DEVELOPMENT SMART ALIGNMENT MONITORING SYSTEM

Mohd Nizam Mohd Talib[1], Azuwien Aida Bohari[2], Mohd Ramadan Mohd Khalid[1], Muhamad Faris Haikal Mohhammad Hafiz[2]

[1]Kolej Komuniti Kluang.
Jalan 7, Taman Delima, 86000 Kluang, Johor.

[2]Universiti Tun Hussein Onn Malaysia.
Jalan Panchor, 84600 Pagoh, Muar, Johor.

mohdnizam@kkkluang.edu.my[1], azuwien@uthm.edu.my[2], ramadan@kkkluang.edu.my[1], Haikalhfiz58@gmail.com[2].

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Abstract

Abstract This study focuses on the limitations of traditional wheel alignment methods in vehicles and the need for a more efficient solution. It aims to develop a Smart Alignment Monitoring System for real-time monitoring of alignment parameters, enhancing vehicle safety and performance by detecting misalignment issues early. Utilizing advanced sensor technologies integrated with tire positions, the system effectively reduces maintenance costs, improves fuel efficiency, and boosts vehicle safety and performance. The findings underscore the importance of adopting advanced technologies like the Smart Alignment Monitoring System in the automotive industry for safer and more efficient vehicles.

Keywords: Alignment, Microcontroller, Monitoring.

INTRODUCTION

The proposed Smart Alignment Tire Monitoring System aims to revolutionize tire alignment maintenance by employing sensors and software to continuously monitor tire alignment and promptly notify drivers of any deviations. This system is designed to mitigate uneven tire wear, reduce fuel consumption, and enhance overall vehicle safety and performance. By utilizing a network of sensors attached to each tire and advanced algorithms to gauge alignment, the system can provide immediate feedback to drivers in case of misalignment (Liang, N.J,2008). This user-friendly system is compatible with various tire sizes and types, and the primary objective is to develop an Internet of Things (IoT) monitoring system capable of accurately measuring tire position and alignment.

Problem Statement

Tire misalignment is a prevalent issue in the automotive industry that adversely affects vehicle performance, safety, and maintenance costs. Misaligned tires result in uneven tread wear, reduced fuel efficiency, compromised vehicle handling, and increased risk of accidents (Senjalia. J et al.,2013). This research proposes the development and implementation of an intelligent alignment monitoring system as a solution to address tire misalignment in vehicles. An article from The Washington Post reported on a study by the American Automobile Association (AAA) highlighting the dangers of driving with misaligned wheels. The study found that vehicles with misaligned wheels experienced increased tire wear, leading to a higher risk of tire blowouts and accidents. In one case, a driver lost control of their vehicle on a highway due to a blowout caused by misaligned wheels, resulting in a serious accident. Thus, the system will employ advanced sensor technologies and intelligent algorithms to monitor alignment parameters, including camber, caster, and toe angles.

Objective

The primary objective of this research is to design and develop an intelligent alignment monitoring system to ensure precise alignment of vehicle tires. The proposed system incorporates advanced sensor technologies and software to continuously monitor and detect any deviations in tire alignment, providing real-time feedback to the user. The second objective involves developing the smart alignment monitoring system specifically focusing on addressing vehicle misalignment issues. This includes integrating components such as sensors and a microcontroller, aiming to create a reliable and responsive system that can promptly identify and alert users to misalignments (Dauta.J et al.,2012). The third objective centers on the experimental verification of the performance and effectiveness of the developed intelligent alignment monitoring system. Through a carefully designed experimental setup, the system's capabilities in accurately detecting and monitoring tire misalignments under various conditions will be assessed, contributing valuable insights for validating and improving the system's functionality.

Scope of work

The ultimate objective of this research is to create and evaluate an intelligent alignment monitoring system that can detect and correct tire misalignments in cars. Toe, caster, and camber misalignments are thoroughly examined as part of the inquiry to determine affected tire wear, vehicle performance, and safety (Park,M,. et al,.2006). The goal is to obtain a comprehensive grasp of each misalignment's properties and detection needs. The main goal is to create an intelligent alignment monitoring system using cutting-edge sensor technologies like accelerometers and gyroscopes. The system's powerful data processing algorithms and user-friendly interface make real-time monitoring and feedback possible. An experimental setup is developed for accurate tire position measurements under various misalignment circumstances to validate the performance. The collected information is then examined and contrasted with reference alignment measurements to validate the precision and dependability of the created system. This technique guarantees a methodical examination of misalignments and offers an all-inclusive resolution for intelligent alignment monitoring within the automotive industry.

METHODOLOGY

The complex alignment monitoring system, which incorporates the MPU6050 sensor, Hc-05 Bluetooth module, and a 9V battery, provides a sophisticated and user-friendly method for monitoring alignment. The MPU6050 sensor, equipped with an integrated gyroscope and accelerometer, guarantees precise quantification of rotational and linear motions over the X, Y, and Z axes. The alignment data is provided wirelessly in real-time using the Hc-05 Bluetooth module, allowing easy connection to an IoT platform for remote monitoring and analysis. The distinguishing feature of this system is user-friendly interface, which closely resembles the layout of traditional alignment machines. The alignment data for the X, Y, and Z axes is supplied in a format that operators and technicians are acquainted with, which easier for individuals who are used to traditional equipment to learn and understand. This design decision improves the accessibility of the system, facilitating the seamless integration of this sophisticated monitoring solution into professionals' regular processes.

Operation of Smart Alignment Monitoring System

The process starts with preparing the vehicle for the alignment process. This involves ensuring that the car is parked on a level surface and then install the alignment sensors in the appropriate positions around the car (Lu,C, et al ,.2022) . These sensors are typically mounted on wheel clamps or placed at specific locations to capture the necessary data. And by then, the sensor detects the position or alignment of the tire. When the alignment system is in front of the vehicle, the system captures the wheel measurements using sensors. The sensors detect the positions and angles of the wheels and transmit the data to the Arduino. The alignment software analyzes the captured data, comparing the measured wheel positions and angles with the desired alignment specifications. The software calculates the required adjustments needed to align the wheels. Based on the analysis results, the alignment system guides the adjustments required to achieve proper alignment. This guidance may include alarming the user that the tire is not in normal condition and needs to be fixed. **Figure 1** shows the flow chart of Smart Alignment monitoring system.

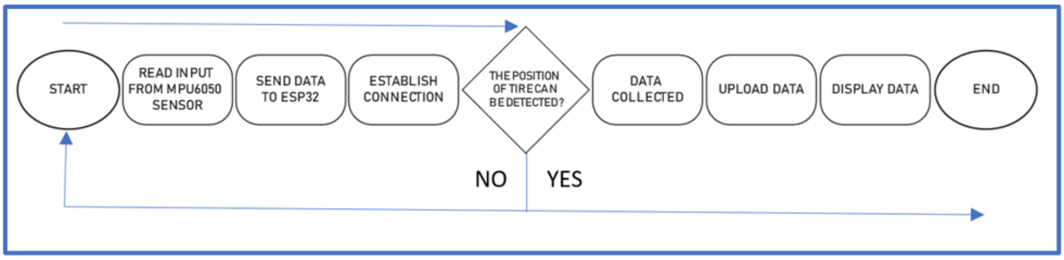

Figure 1: Flow chart of the proposed innovative alignment monitoring system.

Smart Alignment Monitoring System Wiring Connection

The innovative alignment monitoring system consists of several interconnected components that facilitate the measurement and visualization of tire misalignments. At the system's core is the MPU6050 sensor, which combines a three-axis accelerometer and a three-axis gyroscope. This sensor is connected to a microcontroller, such as Arduino, through dedicated communication lines. The microcontroller reads the sensor data and employs customized or built-in algorithms to process the information—the processed data, including camber, caster, and toe angles. The microcontroller is connected to the display interface, allowing real-time visualization of the alignment parameters. The system is powered by a stable power supply, sourced from the vehicle's battery or an external power source. Through seamless connectivity and integration of these components, the smart alignment monitoring system enables accurate and real-time measurement of tire misalignments, providing users with valuable insights into the alignment status of their vehicles (Mananathan R.,2021). **Figure 2** shows the hardware circuit of Smart Alignment Monitoring.

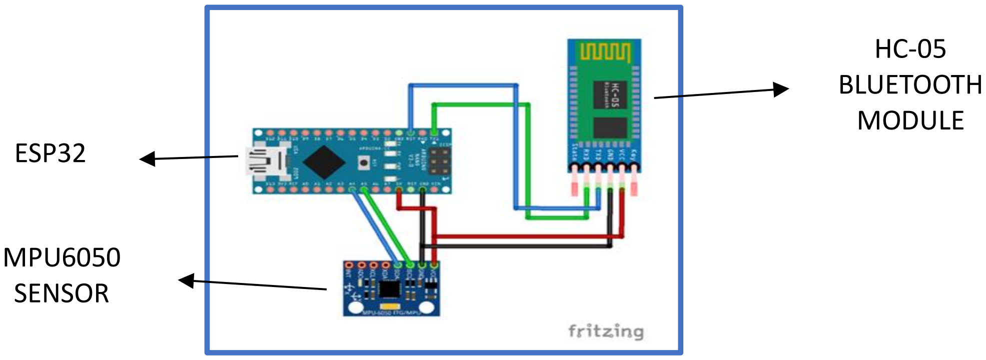

Figure 2: Hardware circuit of Smart Alignment Monitoring

RESULTS AND DISCUSSION

The MPU6050 is a popular accelerometer and gyroscope sensor, and the ESP32 is a versatile microcontroller with built-in Wi-Fi and Bluetooth capabilities. Connecting the MPU6050 to an ESP32 involves wiring the sensor to the microcontroller and using appropriate software to read data from the sensor. The project case contains the electronics circuit such as ESP32, which acts as a microcontroller and three types of sensors that collect data on angles. The battery has also been placed to power up all the electronics actual, thus making the project more dependable in real-life applications. The HC05 Bluetooth module is chosen to apply the IoT, thus making the project much more user-friendly.

Hardware Prototype

Figure 3 shows the prototype of the Smart Alignment Monitoring System. The hardware prototype of the intelligent alignment monitoring system features a core ESP32 microcontroller orchestrating the integration of advanced sensors, including the MPU6050 gyroscope and accelerometer, to meticulously measure tire alignment along the X, Y, and Z axes. The Hc-05 Bluetooth module facilitates wireless communication, transmitting real-time alignment data to external devices for user accessibility. A stable 9V DC power supply enhances the system's practicality, ensuring continuous and reliable monitoring. This holistic hardware configuration forms a robust prototype capable of providing accurate alignment information, adaptable for on-road applications and experimental setups alike, ultimately contributing to the advancement of intelligent alignment monitoring systems (Guan Xu et al.,2021). **Figure 4** shows the values of t the proposed application

Figure 3: Prototype of the Smart Alignment Monitoring System

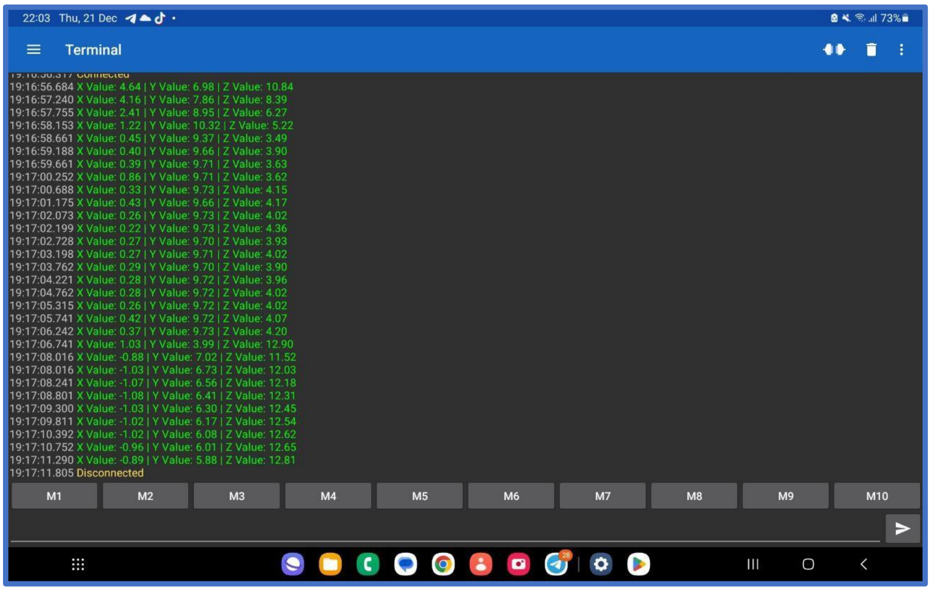

Figure 4: Values of the angle display in the proposes application

Data Collection of the value of angles

The data collected is the process of gathering and measuring information on the parameters; for this project is the detection of the angle of the X axis, Z axis, and Y axis. The data collected are compared to the conventional alignment machine at the car workshop. **Figure 5** visually illustrate the result of a traditional machine of alignment after the alignment setup is completed.

Figure 5: Result of a conventional alignment machine

Angle of the X axis of front tire left side

The comparison of X-axis values between the conventional alignment machine and the prototype is pivotal for evaluating the respective performances in wheel alignment. In the conventional machine, typically adhering to industry standards, X-axis values are obtained through traditional methods like laser or optical systems. These serve as benchmarks. The prototype, employing innovative technologies such as gyro sensor, undergoes scrutiny for potential precision, speed, adaptability, and automation improvements. Safety features and real-time monitoring capabilities also factor into the comparison, elucidating whether the prototype offers advancements in wheel alignment over conventional methods based on the X-axis measurements. **Table 1** shows the comparisons of data on the X axis between the traditional machine of alignment and the prototype.

Table 1: The comparison data of the X axis between the conventional alignment machine and the prototype (front tire left side).

No	Angle System 1	Angle System 2	Angle Workshop 1	Difference 1	Difference 2
1	0.06	0.05	0.04	0.02	0.01
2	0.05	0.04	0.04	0.01	0
3	0.06	0.04	0.04	0.02	0
4	0.04	0.04	0.04	0	0
5	0.04	0.04	0.04	0	0
6	0.05	0.06	0.04	0.01	0.02
7	0.06	0.04	0.04	0.02	0
8	0.04	0.06	0.04	0	0.02
9	0.04	0.05	0.04	0	0.01
10	0.05	0.04	0.04	0.01	0

The table illustrates consistent and accurate angle measurements from Angle System 1 and Angle System 2 compared to Angle Workshop 1, with differences below 0.02. Notably, the sixth measurement shows a 0.02 difference for Angle System 2, signalling a slight discrepancy that warrants further investigation into system calibration. Overall, the findings affirm the reliability of both systems in providing precise angle measurements, emphasizing the need for meticulous calibration to ensure accuracy in wheel alignment systems. Figure 6 shows the graph comparing the data.

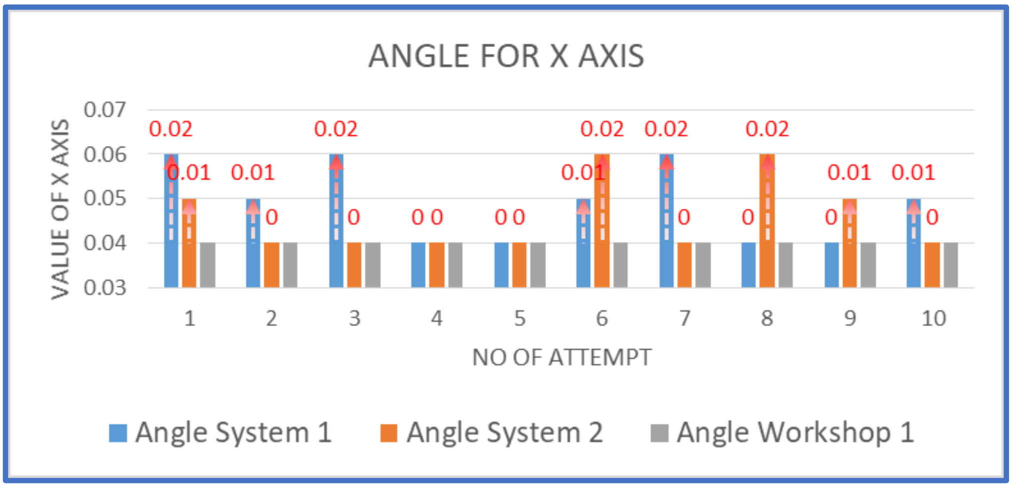

Figure 6: Recorded angle for the X axis (front tire left side).

Value of Y axis for front left tire side

The comparison of Y-axis values between the prototype and the conventional alignment machine is vital in assessing their respective performances in wheel alignment. Traditional gathers Y-axis values through established methods such as laser or optical systems, serving as benchmarks. In contrast, incorporating advanced technologies like a gyro sensor, the prototype undergoes scrutiny for potential enhancements in precision, speed, adaptability, and automation along the Y-axis. Safety features and real-time monitoring also contribute to the comparison, determining whether the prototype introduces advancements in wheel alignment compared to conventional methods based on the Y-axis measurements. **Table 2** visually illustrates the Y-axis data comparisons between the prototype and the conventional alignment machine (front left tire side).

Table 2: The Y-axis data comparisons between the prototype and the conventional alignment machine (front left tire side).

No	Angle System 1	Angle System 2	Angle Workshop 1	Difference 1	Difference 2
1	-1.15	-1.18	-1.2	0.05	0.02
2	-1.15	-1.19	-1.2	0.05	0.01
3	-1.17	-1.15	-1.2	0.03	0.05
4	-1.19	-1.14	-1.2	0.01	0.06
5	-1.19	-1.19	-1.2	0.01	0.01
6	-1.3	-1.2	-1.2	-0.1	0
7	-1.33	-1.23	-1.2	-0.13	-0.03
8	-1.2	-1.18	-1.2	0	0.02
9	-1.19	-1.19	-1.2	0.01	0.01
10	-1.18	-1.2	-1.2	0.02	0

The table presents a comparative analysis of angle measurements from Angle System 1 and Angle System 2 about reference measurements from Angle Workshop 1. Overall, both systems demonstrate high accuracy, with differences generally within 0.05 degrees. Notable variations occur in the sixth and seventh measurements, showing -0.1 and -0.13-degree differences, respectively, suggesting a slight underestimation by the systems compared to the workshop reference. While these discrepancies may indicate potential calibration issues, the overall precision of the systems in capturing angle measurements is evident throughout the dataset. Further investigation into the systematic bias observed in specific measurements could refine the accuracy of these angle measurement systems. **Figure 7** shows the angle for the Y axis that is recorded.

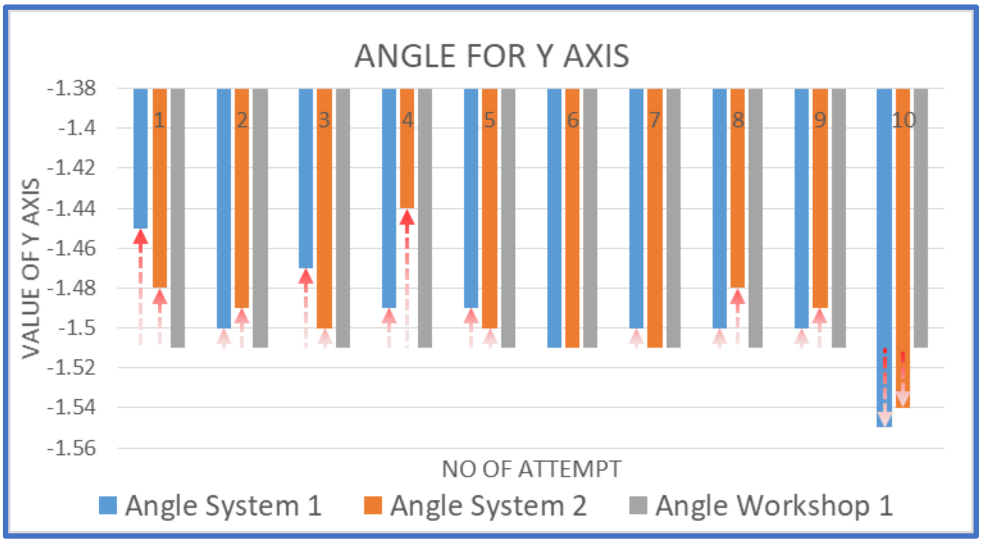

Figure 7: Recorded angle for the Y axis (front tire left side).

Angle of the X axis of front tire right side

The assessment of X-axis values between the standard alignment machine and the innovative prototype is crucial for appraising their respective performances in wheel alignment. The conventional apparatus, typically in line with industry norms, derives X-axis values through traditional techniques like laser or optical systems, serving as benchmarks for comparison. The prototype, integrating cutting-edge technologies such as a gyro sensor, undergoes scrutiny for potential accuracy, speed, adaptability, and automation enhancements. Safety features and real-time monitoring capabilities also contribute to the evaluation, revealing whether the prototype introduces advancements in wheel alignment compared to traditional methods based on the X-axis measurements. **Table 3** visually illustrates the X-axis data comparisons between the prototype and the conventional alignment machine.

Table 3: The X-axis data comparisons between the prototype and the conventional alignment machine (front tire on the right side)

No	Angle System 1	Angle System 2	Angle Workshop 1	Difference 1	Difference 2
1	0.03	0.04	0.02	0.01	0.02
2	0.05	0.04	0.02	0.03	0.02
3	0.04	0.04	0.02	0.02	0.02
4	0.02	0.03	0.02	0	0.01
5	0.04	0.04	0.02	0.02	0.02
6	0.02	0.02	0.02	0	0
7	0.02	0.02	0.02	0	0
8	0.04	0.03	0.02	0.02	0.01
9	0.04	0.05	0.02	0.02	0.03
10	0.05	0.04	0.02	0.03	0.02

The table compares angle measurements from Angle System 1 and Angle System 2, with measurements taken in Angle Workshop 1. The "Difference 1" and "Difference 2" columns show how much the system measurements differ from the workshops. Overall, both systems are slightly close to the workshop measurements, with differences mostly around 0.01 to 0.03 degrees. This suggests that both systems are precise and accurate in measuring angles. Notably, the sixth and seventh measurements show no difference, indicating that these measurements are precisely the same between the systems and the workshop reference. These minor differences could be due to slight variations in measurement tools or calibration. Figure 8 shows the angle for the X axis that is recorded.

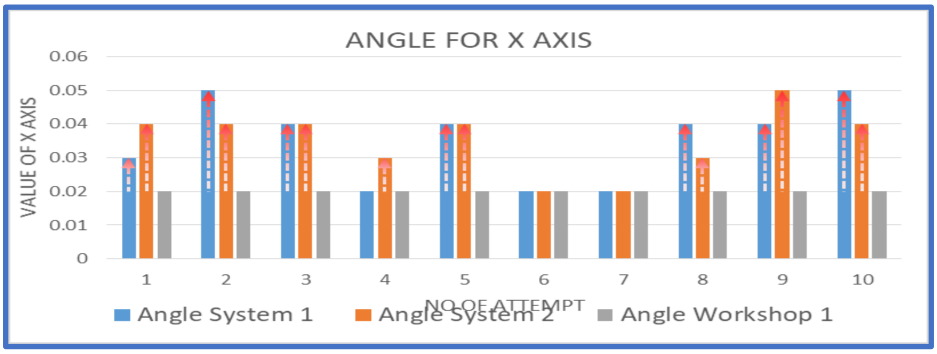

Figure 8: Recorded angle for the X axis machine (front tire on the right side)

Angle of the Y axis of front tire right side

Analyzing the Y-axis values between the prototype and the traditional alignment machine is crucial for evaluating their performances in wheel alignment. The standard machine, aligned with industry norms, collects Y-axis values using well-established methods like laser or optical systems, acting as benchmarks for comparison. Conversely, the prototype, integrating cutting-edge technologies such as a gyro sensor, undergoes examination for potential improvements in accuracy, speed, adaptability, and automation along the Y-axis. **Table 4** compares Y-axis data between the standard alignment machine and the prototype.

Table 4: The comparison of Y-axis data between the standard alignment machine and the prototype.

No	Angle System 1	Angle System 2	Angle Workshop 1	Difference 1	Difference 2
1	-1.15	-1.18	-1.2	0.05	0.02
2	-1.15	-1.19	-1.2	0.05	0.01
3	-1.17	-1.15	-1.2	0.03	0.05
4	-1.19	-1.14	-1.2	0.01	0.06
5	-1.19	-1.19	-1.2	0.01	0.01
6	-1.3	-1.2	-1.2	-0.1	0
7	-1.33	-1.23	-1.2	-0.13	-0.03
8	-1.2	-1.18	-1.2	0	0.02
9	-1.19	-1.19	-1.2	0.01	0.01
10	-1.18	-1.2	-1.2	0.02	0

The table compares angle measurements from Angle System 1 and Angle System 2 to reference measurements from Angle Workshop 1, showing differences in the "Difference 1" and "Difference 2" columns. Overall, both systems demonstrate close agreement with the workshop measurements, with differences ranging from 0.01 to 0.13 degrees. Notable variations occur in the sixth and seventh measurements, indicating a potential underestimation by the systems. Despite these discrepancies, most differences are slight, suggesting reliable performance in measuring angles. The negative differences may point to systematic biases that could be addressed through further calibration. **Figure 9** shows the graph comparing the data.

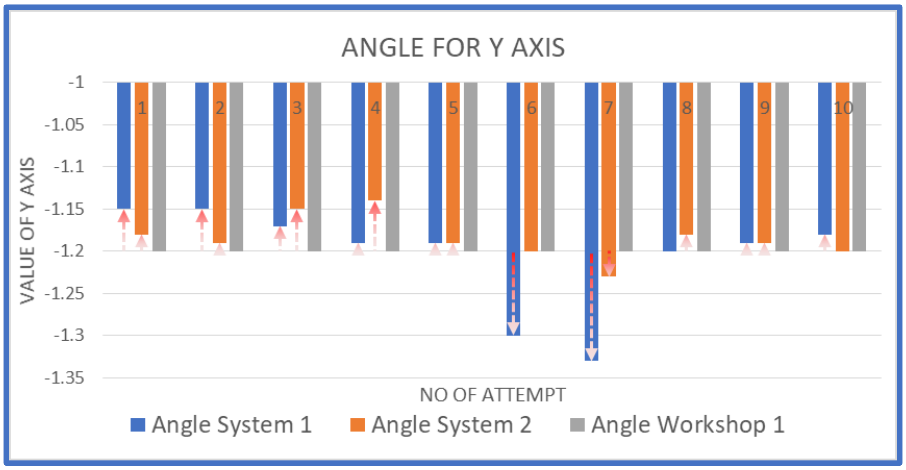

Figure 9 : Recorded angle for the Y axis machine (front tire on the right side)

The Outcome from the Conducted Study

The outcome of the study comparing the built model with conventional methods indicates that while the built model produces similar data to the conventional methods, there are some minor differences. These differences could be attributed to various factors such as the sensitivity of the sensors used in the built model, environmental conditions, or the calibration of the systems (Paudel S et al., 2020). Despite these minor differences, the study suggests that the built model is a viable alternative to conventional methods for monitoring wheel alignment, offering comparable results with potential benefits such as real-time monitoring and enhanced accuracy.

CONCLUSION

In conclusion, the intelligent alignment monitoring system, featuring advanced components such as the MPU6050 sensor, ESP32 microcontroller, and Hc-05 Bluetooth module, presents a significant advancement in vehicle alignment technology. The prototype demonstrates commendable accuracy in real-time tire alignment monitoring, addressing misalignment issues that impact safety, fuel efficiency, and tire wear. The comprehensive examination of toe, caster, and camber misalignments and experimental verification highlights the system's potential to revolutionize automotive maintenance (Weis,K.H ,2014) . To propel this technology forward, the recommendation is to conduct extensive testing under diverse different conditions for robustness assessment to mimic the real-life usage and to build the machine that can be adjust according to different types of tire sizes for predictive maintenance (Xioali Tang et al., 2021). Furthermore, ongoing efforts should focus on optimizing power efficiency for sustained real-world applications. These combined efforts will refine the innovative alignment monitoring system, ushering in a new era of enhanced vehicle performance, safety, and maintenance efficiency.

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