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Development and Validation of a Web Server-Based Internet of Things (IoT) Trainer for Practical Learning in Higher Education

Zainuddin[1]*, Bakhrani A. Rauf[2], Abdul Muis Mappalotteng[3]

1,2,3 Universitas Negeri Makassar

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*Correspondence: Zainuddin
Email: waddasede@gmail.com

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Abstract: *The rapid advancement of Internet of Things (IoT) technology has significantly influenced engineering and computer technology education, particularly in laboratory-based practical learning. However, many higher education institutions still face limitations in providing integrated IoT laboratory facilities, causing learning to rely on simulations or fragmented hardware modules that do not adequately represent real-world IoT system integration. This study aims to develop and validate a web server-based IoT trainer to support practical learning in higher education. The research employed a Research and Development (R&D) approach consisting of six stages: needs analysis, prototype design, product development, expert validation and limited trials, product revision, and dissemination. The developed trainer integrates an ESP32 microcontroller with multiple sensors and actuators, enabling real-time monitoring and control through an embedded web server. Data were collected through functional testing, system performance testing, and expert validation involving six experts in media, content, and instructional design. Data analysis used descriptive statistics and percentage-based feasibility calculations. The results indicate that all hardware components operated with error rates below 5% and response times under 250 ms. The web server system achieved an average response time of 648.1 ms with an error rate of 0%, indicating high reliability. Expert validation showed very high feasibility across all aspects, including programming (99.2%), content relevance (98.8%), and instructional design (100%). These findings demonstrate that the developed IoT trainer is technically reliable, pedagogically appropriate, and suitable for supporting IoT practical learning in higher education.*

Keywords: *Internet Of Things, Trainer Kit, Web Server, Esp32, Engineering Education.*

Introduction

The rapid advancement of digital technologies in the era of Industry 4.0 has significantly transformed various sectors, including higher education. Emerging technologies such as artificial intelligence, big data, cloud computing, and the Internet of Things (IoT) have become key components in modern industrial systems. Among these technologies, IoT has gained considerable attention due to its ability to connect physical devices, sensors, and software systems through network infrastructures, enabling data exchange and automated decision-making processes. The integration of IoT technologies has led to the development of various smart systems, including smart homes, smart healthcare systems, smart agriculture, and smart cities.

The growing adoption of IoT technologies across industries has created an increasing demand for professionals who possess competencies in embedded systems, sensor integration, wireless communication, and data processing. Consequently, higher education institutions, particularly those offering engineering and computer technology programs, are expected to equip students with the necessary knowledge and skills related to IoT system development. In this context, practical learning plays a crucial role in enabling students to gain hands-on experience in designing, implementing, and testing IoT systems. Through laboratory activities, students can develop technical skills in microcontroller programming, sensor interfacing, and network-based device monitoring.

The rapid advancement of Internet of Things (IoT) technology has transformed practices in engineering and computer technology education, particularly in laboratory-based practical learning, by enabling real-time data acquisition, remote monitoring, and smart laboratory environments (Asad et al., 2022; Soegoto et al., 2022; van Deursen et al., 2022). Nevertheless, many higher education institutions still face substantial constraints in providing integrated IoT laboratory infrastructure, including limited equipment, inadequate technical support, and challenges in aligning legacy systems with contemporary IoT standards (Al-Omari et al., 2024; Derbas et al., 2023; Shah & Yaqoob, 2016). As a result, practical learning frequently relies on simulations or fragmented hardware modules that do not fully represent end-to-end IoT system integration and can reduce the authenticity of students' learning experiences (Asad et al., 2022; Work in Progress: Applications of IoT in Distance Lab Checkoff, 2019; JPPIPA, 2022). To address these gaps, recent studies have begun to develop IoT-based learning media and trainer kits using platforms such as ESP32, Arduino, and Raspberry Pi; however, many of these solutions remain context-specific and lack comprehensive validation of technical performance and pedagogical feasibility in higher education settings (AIP Conference Proceedings, 2023; Bisaioti, 2025; JPPIPA, 2022). Building on this emerging body of work, the present study aims to develop and validate a web server-based IoT trainer integrating an ESP32 microcontroller, multiple sensors and actuators, and real-time monitoring and control through an embedded web interface to support authentic and reliable IoT practical learning in higher education.

Practical laboratory learning is considered an essential component in engineering education because it allows students to connect theoretical concepts with real-world technological applications. Experiential learning theory emphasizes that knowledge is constructed through direct experience and active experimentation. By engaging in practical activities, students are able to understand how hardware components interact with software systems within an integrated environment. Therefore, the availability of adequate laboratory facilities and learning media is an important factor in supporting effective IoT education in higher education institutions.

Despite the importance of practical learning in IoT education, many universities still face challenges in providing integrated laboratory facilities. In many cases, IoT learning relies heavily on simulation platforms or separate hardware modules that are not integrated into a unified IoT system. Although simulation tools can help students understand theoretical concepts, they often fail to provide real-world experiences in configuring sensors, establishing network communication, and implementing device monitoring systems. As a result, students may understand the conceptual aspects of IoT but lack practical experience in developing complete IoT applications.

Another challenge in IoT learning relates to the complexity of existing IoT platforms. Many IoT systems require cloud-based services and complex configurations to enable device monitoring and control. These platforms may introduce additional technical barriers for students who are still learning the fundamental concepts of IoT systems. Furthermore, cloud-based platforms require stable internet connectivity, which may not always be available in laboratory environments. This situation can reduce the effectiveness of practical learning activities and limit students' opportunities to experiment with IoT systems directly.

Several previous studies have attempted to address these challenges by developing IoT-based learning platforms and trainer systems for engineering education. For example, Islam et al. developed an IoT trainer platform designed to support embedded systems education using microcontroller-based architectures. Similarly, Rahman et al. designed an IoT-based smart home learning system that allows students to monitor and control household devices through internet-based communication. Other studies have introduced wireless sensor network trainer kits and IoT-based environmental monitoring platforms to enhance practical learning in engineering programs.

Although these studies have contributed to the development of IoT learning media, many existing trainer systems still focus primarily on microcontroller programming and basic sensor experimentation. In addition, several systems depend on external cloud platforms for device monitoring and data visualization. Such dependency may reduce the flexibility of laboratory learning environments, especially when internet connectivity is limited or unstable. Moreover, many trainer systems do not integrate multiple sensors, actuators, and real-time monitoring interfaces within a single learning platform.

Therefore, there is a need to develop an integrated IoT learning platform that combines hardware experimentation, embedded programming, and real-time monitoring capabilities in a unified system. A trainer-based learning medium can provide students with a structured environment where various IoT components are integrated into a single platform. When combined with a web-based monitoring interface, the trainer allows students to observe sensor data, control devices, and analyze system behavior through a standard web browser.

To address these challenges, this study proposes the development of a web server-based Internet of Things trainer designed specifically for practical learning in higher education. The proposed system utilizes an ESP32 microcontroller that functions both as the main processing unit and as an embedded web server. By implementing a web server architecture directly within the microcontroller, the system enables real-time monitoring and control of devices through a browser without requiring external cloud services. This approach allows the system to operate independently within a local wireless network, making it more suitable for laboratory-based learning environments.

The novelty of this research lies in the integration of multiple IoT sensors, actuators, and embedded web server technology within a single modular trainer platform designed for educational purposes. Unlike many existing IoT learning platforms that rely on cloud-based services, the proposed trainer uses a locally hosted web server to provide real-time monitoring capabilities. This design simplifies system configuration and enhances system reliability for laboratory use. In addition, the trainer is designed to support structured practical learning activities that enable students to explore various IoT applications.

Based on these considerations, the objective of this study is to develop and validate a web server-based IoT trainer that can support practical learning in higher education. Specifically, this study aims to design an integrated IoT trainer platform, evaluate its technical performance through functional testing, and determine its feasibility as a learning medium through expert validation. The results of this study are expected to contribute to the development of more effective IoT learning media that support hands-on laboratory activities in engineering and computer technology education.

Methodology

Research Design

This study employed a Research and Development (R&D) approach aimed at developing an instructional product in the form of a web server-based Internet of Things (IoT) trainer fo r practical learning in higher education. The R&D method was selected because it allows researchers to systematically design, develop, evaluate, and refine educational products before implementation in real learning environments.

The development procedure adopted a modified instructional product development model consisting of six stages: (1) learning needs analysis, (2) trainer and web server prototype design, (3) trainer product development, (4) expert validation and limited trials, (5) product revision and improvement, and (6) product dissemination. This development model was adapted to ensure that the resulting product meets both technical feasibility and pedagogical requirements.

Figure 1. illustrates the research and development procedure used in this study

Learning Needs Analysis

The first stage of the development process involved identifying learning needs related to Internet of Things practical learning in higher education. Data were collected through observations of existing laboratory learning activities and informal discussions with instructors involved in IoT-related courses. The analysis revealed several challenges in current IoT learning practices, including limited laboratory equipment, fragmented hardware components, and the frequent use of simulation platforms to replace real hardware experimentation. These limitations reduce students' opportunities to interact directly with sensors, microcontrollers, and network-based monitoring systems. Based on these findings, the development of an integrated IoT trainer was considered necessary to provide a practical learning platform that enables students to conduct real-world IoT experiments.

IoT Trainer System Architecture

The developed IoT trainer uses an ESP32 micro-controller that functions as the central controller and embedded web server. The ESP32 processes sensor data and transmits the data through a local WiFi network to a web dashboard that can be accessed using a standard web browser.

The embedded web server architecture allows users to monitor sensor readings and control output devices in real time without relying on external cloud services. This architecture enables the trainer system to operate independently within a local wireless network, making it suitable for laboratory learning environments.

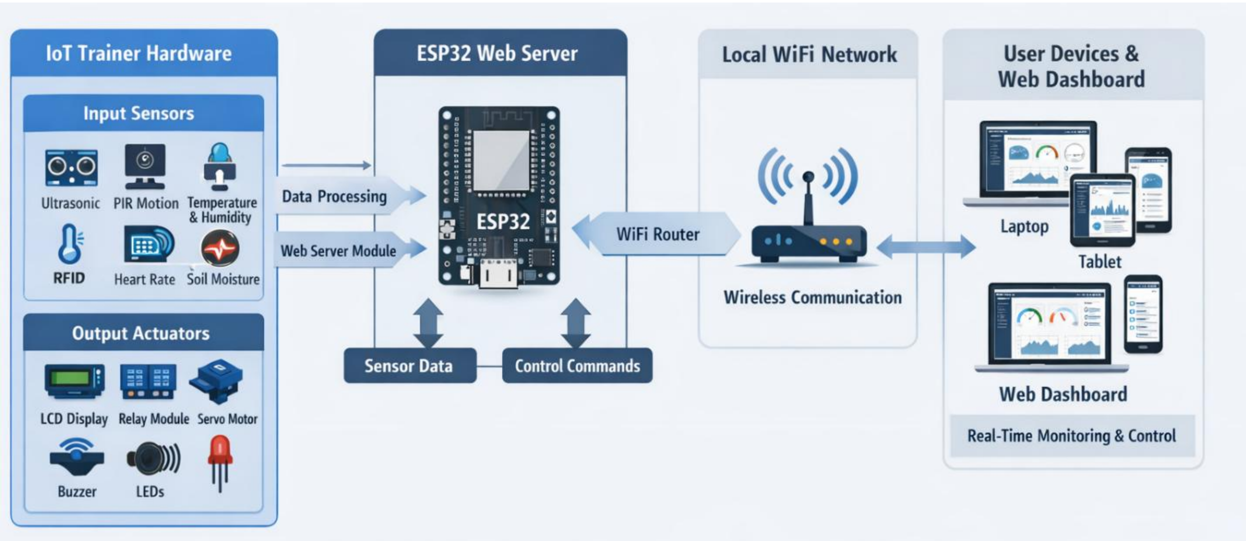

Figure 2. Architecture of the Web Server-Based IoT Trainer System

Trainer Hardware Design

The trainer was designed as a portable ESP32-based system integrated into a custom Printed Circuit Board (PCB) and enclosed in an aluminum case to improve protection, durability, and mobility during laboratory use.

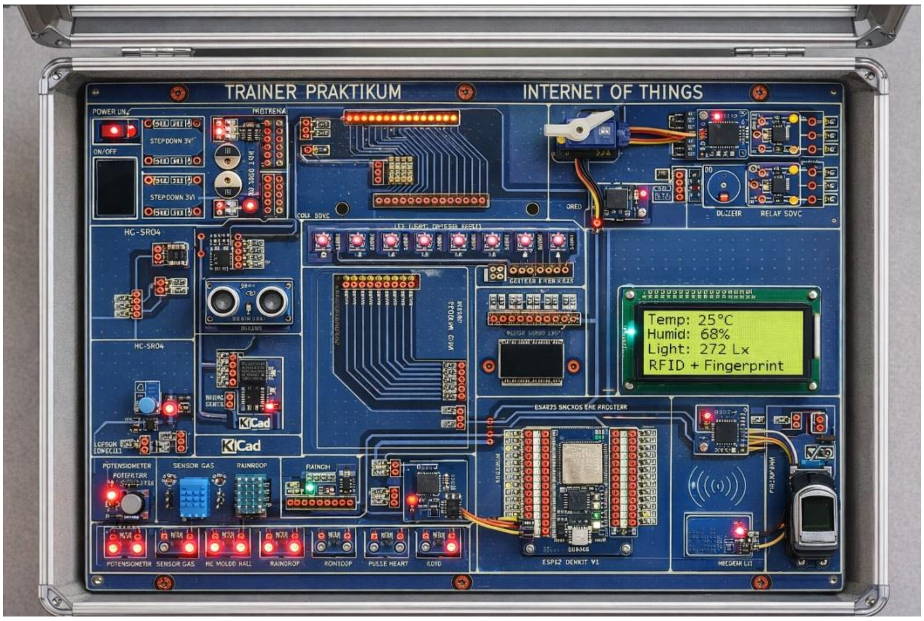

Figure 3. Physical Prototype of the IoT Trainer

The PCB was designed using KiCad software, considering routing efficiency, signal stability, and electrical safety. The PCB layout ensures stable communication between sensors, actuators, and the ESP32 microcontroller.

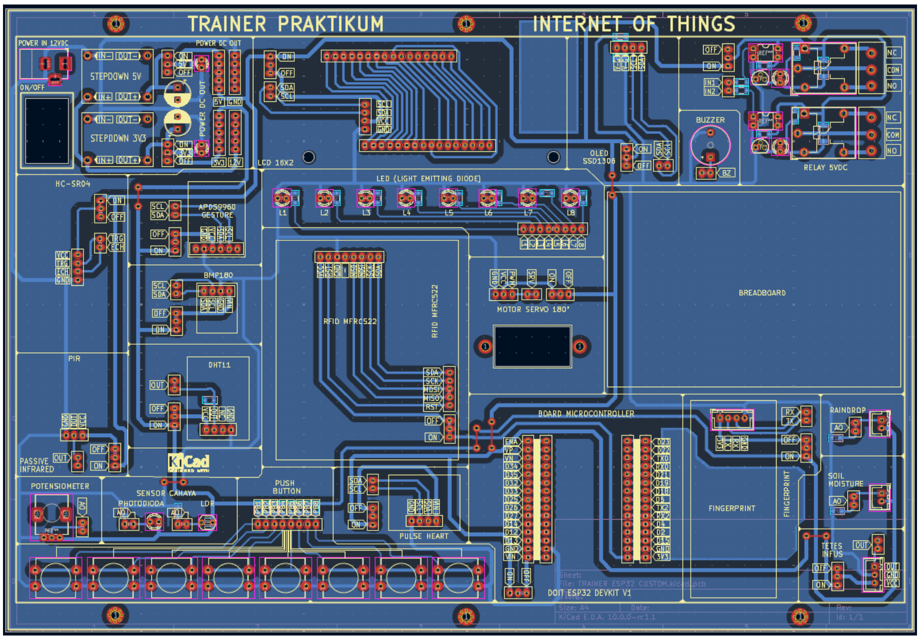

Figure 4. PCB Layout of the IoT Trainer

Product Development

In the product development stage, the IoT trainer prototype was physically constructed and assembled. The trainer integrates multiple sensors and actuators to support different IoT learning scenarios such as environmental monitoring, security systems, and health monitoring. The embedded web server program was also developed and uploaded to the ESP32 microcontroller. The program was designed to read sensor data, process system inputs, and display monitoring information through a browser-based dashboard interface.

Expert Validation

After the prototype development stage, the IoT trainer underwent expert validation to evaluate its feasibility as a learning medium.

The validation process involved two expert validators who are lecturers with expertise in Internet of Things systems and learning media development. Each validator evaluated the developed trainer using three evaluation instruments, covering the following aspects:

a. Media evaluation, which assessed system functionality, hardware integration, and interface usability.
b. Content evaluation, which examined the relevance of the trainer components to Internet of Things learning materials.
c. Instructional design evaluation, which assessed the suitability of the trainer for supporting practical learning activities.
d. Thus, both validators completed three questionnaires, resulting in six evaluation assessments across the three evaluation aspects.
e. The validation instrument consisted of 25 evaluation indicators using a five-point Likert scale ranging from very inappropriate (1) to very appropriate (5).

Limited Trials

Following expert validation, limited trials were conducted to test the technical performance of the developed trainer. The testing process included:

a. Hardware functional testing
   to evaluate the accuracy and response time of sensors and actuators.
b. Web server performance testing
   to measure response time and system reliability during device monitoring and control.
c. System stability testing
   to determine the error rate during repeated web server requests.
d. These tests were conducted to ensure that the developed system operates reliably for laboratory learning activities.

Data Analysis

Data collected from the validation process and system testing were analyzed using descriptive statistical analysis.

The feasibility of the developed trainer was calculated using a percentage-based feasibility formula: Feasibility Percentage = (Obtained Score / Maximum Score) × 100%

The feasibility results were then interpreted based on the following criteria

Table 1. Feasibility Criteria for Trainer Evaluation

Percentage	Category
81–100%	Very Feasible
61–80%	Feasible

41–60%	Moderately Feasible
21–40%	Less Feasible
0–20%	Not Feasible

This analysis was used to determine whether the developed IoT trainer met the criteria for use as a practical learning medium in higher education.

Result and Discussion

IoT Trainer Prototype

The development process resulted in a web server-based Internet of Things (IoT) trainer designed to support practical learning activities in higher education. The trainer integrates multiple sensors, actuators, and a microcontroller system within a portable hardware platform. The system was implemented using an ESP32 microcontroller that functions as both the main processing unit and an embedded web server for monitoring and controlling devices.

The developed trainer was assembled inside an aluminum case to improve durability, protection, and portability for laboratory use. The hardware system integrates various sensors, including environmental monitoring sensors, motion sensors, gesture sensors, and biometric sensors, allowing students to perform a wide range of IoT experiments.

The trainer also includes several output devices such as LEDs, relays, servo motors, buzzers, and display modules to support device control and system visualization during experiments. The integration of these components enables the trainer to simulate multiple IoT application scenarios such as smart environment monitoring, smart security systems, and health monitoring systems.

Figure 5. Physical Prototype of the Web Server-Based IoT Trainer

Hardware Functional Testing

Hardware functional testing was conducted to evaluate the operational performance of the components integrated in the developed IoT trainer. The testing focused on measuring component accuracy, response time, and operational stability. Each sensor and output component was tested repeatedly under controlled laboratory conditions to ensure reliable system performance.

Table 2 presents the performance testing results of the main hardware components integrated into the trainer system.

Table 2. Component Performance Testing

No	Component	Error/Accuracy	Response (ms)	Category
1	WiFi ESP32	99.98% uptime	643	Very Good
2	LED	100% switching	115	Very Good
3	Ultrasonic	2.92% error	129	Very Good
4	LDR	3.86% error	111	Very Good
5	DHT11	1.72% error	229	Very Good
6	PIR	100% detection	187	Very Good
7	Soil moisture	4.24% error	150	Very Good
8	Raindrop	95–100% detection	124	Very Good
9	BMP180	0.025% error	171	Very Good
10	APDS9960	100% detection	145	Very Good

The testing results indicate that all hardware components operate with high reliability. Most sensors show error values below 5%, which indicates acceptable measurement accuracy for educational laboratory applications. The response times of most components range between 100 ms and 250 ms, demonstrating that the system can process sensor inputs and actuator outputs in near real-time conditions.

The ESP32 module also demonstrated stable wireless communication with an uptime of 99.98%, indicating reliable connectivity between the trainer hardware and the web-based monitoring system.

Web Server Performance Testing

The developed IoT trainer includes a web-based monitoring system that allows users to observe sensor data and control output devices in real time. The monitoring interface can be accessed through a standard web browser connected to the same local WiFi network as the ESP32 micro-controller.

The web dashboard displays various sensor readings such as temperature, humidity, light intensity, and other environmental data collected by the integrated sensors. In addition, users can control several output devices including LEDs, relays, and servo motors through the web interface.

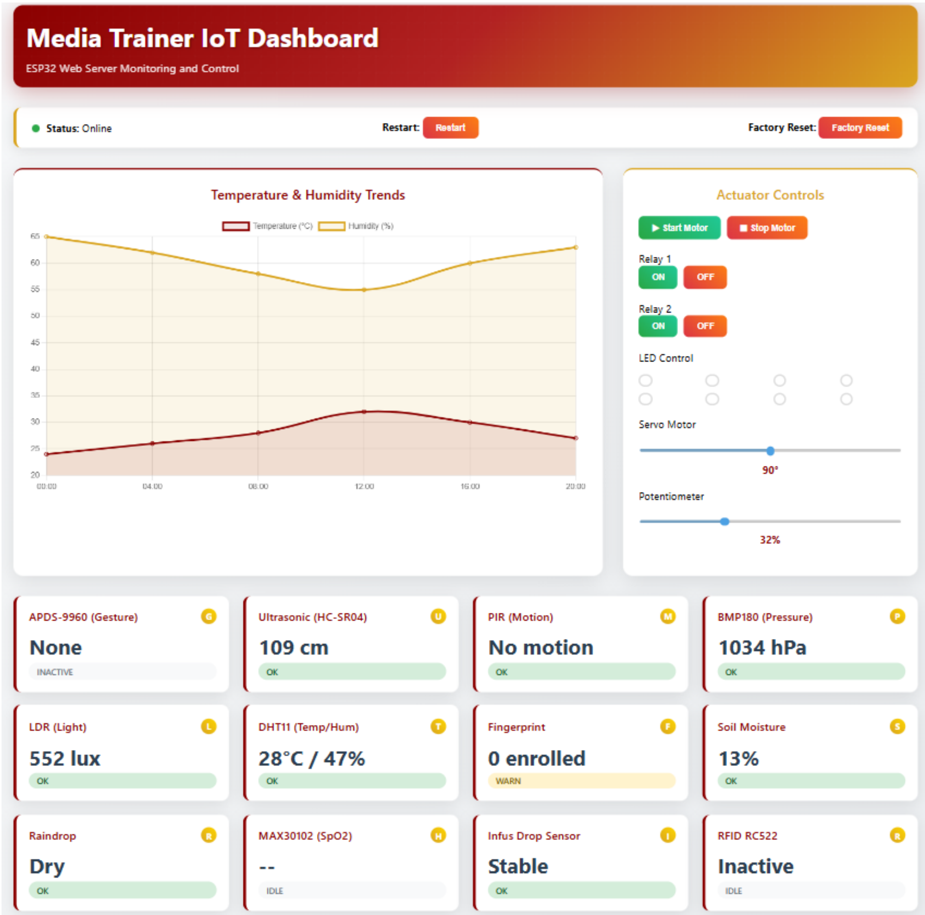

Figure 6. Web Server Dashboard Interface for IoT Trainer Monitoring

In addition to hardware testing, system performance testing was conducted to evaluate the response time and reliability of the embedded web server implemented on the ESP32 microcontroller. The testing involved repeated requests to the web dashboard to measure the system's response time in delivering sensor data and executing control commands.

Table 3. Presents the response time results obtained from ten web server request trials & Web Server Response Time

Trial	Load Time (ms)
1	612
2	645
3	630
4	655
5	622
6	640
7	618

8	670
9	688
10	635

The testing results indicate that the response time of the web server ranges from 612 ms to 688 ms, with an average response time of 648.1 ms. This response time indicates that the web monitoring interface is capable of displaying sensor data and responding to user commands within an acceptable time range for educational applications.

To evaluate system reliability, an additional error rate test was conducted by sending 100 consecutive requests to the web server.

Table 4. Error Rate Testing

Total Requests	Errors	Error Rate
100	0	0%

The results show that no system errors occurred during the testing process, indicating a 0% error rate. This result demonstrates that the embedded web server architecture implemented in the trainer system provides stable and reliable system performance for monitoring and control activities.

Expert Validation Results

To determine the feasibility of the developed IoT trainer as a learning medium, expert validation was conducted involving media experts, subject matter experts, and instructional design experts. The validation process evaluated several aspects, including system programming, content relevance, and instructional design suitability.

The results of the media expert validation are presented in Table 5.

Table 5. Media Expert Validation

Validator	Score	Percentage	Category
Validator 1	123	98.4%	Very Feasible
Validator 2	125	100%	Very Feasible

The media expert evaluation indicates that the developed trainer meets the technical standards required for learning media. The high scores obtained in this evaluation suggest that the trainer has good programming structure, system reliability, and interface usability.

The results of the subject matter expert validation are presented in Table 6.

Table 6. Content Expert Validation

Validator	Score	Percentage	Category
Validator 1	122	97.6%	Very Feasible
Validator 2	125	100%	Very Feasible

The content validation results indicate that the trainer system aligns well with the learning objectives of Internet of Things courses. The integrated sensors and monitoring system allow students to perform practical experiments that represent real-world IoT applications.

The instructional design validation results are presented in Table 7.

Table 7. Instructional Design Validation

Validator	Score	Percentage	Category
Validator 1	125	100%	Very Feasible
Validator 2	125	100%	Very Feasible

The instructional design evaluation indicates that the developed trainer supports effective learning activities. The trainer enables instructors to design structured laboratory experiments and encourages student-centered learning approaches.

Overall, the expert validation results demonstrate that the developed IoT trainer has very high feasibility as a learning medium for supporting practical IoT learning in higher education.

Discussion

The results of this study demonstrate that the developed Internet of Things (IoT) trainer successfully integrates hardware components, embedded web server technology, and instructional learning materials into a unified practical learning system. The integration of various sensors, actuators, and monitoring interfaces allows students to interact directly with IoT technologies in a laboratory environment. This hands-on learning approach enables students to understand the relationship between hardware components, microcontroller programming, and network-based device communication. As a result, the trainer provides a practical platform that supports experiential learning and enhances students' understanding of IoT system implementation.

The functional testing results indicate that the developed hardware components perform reliably with error rates below 5% for all tested sensors. The response times of most hardware components are below 250 ms, which indicates that the system can process sensor inputs and actuator outputs in real time. These results demonstrate that the trainer system is technically stable and suitable for use in practical laboratory activities. The high reliability of the hardware system ensures that students can perform experiments without experiencing significant technical interruptions during learning activities.

In addition to hardware reliability, the web server system also demonstrates stable performance. The average response time of 648.1 ms indicates that the web-based monitoring interface can display sensor data and control devices efficiently. Furthermore, the system testing results show an error rate of 0% during repeated request testing, which indicates that the web server architecture implemented on the ESP32 microcontroller is highly reliable. This finding confirms that embedded web server technology can provide an effective solution for IoT monitoring systems in educational environments.

The implementation of an embedded web server provides several advantages compared with cloud-based IoT platforms. Many existing IoT learning systems depend on external cloud services to enable device monitoring and control. While cloud platforms provide scalability and remote access, they also require stable internet connectivity and complex configuration processes. In contrast, the web server architecture implemented in this study allows the IoT trainer to operate independently within a local wireless network. This approach simplifies system configuration and improves system reliability, making it more suitable for laboratory learning environments where internet connectivity may be limited.

The findings of this study are consistent with previous research highlighting the importance of trainer-based learning media in engineering education. Previous studies have shown that IoT trainer platforms can significantly improve students' understanding of embedded systems and sensor integration through hands-on experimentation. For example, studies conducted by Islam et al. and Garcia et al. emphasized that trainer kits allow students to explore the interaction between hardware and software components in a structured learning environment. Similarly, research by Rahman et al. demonstrated that IoT learning platforms can improve student engagement and practical skills in developing smart systems.

However, many existing trainer systems focus primarily on microcontroller programming and basic sensor experimentation. In contrast, the trainer developed in this study integrates multiple sensors, actuators, and a web-based monitoring system within a single platform. This integration enables students to explore a wider range of IoT application scenarios, including environmental monitoring, security systems, and healthcare-related monitoring applications. The presence of multiple sensors also allows instructors to design more diverse laboratory experiments that reflect real-world IoT applications.

The expert validation results further support the feasibility of the developed trainer as a learning medium. The very high validation scores obtained from media experts, content experts, and instructional design experts indicate that the developed system meets both technical and pedagogical requirements. The high rating in the programming aspect indicates that the embedded system design and code implementation are considered efficient and reliable. Meanwhile, the high score in content relevance suggests that the trainer aligns well with the learning objectives of IoT-related courses in higher education. The perfect score obtained in instructional design evaluation indicates that the trainer supports effective learning activities and can facilitate student-centered learning approaches.

From an educational perspective, the developed IoT trainer can enhance practical learning experiences by enabling students to perform real-time monitoring and device control experiments. The integration of hardware and software components encourages students to explore problem-solving strategies when designing IoT systems. This learning approach aligns with experiential learning theory, which emphasizes the importance of direct experience and experimentation in developing technical competencies. Through hands-on experimentation, students can develop a deeper understanding of IoT system architecture and the interaction between sensors, microcontrollers, and network communication.

Despite the promising results, this study has several limitations. The evaluation of the trainer primarily focused on technical performance and expert validation. Although the system has been tested for functional reliability, further studies are needed to evaluate its effectiveness in improving students' learning outcomes and motivation during IoT courses. In addition, the current trainer system operates primarily within a local wireless network environment and does not yet include advanced cloud-based data storage or remote monitoring capabilities.

Future research may focus on integrating additional features such as cloud connectivity, mobile application interfaces, and advanced data visualization systems. These enhancements could further expand the functionality of the trainer and allow students to explore more complex IoT system architectures. Moreover, future studies could involve larger groups of students to evaluate the impact of the developed trainer on learning outcomes, problem-solving skills, and student engagement in IoT learning environments.

Overall, the findings of this study indicate that the developed web server-based IoT trainer provides a reliable and pedagogically appropriate platform for supporting practical learning in higher education. The integration of hardware experimentation, embedded programming, and web-based monitoring enables students to gain meaningful learning experiences in developing IoT systems.

Conclusion

This study successfully developed and validated a web server-based Internet of Things (IoT) trainer designed to support practical learning in higher education. The developed trainer integrates multiple sensors, actuators, and an ESP32 microcontroller within a portable hardware platform equipped with an embedded web server for real-time monitoring and control.

The results of hardware functional testing show that all integrated components operate reliably, with sensor error rates below 5% and response times within acceptable ranges for educational laboratory applications. In addition, the web server performance testing demonstrates stable system operation with an average response time of 648.1 ms and an error rate of 0%, indicating reliable communication between the trainer hardware and the web-based monitoring interface.

The findings of this study demonstrate that the developed web server-based IoT trainer is not only technically reliable, as evidenced by low hardware error rates and fast response times, but also highly feasible from pedagogical and content perspectives, as indicated by expert validation scores approaching 100%. These results imply that such an integrated IoT trainer can effectively bridge the gap between theoretical instruction and real-world IoT system implementation, enhancing students' practical competencies and readiness for industry. In practical terms, higher education institutions are encouraged to adopt and adapt this trainer within IoT, embedded systems, and networked systems courses, integrating it into project-based and problem-based learning scenarios to maximize student engagement and authentic learning experiences. Lecturers and curriculum developers can also use the trainer as a core platform for capstone projects, interdisciplinary collaborations, and remote or hybrid laboratory activities. For further research, future studies could examine the impact of the trainer on student learning outcomes and higher-order thinking skills using experimental or quasi-experimental designs, explore its integration with cloud platforms and data analytics dashboards, and investigate scalability and usability across different institutional contexts and levels of technological readiness.

Expert validation results also indicate that the developed IoT trainer has very high feasibility as a learning medium. Both validators provided very high ratings for media design, content relevance, and instructional design aspects, demonstrating that the trainer is technically reliable and pedagogically appropriate for supporting Internet of Things practical learning activities.

Overall, the developed IoT trainer provides an integrated learning platform that enables students to conduct hands-on experiments involving sensor monitoring, device control, and web-based data visualization. Future research may focus on evaluating the effectiveness of the trainer in improving students' learning outcomes and integrating additional features such as cloud-based data storage and mobile monitoring applications.

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