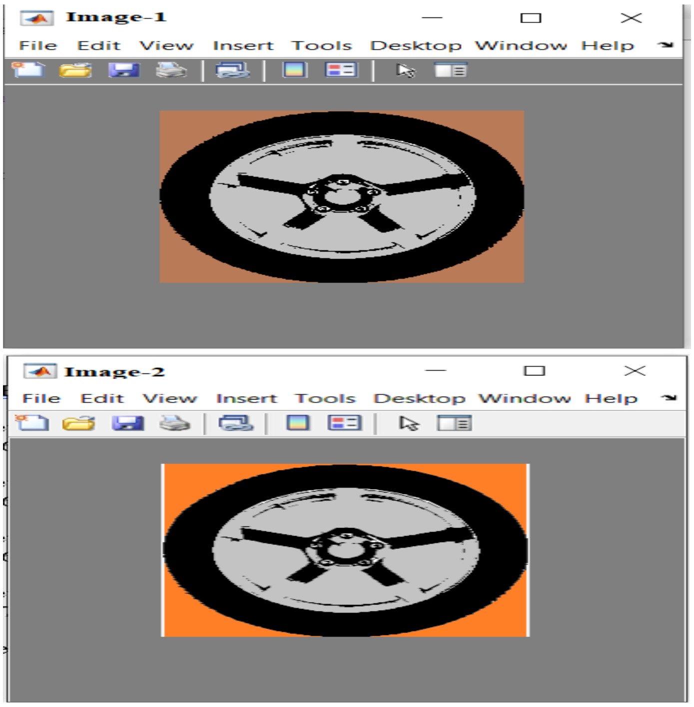
In industries like logistics, where vehicles are subject to high usage, such systems are crucial for reducing downtime and maintenance costs, improving fuel efficiency, and ensuring driver safety.

Fig 6. Device placed on Dashboard

Fig 7. Sensors mounted on vehicle wheel

5. RESULT AND DISCUSSION

Sample outcome obtained from Matlab Application:



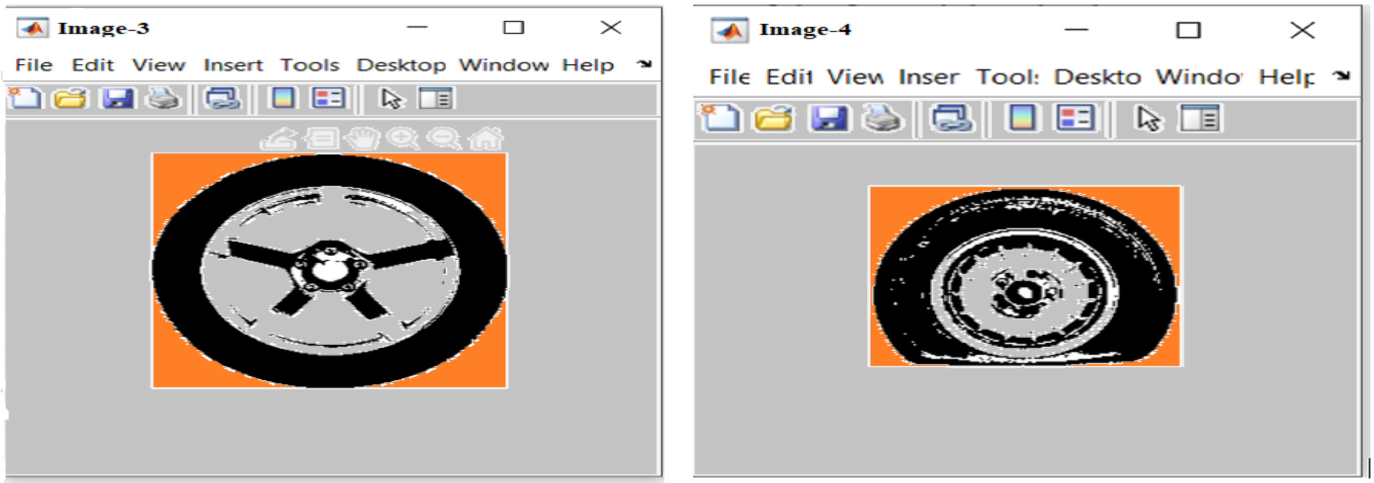


Fig 9. Captured image in application

A simulation model for is a digital imitation of the system's behaviour, used to test and evaluate its performance. It allows us to simulate various scenarios, such as changing environmental conditions, irregular tyre pressure, and system failures, without physically exposing the system to The conditions.
A TPMS simulation model is typically built using programming languages like MATLAB or Simulink, incorporating detailed tyre and atmospheric models, as well as sensor simulations.
Market evaluation suggests that ATHMS has improved road safety, reduced fuel consumption, and lowered maintenance costs. The target audience for Automobile Tyre Health monitoring sytem(ATHMS) in real life includes various individuals and groups. First and foremost, car owners are the primary users of ATHMS. It benefit from the system's warnings and alerts, ensuring Its safety while driving. Fleet managers, who oversee large vehicle fleets, also benefit from ATHMS to optimize tyre performance and prolong the lifespan of Its vehicles. Additionally, tyre professionals, such as mechanics and technicians, may also be interested in ATHMS to diagnose and repair tyre issues more effectively.
Accuracy of Automobile Tyre Health Monitoring System To illustrate the accuracy differences graphically, a comparative chart can be created that compares the accuracy of several popular TPMS brands, such as:

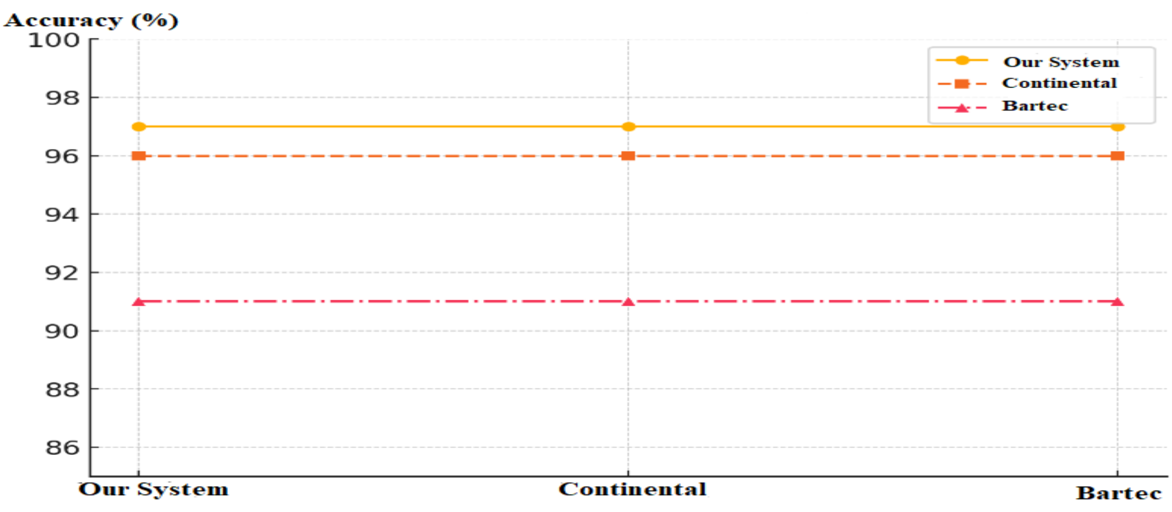


Fig 10. Comparison

Thread-wear after certain distance

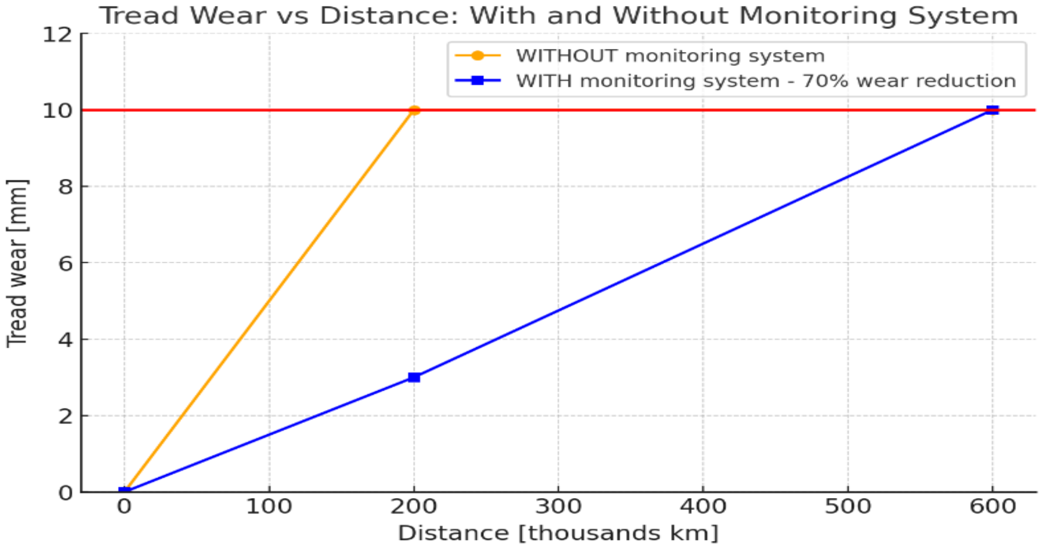


Fig 11. Tread wear from distance travelled

Here graph representing tread wear vs distance with and without a monitoring system. The orange line represents tread wear without a monitoring system, reaching the maximum tread wear (10 mm) much sooner, while the blue line shows a 70% reduction in wear with the monitoring system, extending the tyre's lifespan over more kilometres.

Confusion Matrix For a binary classification (Normal Pressure vs. Abnormal Pressure)

This confusion matrix comprises four elements:

True Positive(TP), True Negative(TN), False Negatives (FN) and False Positives(FP)

To calculate the confusion matrix needs actual and predicted labels. Based on the sample data, ATHMS can calculate the confusion matrix together. With help of an example scenario:

Total tyres checked: 100

Actual normal pressure: 70

Actual abnormal pressure: 30

TP = 25 TN = 60

FP = 10 FN = 5

Let's calculate and visualize the confusion matrix

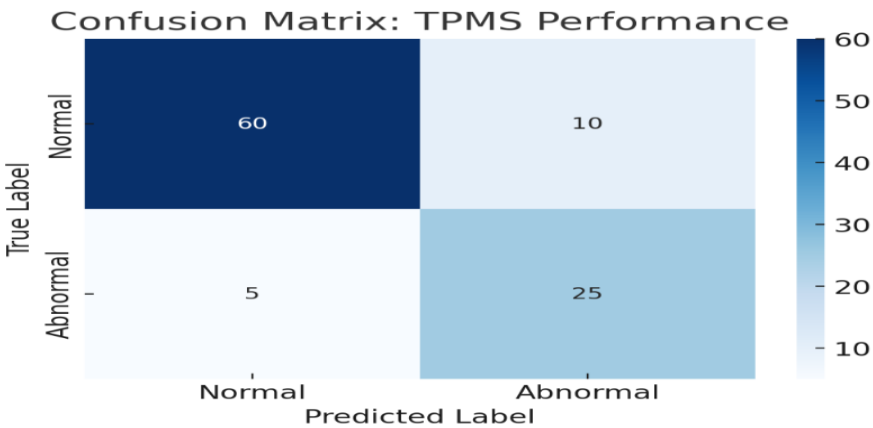


Fig 12. Confusion matrix for Normal vs Abnormal pressure

Here is the confusion matrix for the Automobile Tyre Health Monitoring System (ATHMS) performance:
TP: 25
TN: 60
FP: 10
FN: 5
TPMS confusion matrix helps evaluate the system's ability to correctly identify tyre pressure issues and where it might need improvement.

6. CONCLUSION

ATHMS plays a significant role in playing for improvising vehicles tyre performance also capability incorrect tyre pressure can lead to excessive heat mechanical stain and ultimately tyre failure that poses high risks to both the driver and the surrounding environment while it became easy to implement a monitoring system in larger vehicles a significant challenge lies in compressing and installing such a system in commercial vehicles without losing either performance or accuracy this proposed device is believed to combine alert notifications with tyre health monitoring capability. Users will inflate Tyres without lengthy procedures. It promises to bring an improvement in drivers' safety through immediate notifications when the tyre is damaged. In addition its installation in larger vehicles will increase tyre lifespan with decreased rates of fuel consumption and other improved overall vehicle stabilities. It also saves drivers' finances and time with prevalent identification and rectification of the matters present within the tyre problems, thus avoiding expensive repair or replacement cases. Moreover, its seamless integration into the existing vehicle systems can also help other tyres in serving other drivers as though they check the condition of their tyres, thereby minimising the risk of eventual accidents.
As a future implementation,some measures can be rectified by High development costs, complexity in integrating with existing vehicle systems, and limited consumer awareness and understanding of the technology's benefits. Additionally, regulatory hurdles and certification requirements may pose significant barriers to market entry, particularly in regions with strict safety and quality standards.

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