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Innovative Design and Construction of a Raspberry Pi-Based Smart Ground Clearance Measurement System for Automotive Safety

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Abstract

Ground clearance is one of the vehicle dimensions regulated under Indonesia's motor vehicle type approval testing regulations, with a permissible tolerance of ±50 mm from manufacturer specifications. The current manual measurement procedure requires inspectors to crouch beneath the vehicle, thereby posing occupational safety risks and reducing operational efficiency. Previous studies have developed prototype ground clearance measurement tools; however, these prototypes lack real-time remote monitoring capabilities and data logging functionality. Fundamentally, this study endeavors to conceptualize, develop, and operationalize a Raspberry Pi-driven measurement system for ground clearance assessment, embedded within an Internet of Things (IoT) architectural framework. The device employs the US-015 ultrasonic sensor as the primary measurement component, a Raspberry Pi as the central processing unit, and an ESP32 module for wireless data transmission via the MQTT protocol to the ThingSpeak IoT platform, enabling measurement results to be monitored in real time through a web-based dashboard. Driven by its core research objectives, the present investigation positioned itself firmly within the Research and Development (R&D) methodological tradition, drawing upon the ADDIE

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model as a holistic developmental construct that cohesively structured and steered the advancement of every constituent research phase. Performance testing was conducted on 30 freight vehicles at the UPT PKB (Vehicle Roadworthiness Testing Unit) of Kediri City. The test results demonstrate a mean accuracy of 98.63%, with a mean error rate of 1.37%. Time efficiency evaluation reveals a reduction in measurement duration of 40.25%–45.16% compared to the conventional manual method. Five certified expert validators assessed the device and collectively awarded a score of 90%, confirming its classification as 'Highly Feasible' for operational use. This device offers a safe, efficient, and IoT-connected solution for ground clearance measurement in motor vehicle type approval testing.

Keywords: Ground Clearance; Raspberry Pi; Ultrasonic Sensor; IoT; MQTT.

INTRODUCTION

Transportation is the activity of conveying passengers and/or goods from one location to another, playing a pivotal role in supporting human mobility, goods distribution, and economic growth. Transportation occupies a central position as the driving force behind the cycles of production, distribution, and consumption (Taufan Laode et al., 2025). In 2023, Indonesia's total registered motorized vehicle population stood at 159,134,167 units, broken down into 19,711,593 passenger cars, 6,088,534 freight vehicles, 272,806 buses, and 133,061,234 motorcycles(Badan Pusat Statistik, 2024). This substantial volume of vehicles necessitates rigorous efforts to ensure the safety and operational roadworthiness of vehicles on public roads.

One of the mechanisms implemented to address this concern is the vehicle type approval test, which involves a physical inspection of the vehicle or an engineering design assessment conducted prior to mass production, importation, or modification(Indonesia, 2018). The Indonesian Ministry of Transportation, through Regulation PM 23 of 2021, has prescribed a measurement tolerance of ±50 mm relative to factory-specified ground clearance values(Indonesia, 2021).

Ground clearance refers to the perpendicular gap between the road surface and the lowermost structural point of a vehicle's body(Ridwan et al., 2020). This dimension plays a considerable role in determining how a vehicle performs across varied terrain conditions, maintains stability during maneuvering, and behaves aerodynamically(Ridwan et al., 2020). A real-world accident occurred in Damarsi Hamlet, Kepuh Anyar Village, Mojoanyar District, Mojokerto Regency, on January 26, 2023, in which a trailer truck became stuck at a railway crossing and was

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subsequently struck by the Sancaka Express Train. The Mojokerto Traffic Police Chief attributed the vehicle's entrapment on the rail tracks primarily to its inadequate ground clearance (Prihatini, 2023). This unfortunate event brings to the forefront the irreplaceable significance of conducting ground clearance measurements with both exactitude and regularity, particularly in the context of road safety assurance.

To date, ground clearance measurement has been conducted manually, requiring inspectors to crouch beneath the vehicle. This method poses potential risks to the safety of the inspector, is susceptible to measurement inaccuracies, demands a greater number of personnel, and reduces overall operational efficiency(Novianto et al., 2024). Adi (2024) created a technique for measuring ground clearance using a robotic vehicle platform in earlier study, while Fauzi(2025) developed a prototype utilizing ultrasonic sensors. However, both studies remain limited to local data display without remote monitoring capabilities and lack an integrated data storage system.

The principal objective of this research is to engineer an IoT-integrated ground clearance measurement system, utilizing the Raspberry Pi as its computational core, with data transmission facilitated through the MQTT protocol and cloud visualization managed via the ThingSpeak platform.

LITERATURE REVIEW

Vehicle Type Testing (Uji Tipe)

Under Indonesian transportation law, every motorized vehicle, trailer, and semi-trailer intended for public road use is legally required to pass a type approval examination before operation(Indonesia, 2018). This examination involves both a physical assessment and a technical design evaluation conducted prior to mass production, importation, or any structural modification(Indonesia, 2018). According to Ministerial Regulation PM 23 of 2021, ground clearance constitutes one of the auxiliary technical parameters assessed during type approval testing, whereby the accepted margin of deviation is set at ±50 mm from the specifications declared by the vehicle manufacturer(Indonesia, 2021)

Ground Clearance

Under ISO 612:(1978), ground clearance is conceptualized as the smallest vertical measurement separating the ground plane from the lowermost extremity of the vehicle's central underbody structure, with its lateral boundaries defined by two parallel vertical planes spaced at a distance proportional to 80% of the axle's minimum track gauge. This definition deliberately

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omits peripheral attachments located on the vehicle's sides, including but not limited to side skirts and footsteps. This parameter has been shown to exert considerable influence over a vehicle's aerodynamic behavior and overall performance under diverse road conditions(Ridwan et al., 2020).

Raspberry Pi

The Raspberry Pi is a miniaturized computing board engineered to operate a full-featured Linux-basedoperating system(Ariyani et al., 2022). Its widespread adoption in IoT-based projects as a central processing unit is attributed to several key advantages, including its cost-effectiveness, onboard GPIO pins, wireless and wired network connectivity, and compatibility with multiple programming languages, most notably Python(Ariyani et al., 2022). In the present study, the Raspberry Pi functions as the primary controller, handling sensor data processing and facilitating data transmission to a cloud platform through the MQTT protocol.

ESP32

The ESP32 incorporates a dual-core processing architecture with onboard Wi-Fi and Bluetooth connectivity, making it an efficient and economical choice for IoT applications requiring wireless communication capabilities(Hercog et al., 2023). Within the framework of this study, the ESP32 manages ultrasonic sensor data acquisition, presents measurement outputs on an LCD display, and relays the data to the Raspberry Pi through the MQTT protocol(Hercog et al., 2023)

Ultrasonic Sensor US-015

Equipped with a detection range extending from 2 cm to 400 cm, the US-015 ultrasonic sensor delivers a measurement precision of ±1 mm (Hartoto et al., 2020). Empirical calibration studies have established that its measurement deviation within the 100 mm to 400 mm range consistently falls below 2%, affirming its appropriateness for precision-sensitive applications such as ground clearance measurement(Hartoto et al., 2020).

MQTT

Originally conceived for operation in bandwidth-restricted and resource-limited environments, MQTT (Message Queuing Telemetry Transport) facilitates message exchange

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among networked devices through a publish-subscribe architectural model (Jara Ochoa et al., 2023). Its architecture prioritizes low overhead and high efficiency, making it particularly well-suited for real-time data exchange in IoT systems(Jara Ochoa et al., 2023). In this study, MQTT functions as the primary communication layer interconnecting the ESP32 and the Raspberry Pi, as well as linking the Raspberry Pi to the ThingSpeak cloud platform.

ThingSpeak

ThingSpeak is an IoT platform that runs in the cloud and lets linked devices store, get, and show data in real time. (Nabil Sarmada et al., 2024). Its native compatibility with MATLAB and its open API framework make it particularly appropriate for continuous data monitoring scenarios(Nabil Sarmada et al., 2024). In this investigation, ThingSpeak serves a dual function: as the data repository for measurement records and as the visualization engine underpinning the web-based monitoring dashboard.

Related Research

A ground clearance measurement tool built upon a robotic vehicle platform was developed by Adi(2024), enabling automated sensor positioning; however, the prototype was not equipped with cloud connectivity or integrated data storage. Fauzi (2025) subsequently engineered a ground clearance measurement prototype incorporating ultrasonic sensors, achieving improvements in measurement speed, though the system equally lacked remote monitoring and cloud integration features. In a related domain, Saiful Rahman et al. (2021) proposed a parking distance monitoring system leveraging a Raspberry Pi and web interface, providing evidence of the viability of IoT-based web monitoring in transportation settings. Futhermore, Fredy Naa (2022) demonstrated a multi-device IoT system architecture through the implementation of a greenhouse monitoring solution utilizing ESP32, Raspberry Pi, MQTT, and Node-RED, which serves as a pertinent architectural reference for the present study.

RESEARCH METHOD

Grounded in the Research and Development (R&D) paradigm, this study follows a systematic investigative approach as defined by Sugiyono (2017), who describes R&D as a methodical process aimed at both producing and assessing the effectiveness of a developed product. The ADDIE framework — encompassing the sequential phases of Analyze, Design, Develop, Implement, and Evaluate — was selected as the development model given its recognized

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capacity to balance structural rigor with methodological flexibility in engineering product development contexts(Rahayu, 2025).

Field activities were undertaken at the UPT PKB of Kediri City, specifically located at Jl. Semeru No. 55, Semen, Tamanan, Kediri City, East Java, Indonesia. Data collection and device evaluation were conducted throughout the period spanning October 2025 to May 2026.

ADDIE Development Phases

` (1) Analyze: The existing manual ground clearance measurement process was identified as both hazardous and operationally inefficient, establishing the need for an innovation in the form of an automated system integrated with IoT technology.

(2) The Design phase encompassed three principal activities: defining the physical configuration of the hardware, structuring the user interface layout of the web-based dashboard, and constructing a schematic depiction of how the system operates end-to-end. A block diagram and a functional demonstration illustrate the operational mechanics of the gadget in real-world scenarios. Figure 1 illustrates the block.

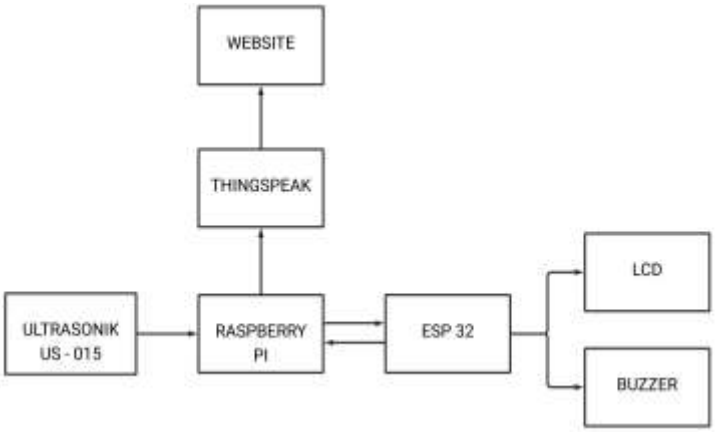


Figure 1. System Block Diagram

Figure 2 describes how the system operates end-to-end, starting from the integration of all components to the final display of measurement results on the web dashboard.

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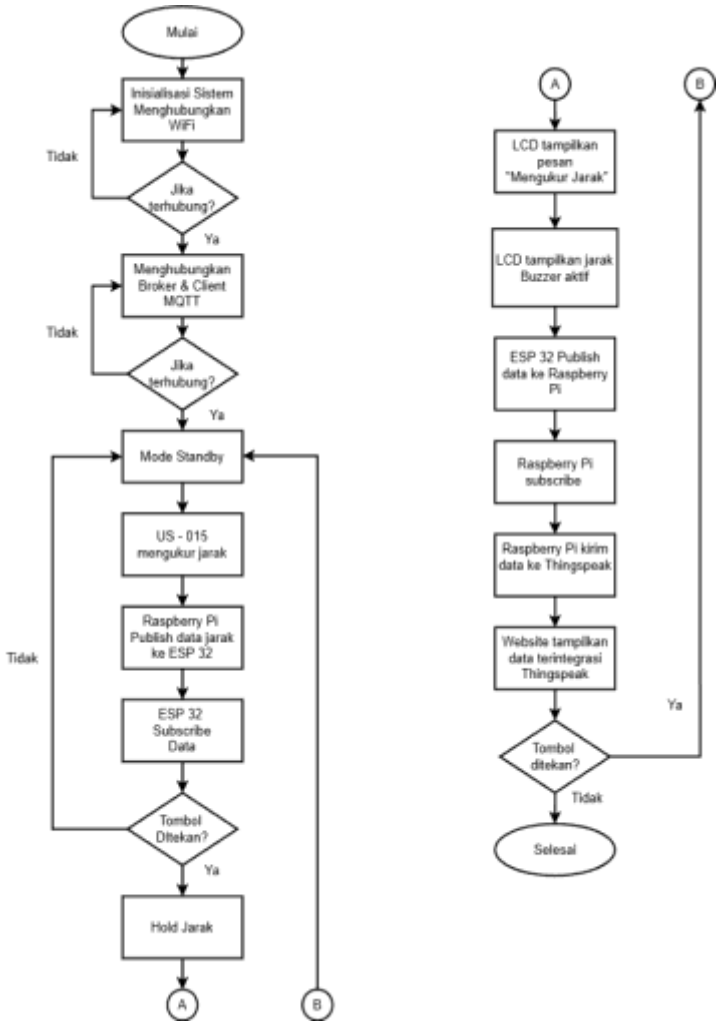


Figure 2. Device Operational Workflow Diagram

(3) Develop: The hardware assembly included putting together an aluminum pipe frame, adding electronic parts, and programming the Raspberry Pi with Python (using Thonny IDE) and the ESP32 with C++ (using Arduino IDE). The dashboard on the web was made with HTML, CSS, and JavaScript, and then put on the Netlify platform.

(4) Implement: The device was tested under real field conditions at the UPT PKB of Kediri City using freight vehicles as the test subjects.

(5) Evaluate: Device evaluation was carried out through performance testing, operational time efficiency testing, sensor calibration, and expert validation.

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Data Collection Instruments

Three instruments were employed in this study: (1) the developed ground clearance measurement device, (2) a manual tape measure as a comparative reference for manual measurement, and (3) a laser distance meter as a calibration reference. Testing was conducted on 30 freight vehicles of various types, including the Colt Diesel, Grand Max, Isuzu ELF, and Suzuki Carry.

Testing Procedures

(1) Device Performance Testing: The measurement results obtained from the developed device were compared against manual measurements conducted on 30 vehicles, and the percentage error was subsequently calculated. (2) Time Efficiency Testing: The measurement time required by the device was compared with that of manual measurement across three sessions: morning (08:00–10:00), midday (10:00–12:00), and a full working session (08:00–12:00). Efficiency was calculated using the following formula:

$$Efficiency = \frac{Manual\ Time - Device\ Time}{Device\ Time} x100\% \quad (1)$$

(3) Sensor Calibration: The US-015 sensor was calibrated against a laser distance meter over a range of 100 mm to 400 mm at 50 mm intervals, with each measurement point repeated three times. (4) Expert Validation: Five motor vehicle inspectors at the UPT PKB of Kediri City provided assessments using a Likert scale (1–5) across four aspects: device appearance, measurement accuracy, ease of operation, and user comfort.

RESULT

Device Construction

In terms of its hardware composition, the ground clearance measurement system is deliberately organized around two self-contained operational assemblies, each fulfilling a designated role within the overall system architecture. The architectural composition of Unit 1 revolves around a Raspberry Pi 3 Model B, which assumes responsibility for central data processing, supported by Wi-Fi and MQTT broker integration to maintain fluid data communication pathways, with a US-015 ultrasonic sensor allocated as the foremost sensing component. A thorough representation of the Unit 1 electrical wiring layout is furnished in Figure 3.

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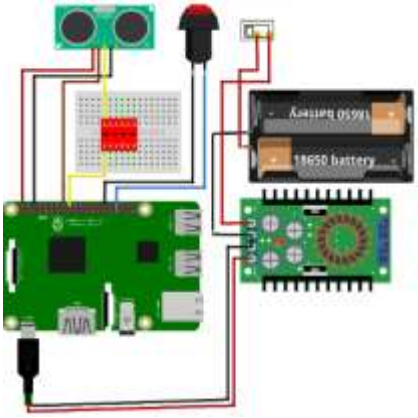


Figure 3. Wiring Diagram of Unit 1 Raspberry Pi

Unit 2 contains an ESP32 microcontroller, a 16x2 LCD screen with an I2C module, a push button for measurement activation, and a buzzer for audio confirmation. Figure 4 illustrates the wiring diagram of Unit 2.

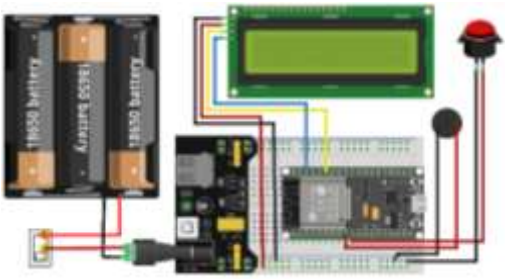


Figure 4. Wiring Diagram of Unit 2 ESP32

Both units are mounted on an aluminum pipe frame equipped with a waterpass level to ensure horizontal alignment during measurement, so that the sensor faces vertically upward in a perpendicular orientation. The device is powered by rechargeable 18650 batteries. Figure 5 presents the complete assembly device.

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Figure 5. Raspberry Pi Based Ground Clearance Measurement Device

Upon activation, the sensor measures the distance from the ground surface to the lowest point of the vehicle. When the push button is pressed, the measurement result is displayed on the LCD screen, confirmed by an audible buzzer signal, and transmitted via MQTT to the Raspberry Pi, which subsequently uploads the data to ThingSpeak for real-time visualization on a web-based dashboard accessible from various devices.

Performance Test

Performance testing was conducted on 30 freight vehicles at the UPT PKB of Kediri City. Table 1 presents a comparison between the measurement results obtained from the developed device and those from manual measurement.

Table 1. Device Performance Test Results

No	Vehicle Number	Vehicle Type	Device (mm)	Manual (mm)	Status	Error (%)
1	AG 8949 AE	COLT DIESEL	192	195	Succes	1,54%
2	AG 8357 AA	COLT DIESEL	195	192	Succes	1,56%
3	AG 9285 AE	COLT DIESEL	197	200	Succes	1,50%

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4	W 8350 PX	COLT DIESEL	185	185	Succes	0%
5	AG 9257 AE	COLT DIESEL	186	180	Succes	3,33%
6	AG 8234 AR	COLT DIESEL	191	188	Succes	1,60%
7	AG 9265 AE	COLT DIESEL	185	185	Succes	0%
8	AG 8156 AK	COLT DIESEL	202	200	Succes	1%
9	AG 8372 AE	COLT DIESEL	194	193	Succes	0,52%
10	AG 8233 AR	COLT DIESEL	186	183	Succes	1,64%
11	AG 8339 AK	GRAND MAX	206	203	Succes	1,48%
12	AG 8039 AN	GRAND MAX	185	185	Succes	0%
13	AG 8973 AT	GRAND MAX	177	178	Succes	0,56%
14	AG 8963 AI	GRAND MAX	181	182	Succes	0,55%
15	AG 8049 AN	GRAND MAX	175	181	Succes	3,31%
16	P 8376 KB	GRAND MAX	176	173	Succes	1,73%
17	S 9169 ND	ISUZU ELF	231	230	Succes	0,43%
18	AG 8002 AM	ISUZU ELF	239	235	Succes	1,70%
19	L 9374 VV	ISUZU ELF	227	225	Succes	0,89%
20	AG 8571 AK	SUZUKI CARRY	186	190	Succes	2,11%
21	AG 9642 A	SUZUKI CARRY	192	190	Succes	1,05%
22	L 8273 BAA	SUZUKI CARRY	191	190	Succes	0,53%
23	AG 8705 YT	ISUZU ELF NMR	184	188	Succes	2,13%
24	W 8274 PX	ISUZU ELF NMR	202	204	Succes	0,98%
25	AG 8957 AG	DAIHATSU ZEBRA	230	225	Succes	2,22%
26	AG 8627 AO	ISUZU PICK UP	181	180	Succes	0,56%
27	AG 8814 AG	HINO DUTRO	186	190	Succes	2,11%
28	AG 8209 AH	L300	181	178	Succes	1,69%
29	AG 8211 AJ	ISUZU TRAGA	196	192	Succes	2,08%
30	AB 8213 BF	ISUZU TRAGA	196	195	Succes	0,51%

Based on the performance test results, the device demonstrated good measurement consistency and accuracy across all 30 test vehicles. The average percentage error recorded was 1.37%, corresponding to an average accuracy of 98.63%. The highest error observed was 3.33%, recorded for vehicles number 5 and 15, while 3 out of 30 vehicles yielded an error of 0%, thereby

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confirming the device's reliability for operational field use.

Time Efficiency Test

Time efficiency testing was conducted across three measurement sessions. During the morning session (08:00–10:00, n=20 vehicles), the total measurement time using the device was 264.04 seconds, compared to 441.93 seconds for the manual method, yielding an efficiency gain of 40.25% (efficiency ratio of 59.75%). During the midday session (10:00–12:00, n=15 vehicles), the device completed measurements in 196.36 seconds compared to 355.01 seconds manually, achieving an efficiency gain of 44.69%. During the full working session (08:00–12:00, n=43 vehicles), the device recorded a total measurement time of 537.57 seconds compared to 980.21 seconds manually, resulting in an efficiency gain of 45.16%. Across all sessions, the device consistently reduced measurement time by 40–45% relative to the manual method.

Sensor Calibration

Calibration of the US-015 sensor was performed by comparing sensor readings against a laser distance meter at fixed distances ranging from 100 mm to 400 mm. Table 2 presents the complete calibration results.

Table 2. US-015 Sensor Calibration Results

Distance (mm)	Trial	Sensor US-015 (mm)	Laser Distance Meter (mm)	Status	Error
100	1	99	100	Succes	1%
	2	100	100	Succes	0%
	3	99	100	Succes	1%
150	1	149	150	Succes	0,67%
	2	149	150	Succes	0,67%
	3	150	150	Succes	0%
200	1	201	200	Succes	0,5%
	2	200	200	Succes	0%
	3	199	200	Succes	0,5%
250	1	250	250	Succes	0%
	2	251	250	Succes	0,4%

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	3	251	250	Succes	0,4%
300	1	301	300	Succes	0,34%
	2	300	300	Succes	0%
	3	300	300	Succes	0%
350	1	350	350	Succes	0%
	2	351	350	Succes	0,29%
	3	351	350	Succes	0,29%
400	1	400	400	Succes	0%
	2	401	400	Succes	0,25%
	3	400	400	Succes	0%

The calibration results indicate that the US-015 sensor performed reliably and consistently within the range of 100–400 mm, with all readings falling within a 2% error margin. The consistent performance observed across every trial validates the suitability of this sensor as a measurement component for ground clearance applications requiring millimeter-level precision.

Expert Validation

Five motor vehicle inspectors at the UPT PKB of Kediri City provided assessments of the device across four evaluation criteria: device appearance, measurement accuracy, ease of operation, and user comfort. Table 3 shows the list of validators and their scores.

Table 3. List of Validators

No	Validator Name	Score
1	Budi Mardi Santoso, A.Ma.PKB., S.H.	18
2	Junailan Rusjanto, A.Ma.PKB., S.T.	18
3	Guntur Lambang Kawitan, A.Ma.PKB., S.E.	17
4	Argan Sakti Purwaka, A.Ma.PKB.	19
5	Achmad Zainul Ma'arif, A.Ma.PKB.	18
Total Score		90

The total validation score obtained was 90 out of a maximum possible score of 100. The validation percentage was calculated as follows:

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$$Percentage = \frac{90}{100} x100\% = 90\% \quad (2)$$

Based on the feasibility criteria table, a score of 90% falls within the category of "Highly Feasible", indicating that the Raspberry Pi-based ground clearance measurement device is highly feasible and valid for operational field use in motor vehicle type approval testing activities.

DISCUSSION

The test results demonstrate that the Raspberry Pi-based ground clearance measurement device operates with an average accuracy of 98.63% and an average error of 1.37% across 30 freight vehicles. As governed by Ministerial Regulation PM 23 of 2021, the measurement outcome is consistent with the stipulated acceptable range of ±50 mm from the manufacturer's specifications(Indonesia, 2021). This shows that the equipment is good for use in the vehicle type approval testing process. Calibration results of the US-015 sensor further indicate consistent readings with an error below 2% within the range of 100–400 mm.

In terms of operational efficiency, the device reduced measurement time by 40.25%–45.16% compared to the manual method, while simultaneously eliminating the necessity for inspectors to crawl beneath vehicles, thereby mitigating occupational safety risks. In comparison to the studies conducted by Adi (2024) and Fauzi (2025), which were limited to local data display, this device offers the added advantages of automatic cloud-based data storage and real-time monitoring through an IoT-based web dashboard. These advantages are further reinforced by an expert validation score of 90%, confirming that the device is not only technically accurate but also convenient and comfortable to operate in the field.

CONCLUSION

This study successfully designed and developed a Raspberry Pi-based ground clearance measurement device integrated with IoT technology via the MQTT protocol and the ThingSpeak platform. The device had a measurement accuracy of 98.63%, a time efficiency improvement of 40.25%–45.16% over the manual approach, a sensor calibration error of less than 2%, and an expert validation outcome of 90%, which puts it in the "Very Eligible" category based on the criteria for feasibility that have been set. The foremost scholarly contribution of this investigation resides in its successful integration of a remote monitoring mechanism and a cloud-anchored data storage infrastructure — two critical functionalities conspicuously absent from all antecedent prototype developments in this domain. Prospective researchers are strongly encouraged to

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diversify the range of vehicle categories under examination, embed an offline data retention functionality within the system architecture, and undertake a more extensive validation effort encompassing numerous motor vehicle testing establishments across different locations.

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