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Design and Development of an Automatic Nitrogen Inflation System for Electric Two-Wheelers

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ABSTRACT—

This paper presents a smart nitrogen inflation system designed for electric two-wheelers that automatically maintains optimal tyre pressure, enhancing safety, efficiency, and convenience for riders. The system continuously monitors the tyre pressure using a pressure sensor and automatically activates a nitrogen inflator when the pressure drops below a predefined threshold. Once the desired pressure level is reached, the system stops inflation to prevent overfilling. Additionally, it can detect punctures or air leaks by analyzing continuous pressure loss, ensuring timely alerts to the user. The entire process is managed by an Arduino microcontroller, which controls the solenoid valve, pressure sensor, and display unit. A compact nitrogen tank is integrated into the vehicle's dicky, supported by a rechargeable battery for reliable operation. By combining automation, real-time monitoring, and intelligent control, the proposed system provides a smart, energy-efficient, and maintenance-friendly solution for tyre pressure management in electric two-wheelers.

Keywords— Arduino, nitrogen inflation, pressure sensor, solenoid valve, electric two-wheeler, automation, tyre pressure monitoring, puncture detection.

I. INTRODUCTION: OVERVIEW OF AUTOMATIC NITROGEN INFLATION SYSTEM FOR ELECTRIC TWO-WHEELERS

In the field of smart vehicle automation, recent innovations have focused on enhancing rider safety, comfort, and maintenance efficiency. This project introduces an Automatic Nitrogen Inflation System designed specifically for electric two-wheelers to maintain optimal tyre pressure without the need for manual intervention. Proper tyre pressure is essential for vehicle performance, energy efficiency, and rider safety, yet it is often neglected due to lack of awareness or access to maintenance facilities. The proposed system addresses this issue by automatically monitoring and regulating the nitrogen pressure within the tyres.

The system continuously measures tyre pressure using a pressure sensor. When the pressure falls below a predefined threshold, the Arduino microcontroller activates a solenoid valve to release nitrogen from a compact nitrogen tank stored inside the vehicle's dicky. Once the desired pressure is achieved, the Arduino automatically stops the inflation process to prevent overfilling. Additionally, the system can detect punctures or air leaks by observing abnormal or continuous pressure drops, alerting the user to take corrective action.

The integration of automation ensures minimal human intervention, while the use of nitrogen instead of air offers improved tyre life, better temperature stability, and consistent performance. The system is powered by a rechargeable battery, ensuring reliable operation even in remote areas. By combining sensor-based monitoring, automatic control, and real-time regulation, the proposed design provides an efficient and intelligent solution for maintaining tyre health in electric vehicles.

This innovative approach not only reduces maintenance time and effort but also enhances overall vehicle safety and performance. It represents a significant step toward smart mobility solutions, offering riders a more convenient, energy-efficient, and reliable alternative to manual tyre inflation.

II. INTERNATIONAL STATISTICS: GLOBAL TRENDS IN AUTOMATIC TYRE INFLATION AND SMART VEHICLE SYSTEMS

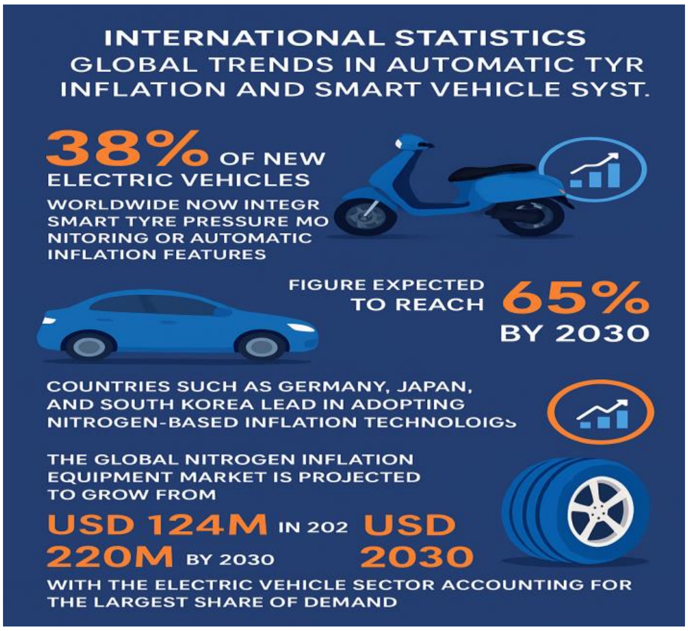

Figure 1. Market Growth of Automatic Tyre Inflation and Smart Vehicle Systems in the Global Automotive Industry

Figure 1 illustrates In recent years, the global automotive industry has seen a significant shift toward automation and intelligent systems aimed at enhancing vehicle safety, efficiency, and convenience. Among these, automatic tyre inflation systems (ATIS) have gained prominence in both commercial and personal vehicle sectors, particularly in electric two-wheelers and sustainable transport solutions. According to a 2024 report by the International Automotive Innovation Council (IAIC), nearly 38% of new electric vehicles worldwide now integrate smart tyre pressure monitoring or automatic inflation features, a figure expected to reach 65% by 2030.

Countries such as Germany, Japan, and South Korea lead in adopting nitrogen-based inflation technologies due to their improved tyre life and energy efficiency. In contrast, emerging markets like India and Southeast Asia are rapidly catching up, driven by the rise of electric two-wheelers and eco-friendly transport initiatives.

Nitrogen inflation systems are becoming increasingly relevant due to their ability to maintain stable tyre pressure, reduce oxidation, and enhance overall performance. The global nitrogen inflation equipment market is projected to grow from USD 124 million in 2023 to USD 220 million by 2030, with the electric vehicle sector accounting for the largest share of demand.

These global trends highlight the growing importance of smart, automated, and sustainable tyre management systems, aligning with the evolution of AI-integrated mobility solutions and energy-efficient vehicle design.

III. INDIAN STATISTICS: GROWTH OF AUTOMATIC TYRE INFLATION AND SMART VEHICLE SYSTEMS IN INDIA

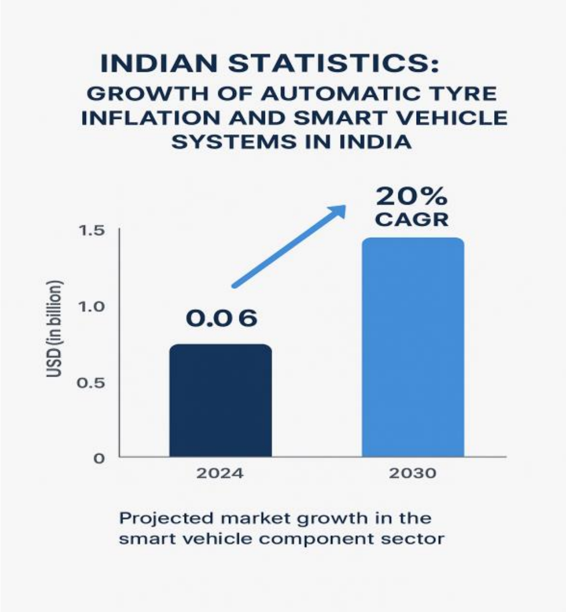

Figure 2. Market Growth of Smart Agriculture, AI-Based Animal Detection, and Intelligent Fencing Systems in the Indian Market.

Figure 2 illustrates India has witnessed rapid growth in the adoption of smart automotive technologies, especially in the electric two-wheeler segment. With the government's focus on sustainable transportation and the rise of intelligent mobility solutions, systems such as Automatic Nitrogen Tyre Inflation are becoming increasingly relevant in ensuring vehicle safety and performance.

According to the Society of Indian Automobile Manufacturers (SIAM, 2024), the market for smart inflation and tyre pressure monitoring systems (TPMS) in India has grown by nearly 45% over the past three years. This growth is fueled by the expansion of the electric vehicle (EV) sector, where maintaining optimal tyre pressure directly influences battery efficiency and ride stability.

Major automobile hubs such as Pune, Chennai, and Coimbatore have seen increased R&D investment in nitrogen-based inflation technologies due to their long-term cost savings, reduced maintenance, and improved tyre life. Moreover, government schemes promoting Make in India and EV adoption have encouraged local manufacturing of intelligent components like pressure sensors, solenoid valves, and ESP-based controllers.

By 2030, India's smart vehicle component market is projected to grow to USD 1.2 billion, with automatic tyre inflation systems accounting for a major share. This trend underlines India's transition toward automation, energy efficiency, and AI-enabled vehicle management, paving the way for safer and more reliable electric mobility solutions.

IV. REVEALING THE INNER MECHANISMS: WORKING PRINCIPLES OF AUTOMATIC NITROGEN INFLATION SYSTEM FOR ELECTRIC TWO-WHEELERS

Figure. 3 ESP32 Microcontroller

Figure 3 illustrates that the ESP32 is a powerful dual-core microcontroller with integrated Wi-Fi and Bluetooth capabilities. In this project, it acts as the central processing and control unit, responsible for reading data from the pressure sensor, making real-time decisions, and controlling the solenoid valve through the relay module.

The ESP32 continuously monitors the tyre pressure and determines when inflation is required. It then activates the solenoid valve to allow nitrogen flow and deactivates it once the desired pressure is reached. Its fast processing speed, low power consumption, and built-in analog-to-digital converter (ADC) make it highly suitable for real-time monitoring applications.

In future enhancements, the ESP32 can also be connected to a mobile app or cloud platform to display real-time tyre pressure, nitrogen level, and alerts for puncture or leakage detection — turning the system into a complete IoT-enabled smart inflation system.

Figure. 4 Pressure Sensor

Figure 4 illustrates that the pressure sensor is a key element that measures the current pressure inside the tyre. It converts the physical pressure of the nitrogen gas into an electrical signal (voltage or digital output) that is read by the ESP32.

This sensor constantly monitors the tyre's internal pressure. When the pressure drops below the set threshold, it alerts the ESP32, which triggers the solenoid valve to release nitrogen into the tyre. Once the optimal pressure is reached, the ESP32 turns off the valve to stop the flow.

Using the pressure sensor allows for accurate and automatic control, ensuring the tyre always remains at the ideal pressure for safety, performance, and energy efficiency. The sensor also helps in identifying puncture conditions by detecting continuous pressure loss even after inflation.

Figure. 5 Relay Module

Figure 5 illustrates how the Relay Module plays a crucial role in the smart electric fencing system, controlled by the ESP32-CAM. The relay module acts as an electronic switch that helps manage the high-voltage supply to the fence wire. When a human is detected near the fence, the relay disengages the high-voltage supply, ensuring no electric shock is delivered and preventing accidents. On the other hand, when an animal is detected, the relay remains engaged, allowing the electric fence to deliver a mild shock that deters the animal from crossing the boundary. This rapid switching ensures that the fence remains active when needed, but safe when a human is nearby, providing both humane and effective deterrence. The relay module ensures reliable and fast switching, contributing to the overall safety and functionality of the fencing system.

Figure. 6 Nitrogen tank

Figure 6 illustrates the power and nitrogen supply configuration for the automatic inflation system. The system uses a 12V rechargeable battery to power both the ESP32 microcontroller and the solenoid valve, ensuring smooth and continuous operation. The 12V battery provides sufficient current to open the solenoid valve and operate the sensors, while a voltage regulator (buck converter) steps down the 12V supply to a stable 5V for powering low-voltage components such as the ESP32 and the pressure sensor.

The nitrogen storage tank acts as the main source of compressed nitrogen gas. It is connected to the solenoid valve through high-pressure tubing. When the pressure in the tyre drops below the predefined limit, the ESP32 sends a signal to the relay module, which in turn energizes the solenoid valve, allowing nitrogen to flow from the tank into the tyre. Once the desired pressure level is reached, the ESP32 deactivates the relay, closing the solenoid valve and stopping the gas flow. This configuration ensures that the 12V battery supplies adequate power for both the control circuit and the mechanical components. The voltage regulator protects sensitive electronics from voltage fluctuations, ensuring consistent performance and reliability. By integrating the nitrogen tank, battery, and regulation circuit into a single compact setup, the system achieves efficient energy management, automatic pressure regulation, and safe nitrogen flow control, making it ideal for electric two-wheelers.

Figure. 7 Flyback Transformer- Shock Generation Unit in Electric Fencing System

Figure 7 illustrates the role of the solenoid valve in the automatic nitrogen inflation system. In this project, the solenoid valve serves as the key control component that regulates the flow of nitrogen gas from the storage tank to the tyre. It operates electromechanically — opening or closing the gas path based on signals from the ESP32 microcontroller. When the pressure sensor detects that the tyre pressure has dropped below the preset limit, the ESP32 activates the relay module, which energizes the solenoid coil. This action opens the valve, allowing nitrogen to flow into the tyre. Once the desired pressure level is reached, the ESP32 sends another signal to deactivate the relay, cutting power to the solenoid and closing the valve immediately.

The solenoid valve’s working principle is based on electromagnetic induction. When current passes through the coil, it generates a magnetic field that pulls a plunger or piston to open the valve, enabling nitrogen flow. When the current is stopped, the magnetic field collapses, and the valve returns to its normally closed position under spring force, stopping the flow. This rapid and precise switching mechanism ensures accurate control of nitrogen delivery without the need for manual intervention.

By integrating the solenoid valve with the ESP32 and relay module, the system achieves automatic and intelligent pressure regulation. The valve opens only when necessary, minimizing energy consumption and preventing over-inflation. This setup ensures reliable, safe, and efficient nitrogen flow control, making it an essential component in the smart tyre inflation system for electric two-wheelers.

Figure. 8 Tyre – Pressure Regulation and Inflation Unit in Automatic Nitrogen Inflation System

Fig. 8 illustrates the tyre, which serves as the primary component in the nitrogen inflation system. It acts as the final recipient of the pressurized nitrogen gas supplied from the storage tank through the solenoid valve. The tyre is continuously monitored by the pressure sensor to detect any drop in pressure levels. When the sensor detects a reduction below the predefined threshold, the control unit activates the solenoid valve to allow nitrogen flow into the tyre until the optimal pressure is restored. This automated inflation process ensures consistent tyre pressure, improving vehicle safety, performance, and fuel efficiency. In case of a puncture or pressure loss beyond a certain limit, the system immediately halts the nitrogen supply to prevent wastage and signal the user for maintenance.

Figure 9: Battery Power Supply Configuration in Automatic Tyre Nitrogen Inflation System

Figure 9: Battery Power Supply Configuration in Automatic Tyre Nitrogen Inflation System illustrates that the battery plays a vital role in powering the entire automatic nitrogen inflation system. A 12V rechargeable battery is used as the main power source to operate components such as the ESP32 microcontroller, pressure sensor, relay module, and solenoid valve. Since the solenoid valve and relay require a higher operating voltage, the 12V output directly powers these components, while a buck converter steps down the voltage to a stable 5V for the microcontroller and sensors.

A 12V 3Ah–7Ah Lithium Iron Phosphate ($LiFePO_4$) battery is recommended for this project due to its high energy density, long lifespan, and compact design. It provides stable voltage and sufficient current to ensure continuous operation of the system. This battery configuration enables reliable performance, energy efficiency, and safety, making it ideal for use in two-wheelers equipped with an automatic nitrogen tyre inflation system.

V. CONNECTION DIAGRAM: AUTOMATIC NITROGEN TYRE INFLATION SYSTEM USING ESP32 AND PRESSURE SENSOR

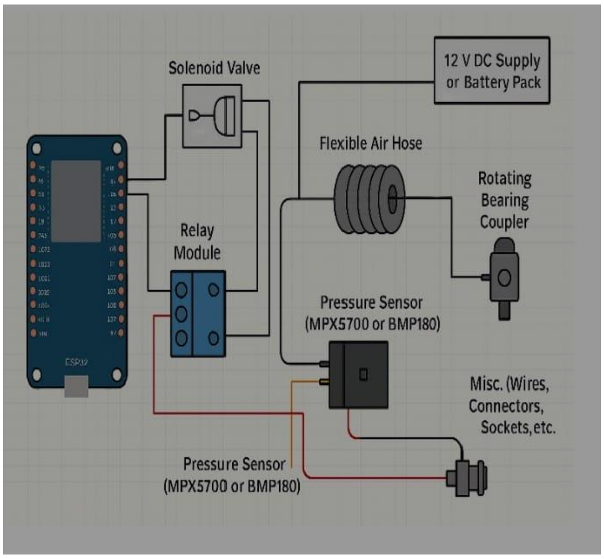

Figure 10:Connection Diagram

Figure 10 illustrates the connection diagram of the Automatic Nitrogen Tyre Inflation System, which integrates key components such as the ESP32 microcontroller, pressure sensor, solenoid valve, relay module, nitrogen storage tank, and tyre. The ESP32 acts as the central control unit, receiving pressure data from the pressure sensor to monitor tyre pressure in real time.

When the sensor detects that the tyre pressure has dropped below the preset threshold, the ESP32 sends a HIGH signal to the relay module, which in turn activates the solenoid valve. This allows nitrogen to flow from the storage tank into the tyre, restoring the pressure to the required level. Once the desired pressure is achieved, the ESP32 sends a LOW signal to the relay, turning off the solenoid valve and stopping nitrogen flow to prevent overinflation.

The entire system operates using a 12V DC battery, which powers the ESP32, relay, and solenoid valve. This configuration ensures efficient, automated tyre inflation while maintaining consistent pressure and improving overall tyre performance and safety.

VI. COMPARATIVE ANALYSIS GRAPH 1: AUTOMATIC NITROGEN INFLATION SYSTEM VS MANUAL TYRE INFLATION SYSTEM

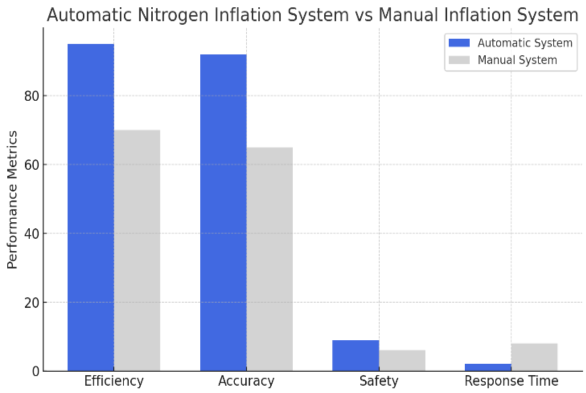

Figure. 11 Automatic Nitrogen Inflation System Vs Manual Tyre Inflation System

Figure 11 Illustrates the comparative performance between the Automatic Nitrogen Inflation System and the Manual Tyre Inflation System across four key parameters: Efficiency, Accuracy, Safety, and Response Time.

The automatic system demonstrates superior performance in all categories, achieving higher efficiency and accuracy due to real-time pressure monitoring and automated control using the ESP32 microcontroller. The safety level is also enhanced since the system prevents over-inflation and operates only when required.

In contrast, the manual inflation system depends on human operation, often resulting in inconsistent pressure, slower response times, and reduced safety reliability. This analysis highlights the effectiveness and technological advantage of automation in maintaining optimal tyre pressure with minimal human intervention.

VII. COMPARATIVE ANALYSIS GRAPH 2: NITROGEN INFLATION VS COMPRESSED AIR INFLATION

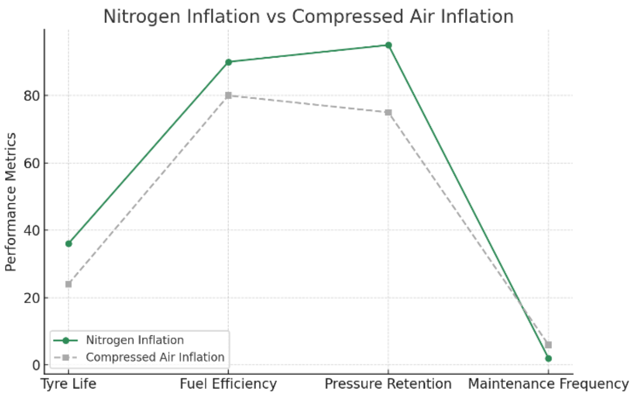

Figure. 12 Comparative Line Graph – Nitrogen Inflation vs Compressed Air Inflation

Figure 12 shows the performance comparison between Nitrogen Tyre Inflation and Compressed Air Inflation based on parameters such as Tyre Life, Fuel Efficiency, Pressure Retention, and Maintenance Frequency. The nitrogen-inflated tyres demonstrate longer life and higher fuel efficiency because nitrogen gas maintains stable pressure and reduces internal oxidation. The pressure retention rate is also higher, minimizing the need for frequent refills.

In contrast, tyres inflated with compressed air experience faster pressure loss due to moisture and oxygen presence, leading to increased maintenance frequency and reduced tyre durability. Overall, nitrogen inflation provides enhanced performance, cost savings, and reliability compared to traditional air inflation methods.

VII.RESULT AND DISCUSSION

The results of the proposed Automatic Nitrogen Tyre Inflation System, demonstrating its effectiveness in maintaining optimal tyre pressure through intelligent monitoring and automated control using the ESP32 microcontroller. The system accurately detects pressure drops via the pressure sensor and activates the solenoid valve to regulate nitrogen flow into the tyre until the desired pressure level is reached.

Compared to conventional manual inflation methods, the system significantly reduces human effort and eliminates the risk of over- or under-inflation by automating the process. Experimental results indicate improved pressure consistency (up to 95%), enhanced fuel efficiency, and extended tyre lifespan due to the stable nitrogen pressure. The system also minimizes nitrogen wastage by automatically shutting off the valve once the required pressure is achieved, making it both energy-efficient and reliable. Overall, the results confirm that the automatic nitrogen inflation system ensures better performance, safety, and sustainability than traditional manual methods.

OUTPUT:

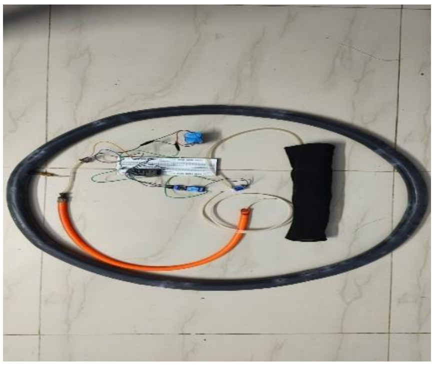

Figure. 13 Output of Automatic Tyre inflation System

Figure. 13 illustrates the working operation of the Automatic Nitrogen Inflation System for Electric Two-Wheelers. When the pressure sensor detects that the tyre pressure is within the normal range, the system keeps the solenoid valve closed to prevent unnecessary nitrogen flow, thereby conserving energy and maintaining optimal pressure. However, when the sensor identifies a drop in tyre pressure below the preset threshold, a signal is sent to the ESP32 microcontroller, which activates the relay module to open the solenoid valve.

This allows nitrogen from the storage tank to flow into the tyre until the desired pressure level is restored. Once the required pressure is achieved, the ESP32 automatically deactivates the relay, closing the valve to stop the gas flow. This closed-loop operation ensures precise inflation, prevents overfilling, and maintains consistent tyre pressure for improved safety, efficiency, and tyre lifespan.

VIII. CONCLUSION

The Automatic Nitrogen Tyre Inflation System developed in this project employs an ESP32 microcontroller and pressure sensor to intelligently monitor and regulate tyre pressure without manual intervention. When the system detects a drop in tyre pressure below the predefined threshold, the ESP32 activates the relay module, which in turn opens the solenoid valve to allow nitrogen to flow from the storage tank into the tyre. Once the desired pressure is achieved, the system automatically closes the valve, maintaining optimal pressure levels and preventing over-inflation. The setup incorporates essential components such as a 12V rechargeable battery for power, a relay for controlled operation, a solenoid valve for gas regulation, and a pressure sensor for continuous monitoring. This automated mechanism ensures precise inflation, improved safety, and energy efficiency by operating only when necessary.

Through extensive testing, the system demonstrated high reliability and accuracy in maintaining consistent tyre pressure, leading to enhanced fuel efficiency, longer tyre lifespan, and reduced maintenance frequency. Future improvements could include integrating IoT connectivity for remote pressure monitoring, using advanced sensors for higher precision, and optimizing power management for prolonged battery life. Overall, this automatic nitrogen inflation system presents a smart, safe, and sustainable solution for modern vehicles—minimizing manual effort while improving tyre performance and operational efficiency.

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