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Design and Construction of a Calibration Tool for the Side Slip Tester on the Muller BEM10000 Motor Vehicle Testing Equipment

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Abstract

Accurate calibration of motor vehicle testing equipment is crucial to ensure safety, roadworthiness, and compliance with technical standards. Among these instruments, the side slip tester is essential for assessing wheel alignment, vehicle stability, and driving comfort. Manual calibration is time-consuming and prone to human error, potentially causing measurement inaccuracies. This study developed a microcontroller-based calibration tool for the Muller BEM10000 side slip tester to enhance efficiency and reliability. A research and development approach using the ADDIE model—analysis, design, development, implementation, and evaluation—was applied. The tool integrates a mechanical structure with a microcontroller, servo actuators, adjustable rod mechanism, control buttons, and LCD display. Calibration accuracy was validated using a dial gauge. Experimental results show that the microcontroller-based tool reduced calibration time from 10 to 1 minute and decreased personnel requirements from three to one operator, while improving displacement control and measurement consistency. The tool supports effective calibration procedures, minimizes errors, and offers potential to strengthen vehicle testing performance in periodic inspection systems.

Keywords: calibration, microcontroller, operational efficiency, side slip tester, vehicle testing.

1 Introduction

Road transportation systems play a crucial role in supporting economic development and social mobility. However, the rapid growth of motor vehicles has increased concerns related to road safety, environmental sustainability, and vehicle operational reliability. Ensuring that vehicles meet technical and roadworthiness standards is therefore essential to maintain safe transportation systems. Periodic vehicle inspection is widely implemented to evaluate the safety condition of vehicles and to ensure compliance with established technical standards. In Indonesia, this process is regulated through the Regulation of the Minister of Transportation of the Republic of Indonesia No. 133 of 2015 on Periodic Motor Vehicle Testing, which defines vehicle testing as a series of inspection and measurement activities to determine whether a vehicle meets the required technical and roadworthiness criteria. The legal basis for these activities is further supported by Law of the Republic of Indonesia No. 22 of 2009 on Road Traffic and Transportation and Government Regulation of the Republic of Indonesia No. 55 of 2012 on Vehicles, which emphasize that vehicles operating on public roads must comply with technical standards to ensure safety and environmental protection.

The implementation of periodic vehicle testing requires reliable testing equipment to measure various parameters such as braking performance, emissions, lighting systems, noise levels, vehicle weight, and wheel alignment. Among these parameters, wheel alignment plays an important role in maintaining vehicle stability, steering control, and tire wear characteristics. Incorrect wheel alignment can significantly affect vehicle handling performance and may increase the risk of accidents. Therefore, accurate measurement and inspection of wheel alignment are essential components of vehicle inspection systems. Several studies have investigated different methods for measuring wheel alignment parameters, including camber angle inspection systems and alignment measurement technologies for suspension modules (Kim & Lee, 2020; Young et al., 2017). Advanced wheel alignment measurement systems have also been developed using automated detection and sensor-based approaches to improve measurement accuracy and efficiency (Jie Liang, 2008; Shao et al., 2019).

To ensure the accuracy and reliability of measurement results in vehicle inspection systems, testing equipment must be maintained and calibrated periodically. Calibration is a fundamental process that ensures measurement instruments provide accurate results by comparing their outputs with established reference standards. The importance of calibration in measurement systems has been widely discussed in the field of sensor technology and instrumentation (Haitjema, 2020). Various calibration techniques have been developed to improve measurement performance, including automatic calibration algorithms and hardware-based calibration approaches (Kokolanski et al., 2013; Kouider et al., 2003). Additionally, modified calibration methods have been proposed to enhance calibration efficiency and reduce measurement uncertainty in sensor-based systems (Cui et al., 2025; Kokolanski et al., 2014).

In the context of vehicle inspection equipment, calibration procedures are essential to ensure that measurement systems operate within acceptable tolerance limits. Several studies have proposed calibration methods for automotive measurement systems, including calibration techniques for wheel hub detection systems and tire dynamic balance detection equipment (J. F. Yang et al., 2012; X. D. Yang et al., 2014). Furthermore, calibration and verification systems have also been developed for vehicle testing equipment such as wheel load scales and vehicle speed measurement devices (Hao et al., 2025; Martucci et al., 2019). These studies demonstrate that accurate calibration procedures are critical to ensuring the reliability of vehicle inspection systems and the validity of measurement results.

In Indonesia, the requirement for calibration of vehicle testing equipment is regulated through the Regulation of the Minister of Transportation of the Republic of Indonesia No. 19 of 2021 on Motor Vehicle Testing, which states that testing equipment must be calibrated periodically to maintain measurement accuracy. The implementation procedures for calibration activities are outlined in the Director General of Land Transportation Decree No. SK2405/AJ.402/DRDJ/2014 regarding the Standard Operating Procedures for Calibration of Motor Vehicle Testing Equipment.

Recent developments in measurement technology have enabled the use of microcontroller-based systems to improve calibration performance and measurement accuracy. Microcontroller platforms such as Arduino and ATmega have been widely utilized in the development of measurement instruments due to their flexibility, low cost, and ease of integration with sensors. Several studies have demonstrated the effectiveness of microcontroller-based measurement systems in various applications, including sensor calibration systems and automated measurement devices (Febriansyah, 2023; Putra et al., 2024; Yakin et al., 2021). In addition, Arduino-based instrumentation has been successfully implemented for developing magnetic measurement devices and other sensor-based measurement systems (Matsun & Boisandi, 2024). Calibration techniques for optical and IoT-based sensors have also been explored to improve measurement accuracy and reliability in modern instrumentation systems (Ayub et al., 2015).

Despite these technological advancements, calibration procedures for certain vehicle testing instruments, such as the side slip tester used for measuring the front wheel alignment condition, are still conducted manually in several testing facilities. Manual calibration methods may lead to longer calibration times and potential measurement inaccuracies due to human factors. These limitations may affect the reliability of calibration results and consequently influence the accuracy of vehicle inspection outcomes. Recent studies on vehicle safety testing equipment have emphasized the importance of developing improved calibration systems to enhance measurement reliability and operational efficiency (Li, Y., et al, 2025).

Based on these considerations, the development of a microcontroller-based calibration system for side slip tester equipment is considered necessary to improve the efficiency and accuracy of calibration procedures. Therefore, this research aims to design and develop a microcontroller-based calibration device for the side slip tester used in the Muller BEM10000 motor vehicle testing system. The proposed system is expected to assist calibration personnel in performing calibration activities more efficiently, reduce measurement errors, and improve the reliability of vehicle testing equipment used in periodic vehicle inspection systems.

2 Research Method

This study employed a research and development (R&D) approach to design and construct a microcontroller-based calibration tool for the side slip tester used in the Muller BEM10000 motor vehicle testing system. The development process followed the ADDIE instructional design model, which consists of five main stages: analysis, design, development, implementation, and evaluation. The ADDIE model was created by Florida State University for the military in the 1970s and has been widely applied in system development and engineering design due to its systematic and iterative structure (Branch, 2010).

The use of a structured development framework is particularly important in the design of measurement and calibration systems to ensure that the resulting instrument meets operational requirements and maintains measurement accuracy. Calibration systems require systematic design procedures to minimize measurement errors and improve reliability (Haitjema, 2020; Kouider et al., 2003). In addition, hardware-based calibration approaches have been shown to enhance measurement performance and reduce uncertainty in measurement systems (Kokolanski et al., 2013, 2014).

The conceptual design flow of the developed calibration tool is illustrated in Figure 1.

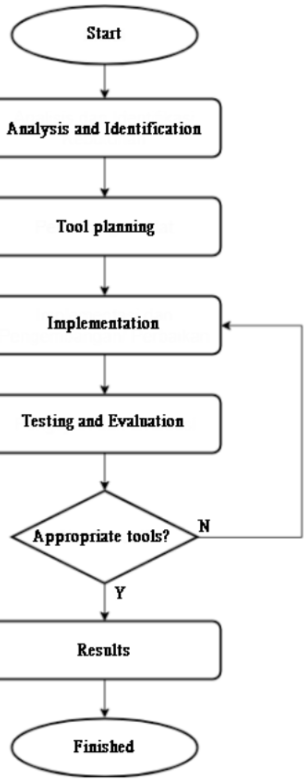

Figure 1. Flowchart of the tool's conceptual design

Analysis

The analysis stage involved identifying the operational requirements for the calibration tool used in the side slip tester system. This stage included needs identification and needs analysis conducted through observation and evaluation of the existing calibration procedures used in motor vehicle testing facilities.

The analysis revealed that the calibration of the side slip tester in several testing laboratories is still performed manually, which may result in longer calibration times and potential measurement inaccuracies. Accurate wheel alignment measurement is critical because improper alignment can affect vehicle stability, steering performance, and tire wear characteristics (Kim & Lee, 2020; Young et al., 2017). Therefore, an automated or microcontroller-based calibration device is required to improve calibration efficiency and measurement reliability.

Previous studies have demonstrated that sensor-based calibration systems can significantly improve measurement accuracy and operational efficiency in various measurement instruments (Cui et al., 2025; J. F. Yang et al., 2012). These findings support the development of an automated calibration tool for vehicle testing equipment.

Design

The design stage focused on developing the conceptual and technical design of the calibration tool. The microcontroller-based calibration tool for the Muller BEM10000 motor vehicle side slip tester was designed as an auxiliary instrument to assist calibration officers in performing calibration procedures more efficiently.

To realize the proposed system, it was necessary to identify the components required to support the functionality and reliability of the calibration tool. The key elements used in the construction of the tool are presented in Table 1.

Table 1. Components of the Microcontroller-based Calibration Tool

No.	Component	Quantity	Units
1	Arduino Mega 2560	1	units
2	Universal Cable	1	units
3	Servo Motor Actuator	2	pieces
4	30x30x2 Hollow Iron Pipe	3	pieces
5	4" Grinding Bit	2	box
6	14" Grinding Bit	4	pieces
7	Thinner	1	gallon
8	Sandpaper	6	pieces
9	Epoxi Paint	1	pieces
10	Black Paint	1	liters
11	Putty	3	pieces
12	4" Wheel	4	pieces
13	Electrode	3	pieces
14	Actuator Drive Mechanism	1	pieces
15	Wire Brush	1	pieces
16	LCD Display	1	pieces
17	Panel Button	4	pieces
18	Adjustable Rod Mechanism	1	pieces

The design phase was divided into two main aspects: mechanical design and electrical design. The mechanical design involved developing the physical structure of the calibration device, including the supporting frame, actuator mechanism, adjustable rod system, and wheel support system. The electrical design focused on integrating the microcontroller, servo actuators, control buttons, and display system.

Arduino Mega 2560 was selected as the main controller due to its flexibility and compatibility with various sensors and actuators. Microcontroller-based platforms such as Arduino and ATmega have been widely used in measurement instrumentation and calibration systems due to their reliability, low cost, and ease of integration (Febriansyah, 2023; Putra et al., 2024; Yakin et al., 2021).

The design process also considered several engineering factors, including size, weight, portability,

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ease of operation, and manufacturing cost. Figure 2 illustrates the 3D conceptual model of the proposed calibration tool.

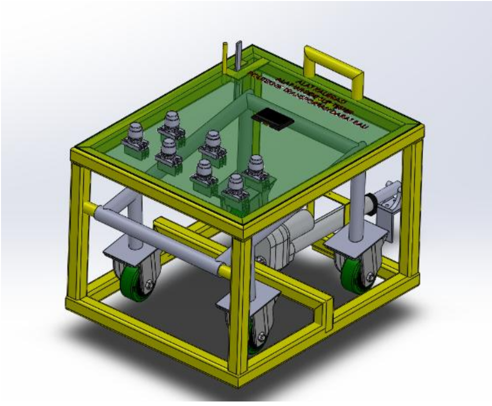

Figure 2. Model of the calibration tool

Development

The development stage involved constructing the prototype of the calibration tool based on the design specifications. The first step in the fabrication process was preparing all necessary materials and equipment to ensure that they met the design requirements and would not interfere with subsequent development stages.

The second step involved constructing the main frame of the calibration tool using hollow iron pipes as structural support. After completing the frame construction, mounting brackets for electronic components were installed to accommodate the microcontroller, actuator system, and display unit.

The next stage involved assembling the actuator drive mechanism and adjustable rod system that would interact with the side slip tester measurement platform. Servo motors were installed to provide controlled movement for the calibration mechanism.

Following the mechanical assembly, the electrical wiring process was performed to connect the microcontroller, servo motors, control buttons, and LCD display. The wiring configuration ensured stable communication between hardware components and enabled real-time control of the calibration mechanism.

The integration of microcontroller-based control systems in measurement devices has been widely applied to improve measurement automation and operational efficiency (Arifa et al., 2025; Matsun & Boisandi, 2024). Such systems enable more precise control of measurement parameters and facilitate the implementation of automated calibration procedures.

Implementation

The implementation stage involved testing the developed calibration tool in a controlled environment to evaluate its operational performance. The prototype was installed and tested in conjunction with the Muller BEM10000 side slip tester system.

During this stage, the calibration tool was used to simulate calibration procedures and observe the response of the side slip tester measurement system. Data obtained from the calibration process were recorded and analyzed to evaluate the performance and accuracy of the developed tool.

Automated calibration methods have been shown to improve calibration speed and reduce human error compared to manual calibration approaches (Shao et al., 2019; J. F. Yang et al., 2012).

Evaluation

The final stage of the research involved evaluating the performance and effectiveness of the developed calibration system. The evaluation focused on several aspects, including measurement accuracy, system stability, operational efficiency, and ease of use.

The calibration results obtained using the developed tool were compared with standard calibration procedures to determine the effectiveness of the system. Verification of measurement performance is an important aspect of calibration system development to ensure that the instrument operates within acceptable tolerance limits (Hao et al., 2025; Martucci et al., 2019).

The evaluation results were then used to assess the feasibility of implementing the proposed calibration tool as a supporting instrument for the calibration of side slip tester equipment in motor vehicle testing facilities.

3 Results and Discussion

The manufacturing process represents the realization of the design phase described in the methodology section. This stage is crucial to ensure that the developed calibration tool meets the functional and operational objectives of the study. The fabrication process involved assembling the mechanical structure, integrating electronic components, and performing electrical wiring for the control system. The electronic system was designed to enable the microcontroller to control the actuator mechanism and display the calibration parameters in real time. The process of assembling and wiring the electronics used in the calibration tool is illustrated in Figure 3.

Figure 3. Manufacturing of the calibration tool

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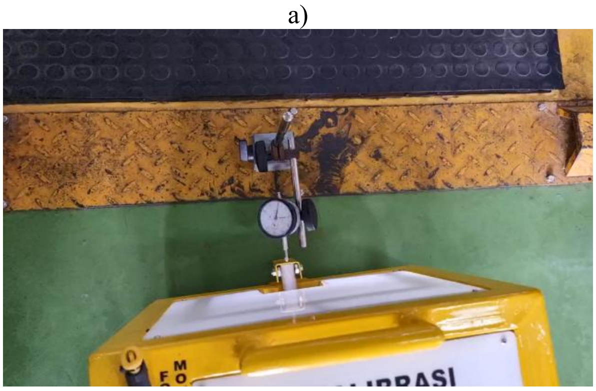
During the assembly phase, the mechanical frame of the device was integrated with electronic components such as the microcontroller unit, servo motor actuators, control buttons, and LCD display. The use of microcontroller-based instrumentation has been widely applied in measurement devices due to its flexibility and ability to improve automation and measurement precision (Putra et al., 2024; Yakin et al., 2021). In addition, microcontroller-based systems allow accurate control of mechanical movement, which is important for calibration processes involving displacement measurement (Haitjema, 2020).

After completing the assembly process, the developed calibration tool was tested to evaluate its operational performance. The testing process involved validating the measurement output of the calibration tool using a dial gauge as a reference instrument. The dial gauge was used to ensure that the displacement generated by the calibration mechanism corresponded to the intended movement values. The calibration stages conducted during the experiment are presented in Figure 4.

a)



b)

Figure 4. Calibration stages of the side slip tester calibration tool: (a) coding synchronization, (b) validation with dial gauge measurement

The validation of measurement systems using reference instruments is a common practice in calibration procedures to maintain measurement accuracy and reliability (Kokolanski et al., 2013, 2014).

Manual Calibration Results

The results obtained from the manual calibration method were analyzed to determine the performance of the existing calibration procedure used for the side slip tester. The experimental results showed that the average plate movement for a 1 mm input displacement was 1.33 mm. For a 2 mm input displacement, the average plate movement was recorded at 2.59 mm, while for a 3 mm input displacement, the average plate movement reached 3.88 mm.

In addition to measurement deviation, the manual calibration process required a relatively long operational time. Each calibration test required approximately 10 minutes to complete, and the process required the involvement of three calibration officers. The manual calibration procedure and the data collection process are shown in Figure 5.

Figure 5. Manual calibration process

Manual calibration procedures often depend heavily on operator experience and manual adjustments, which can introduce measurement uncertainties and reduce calibration efficiency. Previous studies have reported similar limitations in manual calibration systems, particularly in sensor-based measurement systems and automotive testing equipment (Kokolanski et al., 2013; J. F. Yang et al., 2012).

Microcontroller-Based Calibration Results

The performance of the developed microcontroller-based calibration tool was evaluated through the same experimental procedure used for the manual method. The results indicated that the average plate movement for a 1 mm displacement was 1.26 mm. For a 2 mm displacement, the average plate movement was recorded at 2.51 mm, while for a 3 mm displacement the average plate movement was 3.70 mm.

Compared with the manual method, the microcontroller-based calibration system required significantly less time to perform the calibration process. The average calibration time was approximately 1 minute, and the entire calibration process could be performed by a single calibration officer. The data collection process using the developed calibration tool is illustrated in Figure 6.

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Figure 6. Microcontroller-based calibration process

The improved operational efficiency observed in this study is consistent with previous research indicating that automated calibration systems can significantly reduce calibration time and human intervention while maintaining measurement accuracy (Cui et al., 2025; Shao et al., 2019). Microcontroller-based systems also provide better control of actuator movement, allowing more precise displacement generation for calibration purposes (Febriansyah, 2023; Matsun & Boisandi, 2024).

Comparison Between Manual and Microcontroller-Based Calibration

The comparison between manual and microcontroller-based calibration methods highlights several significant differences in operational performance. Figure 7 presents a graphical comparison between the two calibration methods.

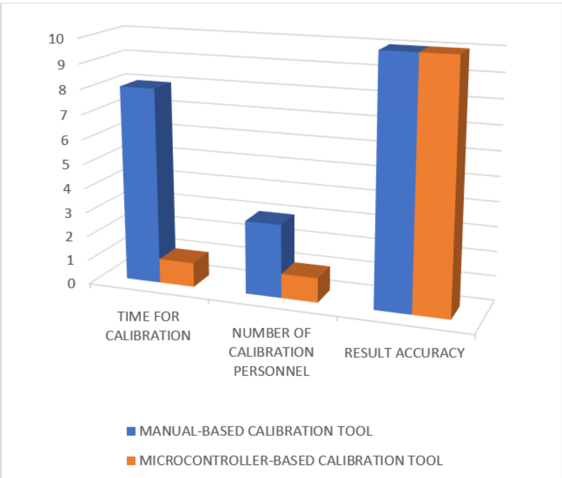

Figure 7. Comparison between manual and microcontroller-based calibration

The main differences observed between the two methods are summarized in Table 2.

Table 2. Differences in Calibration Test Results

Category	Manual	Microcontroller
Time	10 minutes	1 minute
Number of Calibration Officers	3 calibration officers	1 calibration officer
Accuracy of Results	Compared the dial gauge reading and the side-slip tester plate movement displayed on the test equipment's screen.	This microcontroller-based calibration tool is first calibrated with a dial gauge to maintain the servo motor's movement accuracy within the specified size.

The results demonstrate that the microcontroller-based calibration system provides significant advantages in terms of time efficiency and manpower requirements. Automated calibration tools reduce operational complexity and enable faster calibration procedures. Similar findings have been reported in previous studies on automated calibration systems for automotive measurement devices (Li. Y., et al, 2025; Yang et al., 2014).

Analysis of Measurement Deviation

The experimental results obtained from both calibration methods were analyzed in relation to the regulatory tolerance limits for vehicle testing equipment calibration. The graphical representation of the test results is shown in Figure 8.

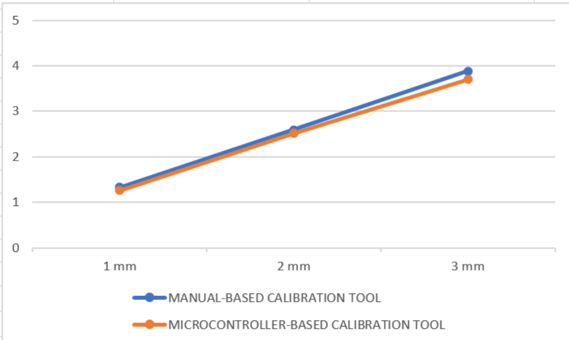

Figure 8. Test results comparison

Based on the applicable calibration standards stated in the Director General of Land Transportation Regulation No. KP.1954/AJ.502/DRJD/2019 regarding procedures for periodic motor vehicle testing equipment calibration, the allowable tolerance limit for measurement deviation is ±10% from the standard value. According to these regulations, for a 1 mm displacement, the acceptable measurement range is 0.9–1.1 mm. For a 2 mm displacement, the acceptable measurement range is 1.8–2.2 mm. For a 3 mm displacement, the acceptable measurement range is 2.7–3.3 mm.

The experimental results indicate that both the manual calibration method and the microcontroller-based calibration method produced measurement values that exceeded the recommended tolerance limits. This finding suggests that the side slip tester equipment requires further adjustment or repair before it can achieve calibration results that comply with the regulatory standards.

Nevertheless, despite the deviation from the tolerance limits, the microcontroller-based calibration system demonstrated significant improvements in operational efficiency, reduced calibration time, and lower manpower requirements. These results indicate that automated calibration tools can enhance the calibration process in motor vehicle testing facilities while maintaining consistent measurement procedures. Similar conclusions have been reported in previous studies on automated calibration and vehicle testing systems (Kim & Lee, 2020; Martucci et al., 2019; Young et al., 2017).

4 Conclusion

This study developed a microcontroller-based calibration tool for the Muller BEM10000 side slip tester to improve the efficiency and reliability of vehicle testing calibration. The tool integrates a mechanical structure supporting the calibration mechanism with a microcontroller-based electronic control system. Servo motor movements were calibrated using a dial gauge reference and programmed to generate precise displacements corresponding to calibration values. The electrical system converts AC 220 V to 12 V DC for the actuator and further to 5 V DC for the microcontroller, enabling accurate and automated calibration operations.

Experimental results demonstrated substantial improvement in calibration efficiency: the average calibration time decreased from approximately 10 minutes manually to 1 minute with the microcontroller-based system, while personnel requirements dropped from three operators to one. The automated control also reduced human error, providing more consistent and repeatable measurements. Although both manual and automated measurements exceeded allowable tolerance limits, the tool effectively supports the calibration process and assists officers in identifying deviations. Overall, the microcontroller-based calibration tool enhances time efficiency, reduces labor, minimizes manual errors, and improves the reliability of calibration procedures. Its implementation demonstrates significant potential to strengthen the performance and accuracy of motor vehicle testing equipment in periodic inspection systems.

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References

Arifa, A., Suharno, Kamaruddin, M., & Harjunowibowo, D. (2025). Enhancing Measuring Reliability: Calibration and Validation of IoT-based DC Power Logger . *Journal of Engineering and Applied Technology* , *6*, 27–39. https://doi.org/https://doi.org/10.21831/jeatech.v6i01.83282

Ayub, M. A., Mohamed Rosli, N. F., Esa, A. H., Abdul Latif, A., & Jaafar, R. (2015). Calibration of Optical Silicone Tactile Sensor. *Jurnal Teknologi*, *76*(8). https://doi.org/10.11113/jt.v76.5626

Branch, R. (2010). Instructional design: The ADDIE approach. In *Instructional Design: The ADDIE Approach*. https://doi.org/10.1007/978-0-387-09506-6

Cui, J., Zhang, S., & Jiang, Y. (2025). Design of a Rapid and Accurate Calibration System for Pressure Sensors with Minimized Temperature Variation. *Sensors*, *25*(17), 5288. https://doi.org/10.3390/s25175288

Directorate General of Land Transportation. (2014). Standard operating procedure for calibration of motor vehicle testing equipment (Decree No. SK2405/AJ.402/DRDJ/2014). Ministry of Transportation, Indonesia.

Febriansyah, D. (2023). Pengujian Ketidakpastian Pengukuran Alat Ukur Debit Air Rendah Biaya Berbasis Mikro Kontroler Arduino. *Jurnal Asiimetrik: Jurnal Ilmiah Rekayasa & Inovasi*, 305–314. https://doi.org/10.35814/asiimetrik.v5i2.4986

Government of Indonesia. (2009). Law No. 22 of 2009 concerning road traffic and transportation. Jakarta, Indonesia.

Government of Indonesia. (2012). Government Regulation No. 55 of 2012 concerning vehicles. Jakarta, Indonesia.

Haitjema, H. (2020). The Calibration of Displacement Sensors. *Sensors*, *20*(3), 584. https://doi.org/10.3390/s20030584

Hao, L., Xu, Z., Zhou, B., & Zhang, G. (2025). Design of a Verification Device of Motor Axle Wheel Load Scales Based on Pump-Controlled Hydraulic Cylinder. *Sensors*, *25*(23), 7180. https://doi.org/10.3390/s25237180

Jie Liang. (2008). Design of an automobile wheel alignment measuring system based on Position

Sensitive Detector. *2008 IEEE International Conference on Automation and Logistics*, 2701–2704. https://doi.org/10.1109/ICAL.2008.4636630

Kim, S. H., & Lee, K. I. (2020). Wheel Alignment of a Suspension Module Unit Using a Laser Module. *Sensors*, *20*(6), 1648. https://doi.org/10.3390/s20061648

Kokolanski, Z., Gavrovski, C., & Dimcev, V. (2014). Modified Single Point Calibration with Improved Accuracy in Direct Sensor-to-Microcontroller Interface. *Measurement*, *53*, 22–29. https://doi.org/10.1016/j.measurement.2014.03.011

Kokolanski, Z., Gavrovski, C., Dimcev, V., & Makraduli, M. (2013). Hardware Techniques for Improving the Calibration Performance of Direct Resistive Sensor-to-Microcontroller Interface. *Metrology and Measurement Systems*, *20*(4), 529–542. https://doi.org/10.2478/mms-2013-0045

Kouider, M., Nadi, M., & Kourtiche, D. (2003). Sensors Auto-calibration Method - Using Programmable Interface Circuit Front-end. *Sensors*, *3*(10), 491–497. https://doi.org/10.3390/s31000491

Li, Y. , et al, & et al. (2025). *Calibration Methods for Vehicle Safety Testing Equipment*. https://doi.org/https://doi.org/10.12338/j.issn.2096-9015.2024.0314

Martucci, A., Cerasuolo, G., Petrella, O., & Laracca, M. (2019). An Uncertainty Analysis for the Calibration of GNSS-Based Vehicle Speed Meters. *2019 II Workshop on Metrology for Industry 4.0 and IoT (MetroInd4.0&IoT)*, 6–11. https://doi.org/10.1109/METROI4.2019.8792839

Matsun, M., & Boisandi, B. (2024). Magnetic Measuring Instrument Based on Arduino Uno Microcontroller and its Implementation as A Learning Medium. *Kappa Journal*, *8*(1), 34–38. https://doi.org/10.29408/kpj.v8i1.24447

Ministry of Transportation. (2015). Periodic motor vehicle testing regulation (Regulation No. 133 of 2015). Jakarta, Indonesia.

Ministry of Transportation. (2021). Motor vehicle testing regulation (Regulation No. 19 of 2021). Jakarta, Indonesia.

Putra, A. A. N. S. M., Rupiasih, N. N., & Supardi, I. W. (2024). Calibration Method for Capacitive Silver Sensor Based on ATmega328 Microcontroller as a Membrane Potential Difference Measuring Instrument. *BULETIN FISIKA*, *25*(2), 229. https://doi.org/10.24843/BF.2024.v25.i02.p11

Shao, C. H., Xu, S. S., Song, Y., Zhang, Z. Y., & Zhang, Q. X. (2019). Methods of Aautomatic Calibration for Four-Wheel Alignment Based on Superimposing Angles. *International Journal of Vehicle Design*, *81*(1/2), 42. https://doi.org/10.1504/IJVD.2019.110701

Yakin, G. H., Satriya Wibawa, I. M., & Putra, I. K. (2021). Design of Soil pH Measuring Instruments Using pH Meter Sensor Module V1.1 SEN0161 Based on Arduino Uno. *BULETIN FISIKA*, *22*(2), 105. https://doi.org/10.24843/BF.2021.v22.i02.p08

Yang, J. F., Feng, X. Y., Fu, H. J., & Zhao, L. F. (2012). Research on Calibration Method of Tire Dynamic Balance Detection System. *Advanced Materials Research*, *542–543*, 828–832. https://doi.org/10.4028/www.scientific.net/AMR.542-543.828

Yang, X. D., Men, Y. Z., Yu, L., Gao, J. G., & Yu, H. B. (2014). Study on Calibration and Test of Automotive Wheel Hub Detection System. *Advanced Materials Research*, *1061–1062*, 970–973. https://doi.org/10.4028/www.scientific.net/AMR.1061-1062.970

Young, J.-S., Hsu, H.-Y., & Chuang, C.-Y. (2017). Camber Angle Inspection for Vehicle Wheel Alignments. *Sensors*, *17*(2), 285. https://doi.org/10.3390/s17020285