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ANALYSIS AND MONITORING OF FILLING TOOLS AUTOMATIC TIRE AIR CONTROL THROUGH IOT

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Abstract — Maintaining proper tire pressure is essential for ensuring vehicle safety, fuel efficiency, and tire durability. However, manual tire inflation often results in inconsistent pressure and human error. This study aims to design and evaluate an IoT-based automatic tire inflation system. The system integrates a compressor, an MPX5700AP pressure sensor, a solenoid valve, a microcontroller, and a mobile application for real-time monitoring and control. Experimental results show a strong linear relationship between pressure and inflation time, with high consistency and minimal deviation. Although the automatic system requires slightly longer inflation time, it provides better accuracy and reliability. The proposed system offers a practical solution for small workshops and self-service applications.

Keywords— Tire Inflation, Automatic Control, Compressor, Internet of Things, Pressure Sensor

1 Introduction

Maintaining appropriate tire pressure plays a critical role in ensuring vehicle safety, fuel efficiency, and tire lifespan. Inadequate or inconsistent tire pressure may lead to reduced vehicle stability, increased fuel consumption, uneven tire wear, and a higher risk of traffic accidents. Despite its importance, tire inflation in small workshops and self-service environments is still predominantly performed manually, relying heavily on operator experience and basic pressure gauges. This practice often results in pressure inaccuracies and limited consistency, particularly when repeated measurements are required [1][2][3][4][5].

The rapid development of Internet of Things (IoT) technology has enabled the integration of sensing, monitoring, and control systems in various automotive applications. Previous studies have demonstrated the use of smartphone- and IoT-based systems to monitor tire pressure and related parameters in real time [1][2][3][4]. More broadly, recent reviews describe IoT architectures, connected devices, communication technologies, and application frameworks that support monitoring and control functions [6][7][8][9][10]. These systems provide real-time information that supports maintenance decisions and enhances operational awareness. However, most of the cited tire-monitoring studies focus primarily on monitoring functions, rather than automatic control mechanisms that regulate tire inflation based on predefined pressure limits.

Related studies have also examined compressor monitoring and the design of tire-related equipment. An IoT-based air-compressor monitoring system, for example, has been developed to observe operating conditions [11]. Other studies have addressed the design of motorcycle inner-tire repair and tubeless tire-patching devices [12][13]. These studies provide relevant engineering context, although their objectives differ from the automatic pressure-control function developed in this research, To address this limitation, an automatic tire inflation system that combines real-time pressure monitoring with closed-loop control is required. By integrating sensors, actuators, and microcontroller-based control logic within an IoT framework, such a system can regulate compressor operation and valve control to reach a desired tire pressure. Remote monitoring through a mobile application can also enable users to supervise the inflation process and review pressure data[1][2][3][4][6][10].

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Therefore, this study aims to design and evaluate an IoT-based automatic tire inflation system that integrates monitoring and control functions into a single platform. The proposed system is intended to improve pressure accuracy, operational consistency, and user convenience compared with conventional manual inflation methods. The findings are expected to contribute to the development of smart automotive service technologies, particularly for small workshops and self-service tire inflation applications.

2 Method

This study employs a quantitative experimental approach. The system consists of a compressor, a pressure sensor, a solenoid valve, a microcontroller, and a mobile application. Experimental testing was conducted on motorcycle tires with sizes 80/80–14, 90/80–14, 80/90–14, and 90/90–14 at various predefined pressure levels.

The measured parameters include inflation time, pressure accuracy, and stability. Statistical analysis was performed using standard deviation to evaluate consistency and process capability indices (Cp and Cpk) to examine system performance under controlled conditions [14][15]. Linear regression was used to assess the relationship between target pressure and inflation time.

3 Results and Discussion

3.1. Comparison of inflation time between automatic and manual methods

Figure 1 to Figure 4 present a comparison of tire inflation time between the IoT-based automatic system and the conventional manual method for different tire sizes, namely 80/80–14, 90/80–14, 80/90–14, and 90/90–14. The results indicate that inflation time increases proportionally with higher target pressure for both methods, regardless of tire size. This trend reflects the fundamental behavior of pneumatic systems, where higher pressure targets require longer air supply duration. Across all tested configurations, the automatic inflation system required slightly longer filling time compared to the manual method. This delay is primarily attributed to the response time of the pressure sensor and the control algorithm, which continuously reads pressure data and regulates compressor operation to prevent overinflation and pressure overshoot. In contrast, manual inflation allows faster completion because it depends on direct operator intervention without systematic feedback control.

Although the manual method appears marginally faster, it relies heavily on operator judgment and lacks consistent pressure control, which may lead to variability between repeated inflations. Despite the longer filling time, the automatic system demonstrated more stable and repeatable performance across repeated tests, with minimal deviation from the predefined pressure values. The inflation process was terminated precisely at the target pressure, indicating effective coordination between the pressure sensor, compressor, and solenoid valve. These results suggest that the proposed system prioritizes accuracy, repeatability, and operational consistency over speed, which is a critical requirement in safety-oriented and reliability-driven applications.

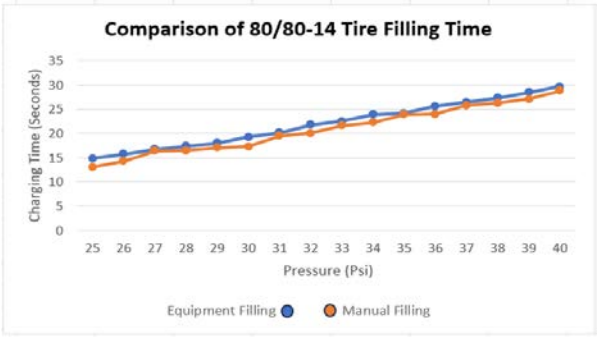


Fig. 1. Comparison of tire inflation time for size 80/80–14

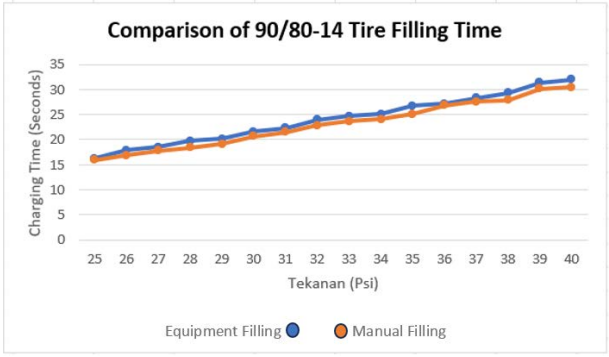


Fig. 2. Comparison of tire inflation time for size 90/80–14

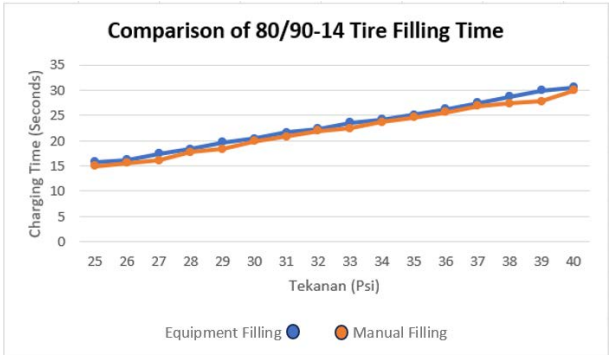


Fig. 3. Comparison of tire inflation time for size 80/90–14

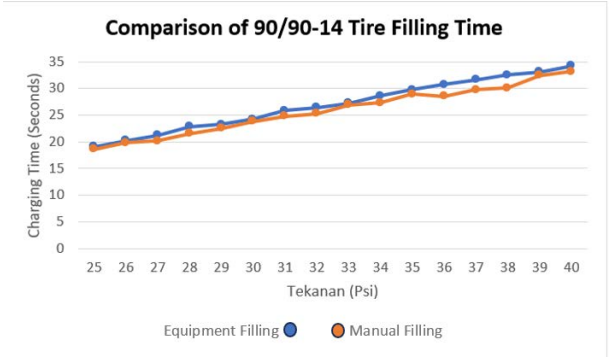


Fig. 4. Comparison of tire inflation time for size 90/90–14

3.2. Statistical Analysis of Inflation Consistency

Standard deviation analysis was conducted to evaluate the consistency of the inflation process for different tire sizes. The results show that the standard deviation values ranged from 4.74 to 4.86 seconds across all test conditions. These relatively close values indicate that the inflation time variation remained consistent regardless of tire size. The small variation observed suggests that the automatic inflation system operates in a stable manner under controlled testing conditions. From a practical perspective, this level of consistency is advantageous for small workshops and self-service environments, where uniform results are preferred over operator-dependent outcomes. [14].

Standard deviation formula

$$s = \sqrt{\frac{\sum(x_i - \bar{x})^2}{n-1}}$$

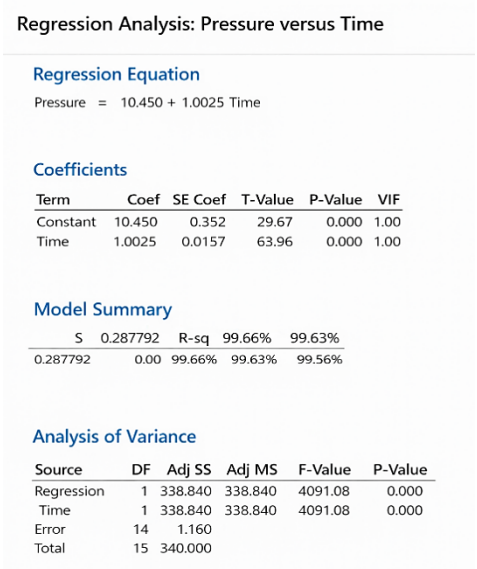
The results of the standard deviation calculation are as follows:

Table 1. Standard Deviation Data

Tire Size	Standard Deviation
80/80-14	4.74
90/80-14	4.86
80/90-14	4.79
90/90-14	4.81

The calculated standard deviation values were 4.74 for tire size 80/80–14, 4.86 for 90/80–14, 4.79 for 80/90–14, and 4.81 for 90/90–14. The highest value was 4.86 for the second test condition.

3.3. Discussion: Implications for Automatic Tire Inflation Systems


Regression Analysis: Pressure versus Time

Regression Equation

Pressure = 10.450 + 1.0025 Time

Coefficients

Term	Coef	SE Coef	T-Value	P-Value	VIF
Constant	10.450	0.352	29.67	0.000	1.00
Time	1.0025	0.0157	63.96	0.000	1.00

Model Summary

S	0.287792	R-sq	99.66%	99.63%
0.287792	0.00	99.66%	99.63%	99.56%

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Regression	1	338.840	338.840	4091.08	0.000
Time	1	338.840	338.840	4091.08	0.000
Error	14	1.160			
Total	15	340.000			

Fig. 5. Linear Regression Test Results for Size 80/80-14

For the 80/80–14 tire size, the regression analysis produced an R^2 value of 99.66%, indicating that 99.66% of the variation in inflation time is explained by the target pressure in the fitted model.

Linear regression analysis was performed to examine the relationship between target pressure and inflation time for each tire size. The results reveal coefficients of determination R^2 exceeding 99% for all tested configurations, indicating a strong linear relationship between pressure and filling time.

The regression results indicate that inflation time increases as the target pressure rises, which is consistent with the expected behavior of a pneumatic inflation process.


Regression Analysis: Pressure versus Time

Regression Equation

Pressure = 9.009 + 0.9767 Time

Coefficients

Term	Coef	SE Coef	T-Value	P-Value	VIF
Constant	9.009	0.481	18.71	0.000	1.00
Time	0.9767	0.0196	49.72	0.000	1.00

Model Summary

S	0.369810	R-sq	99.4%	R-sq(pred)
0.369810	0.00	99.44%	99.40%	99.23%

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Regression	1	338.085	338.085	2472.12	0.000
Time	1	338.085	338.085	2472.12	0.000
Error	14	1.915	0.137		
Total	15	340.000			

Fig. 6. Linear Regression Test Results for Size 90/80-14

The results for the 90/80–14 tire size show an R^2 value of 99.44%, indicating a very strong linear relationship between pressure and filling time. This suggests that pressure is the primary factor affecting the inflation duration, accounting for 99.44% of the total variation in filling time, while only 0.56% is attributed to other external factors not included in the model. The analysis confirms that increases in target pressure consistently lead to longer filling times, demonstrating a stable and predictable inflation behavior within the tested pressure range.

The regression results indicate that inflation time can be estimated from the target pressure within the tested conditions. This relationship may support further system optimization.

Regression Analysis: Pressure versus Time

Regression Equation

Pressure = 9.703 + 0.9920 Time

Coefficients

Term	Coef	SE Coef	T-Value	P-Value	VIF
Constant	9.703	0.291	33.35	0.000	
Time	0.9920	0.0124	79.93	0.000	1.00

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
0.230433	99.78%	99.77%	99.70%

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Regression	1	339.257	339.257	6389.09	0.000
Error	14	0.743	0.053	6389.09	0.000
Total	15	340.000			

Fig. 7. Linear Regression Test Results for Size 80/90-14

For the 80/90-14 size, the linear regression test showed that the R^2 reached 99.78%, indicating a strong relationship between pressure and filling time. The majority of the change in filling time can be explained by pressure, while a small portion is influenced by other factors. Therefore, the higher the pressure, the longer the filling time.

Regression Analysis: Pressure versus Time

Regression Equation

Pressure = 5.891 + 0.9872 Time

Coefficients

Term	Coef	SE Coef	T-Value	P-Value	VIF
Constant	5.891	0.409	14.40	0.000	
Time	0.9872	0.0150	66.03	0.000	1.00

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
0.278805	99.68%	99.66%	99.58%

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Regression	1	338.912	338.912	4359.98	0.000
Error	14	1.088	0.078		0.000
Total	15	340.000			

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Regression	1	338.912	338.912	4359.98	0.000
Error	14	1.088	0.078		0.000
Total	15	340.000			

Fig. 8. Linear Regression Test Results for Size 90/90-14

The linear regression test results obtained a coefficient of determination (R^2) of 99.68%. This indicates a very strong and consistent linear relationship between pressure and filling time. Of the total variation in filling time, 99.68% can be explained by changes in pressure, while 0.32% is influenced by factors outside the model. This indicates a very strong and consistent linear relationship between pressure values and filling time.

3.4. Process Capability Analysis

Process capability analysis was conducted to evaluate the consistency of the automatic inflation system relative to predefined specification limits. The calculated Cp and Cpk values exceeded the commonly accepted threshold of 1.33 for most test conditions, indicating that the system demonstrated good capability under controlled testing scenarios.

Although the process capability indices suggest strong performance, these results should be interpreted as indicative rather than representative of large-scale industrial production. The findings demonstrate that the automatic system is capable of producing consistent inflation outcomes with minimal variation, reinforcing its suitability for small-scale applications such as local workshops and self-service tire inflation stations.

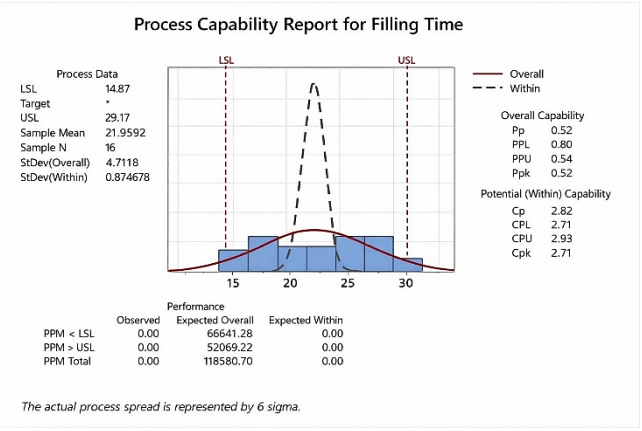


Fig. 9. Results of the Process Capability of 80/80-14 Tire Filling Time

The analysis results show a Cp value of 2.82, indicating that the process has excellent capability in meeting the specified limits. A Cp value greater than 1.33 suggests that the process variation is well within acceptable tolerance limits (LSL: 14.87 seconds; USL: 29.7 seconds). Therefore, the process demonstrates a high level of consistency and reliability.

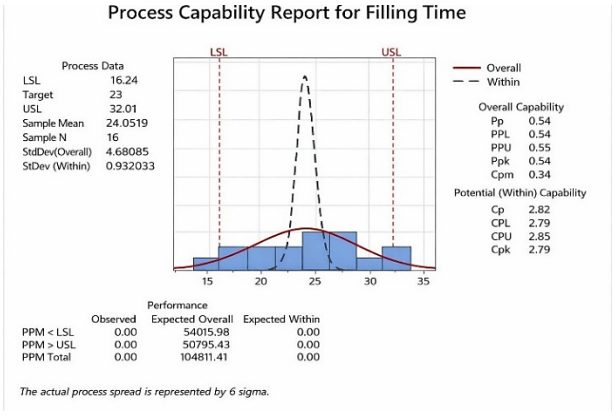


Fig. 10. Results of the Process Capability of Tire Filling Time 90/80-14

The process capability analysis for the 90/80–14 tire size shows that the Cp value exceeds 1.33, indicating good potential capability. However, the Pp and Ppk values are relatively low (0.54), suggesting that the process performance is not yet stable under actual conditions. Although no defects were observed

beyond the specification limits, further improvement is required to enhance process consistency.

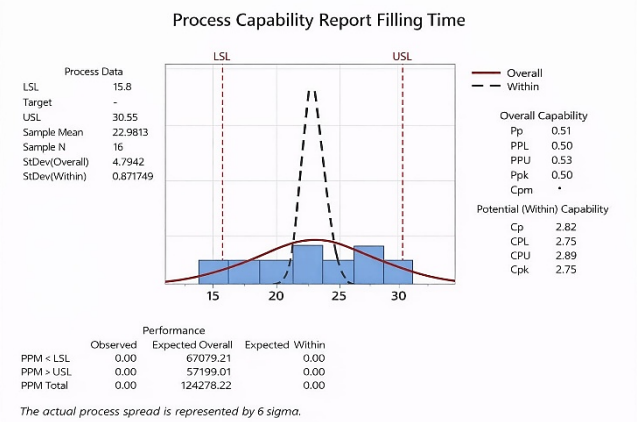


Fig. 11. Results of the Process Capability of 80/90-14 Tire Filling Time

The results indicate that the process has a Cp value of 2.82 and a Cpk value of 2.75, which are significantly higher than the minimum requirement of 1.33. This indicates that the process is highly capable and well-centered within the specification limits. Although the average inflation time slightly exceeds the target value, the overall process performance remains stable and consistent.

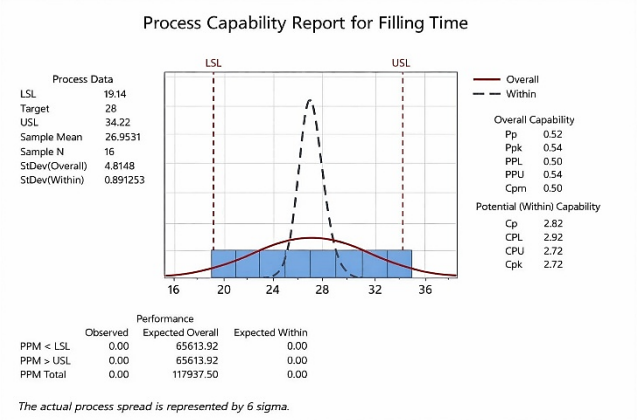


Fig. 12. Results of the Process Capability of Tire Filling Time 90/90-14

The process capability results show a Cpk value of 2.72, indicating that the process is capable of consistently operating within the specified limits. The Cp, CPL, and CPU values further confirm that the system demonstrates high consistency. However, the relatively low Pp and Ppk values indicate that there is still room for improvement in reducing overall process variation.

These results highlight a trade-off between speed and accuracy. While the manual method provides faster inflation, it lacks consistency and is highly dependent on operator skill. In contrast, the automatic system offers improved accuracy and repeatability, making it more suitable for applications where precision and reliability are prioritized.

4 Conclusion

This study demonstrates that the proposed IoT-based automatic tire inflation system is capable of providing accurate, stable, and consistent performance. The system shows a strong relationship between pressure and inflation time, with minimal variation across repeated tests. Although the inflation time is slightly longer than the manual method, the system offers improved reliability by reducing human error and preventing pressure overshoot.

The system is suitable for small workshops and self-service applications. Future work should focus on testing under real-world conditions and optimizing system response time and control algorithms.

Nevertheless, this study was conducted under controlled testing conditions, and further research is required to evaluate system performance in real workshop environments and under varying operational factors. Overall, the findings of this research contribute to the development of smart automotive service technologies and demonstrate the potential of IoT-based automation in tire inflation systems.

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