

Enhancing the Effectiveness of Industrial IoT Training through the Integration of Augmented Reality and the Quality Function Deployment (QFD) Approach

Original Article

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Abstract

With the increasing complexity of Industrial Internet of Things (IIoT) systems and the growing demand for effective technical training, innovative learning media are needed to improve learners' understanding of abstract and dynamic industrial processes. This paper outlines the creation and evaluation of an Augmented Reality (AR) learning approach for better Industrial Internet of Things (IIoT) training delivery. The AR-based medium was developed to address issues of usability associated with the traditional Demo Box experience, including reduced visualization and interaction capacity, and heavy reliance on instructor modeling and explanations. A quantitative survey completed by 110 respondents (44 Demo Box learners and 66 AR media learners) explored the learners' perceptions in four domains: usability, satisfaction, functionality, and learning effectiveness. The results indicate a statistically significant difference after using AR media, in ease of use (4.17 → 5.45) and satisfaction (4.41 → 5.32). The AR process is also capable of collaborating with the IIoT devices using the MQTT protocol, allowing learners to see real-time data being sent and received from the sensors and actuators. In summary, AR-based learning media enhanced learner engagement, reduced cognitive load, and improved conceptual understanding of IIoT processes and acted as an additional educational tool to the Demo Box and discussed how AR media supports IIoT education that leverages immersive, data-driven learning environments.

Keywords: Augmented Reality (AR), Cognitive Load Theory, Experiential Learning, Industrial Internet of Things (IIoT), MQTT.

1. Introduction

In the Industry 4.0 era, Industrial Internet of Things (IIoT) technology has become an important component in digital transformation in the industrial sector. This technology enables real-time data integration, process automation, and data-based analysis to improve efficiency and accuracy in decision-making. For Business-to-Business (B2B) companies, IIoT implementation not only functions to monitor machine conditions and manage sensor data, but also helps implement predictive maintenance strategies that can prevent operational disruptions and increase productivity.

Despite its great benefits, IIoT implementation still faces challenges, especially regarding human resource readiness. The complexity of technology requires effective training so that workers are able to understand and apply IIoT concepts appropriately. So far, training has generally used demo boxes as the main learning medium. However, evaluation results at automation system companies show that this method still has limitations, such as insufficient



equipment, minimal interactivity, and inability to provide a real picture of IIoT technology implementation in the industrial world. Many training participants only understand the technical functions of tools without relating them to the actual operational context.

This condition emphasizes the need for innovation in IIoT training methods that are more interactive, efficient, and relevant to industry needs. One potential solution is the application of Augmented Reality (AR) technology as a learning medium. This technology allows participants to directly interact with virtual IIoT device simulations in a real environment. AR provides in-depth visualization of components such as sensors, networks, and data transmission processes, so participants can comprehensively understand IIoT working concepts without operational risks.

To ensure that the development of this training medium truly matches user needs, this research adopts the Quality Function Deployment (QFD) approach. Through QFD, training participant needs such as ease of use, interactivity, and real-time simulation capabilities can be translated into measurable technical specifications. This approach ensures that the application developed is not only innovative, but also oriented toward end-user needs.

Previous studies have emphasized that the successful implementation of Industrial Internet of Things (IIoT) systems is strongly influenced by workforce competence and the effectiveness of training methods. Research on Industry 4.0 adoption highlights that inadequate human resource readiness remains a major barrier, despite rapid technological advancement (Stentoft et al., 2019). Conventional training media, such as demo boxes, are often limited in interactivity and visualization, leading to fragmented understanding of complex industrial systems (Encarnação et al., 1992). In response, several studies have demonstrated that Augmented Reality (AR) can enhance learning outcomes by providing immersive visualization, real-time interaction, and experiential learning in technical education settings (Jantjies et al., 2018). Furthermore, integrating user-centered design approaches such as Quality Function Deployment (QFD) has been shown to improve system usability and alignment with learner needs by systematically translating user requirements into technical specifications (Koswara & Alifin, 2024).

This research aims to improve IIoT training effectiveness through the integration of Augmented Reality technology and QFD approach in an automation system company environment. By combining these two approaches, it is expected to create a training medium capable of enhancing participant understanding, strengthening their involvement in the learning process, and accelerating adaptation to industrial technology. Practically, this research can serve as a reference for companies and training institutions in developing interactive learning media based on high technology. Academically, this research contributes to the development of literature on the application of Augmented Reality and QFD in the context of industrial technology training, while supporting the shift toward a more immersive and data-based learning environment.

2. Literature Review

2.1. Industrial Internet of Things (IIOT) Training at Automation System Companies

IIoT training is an important step to improve human resource competence so they are able to operate complex industrial technology. At automation system companies, this training generally uses demo boxes as learning media to introduce IIoT devices and systems. Although effective in demonstrating basic functions, this method still has limitations, such as insufficient available equipment and minimal visualization of real industrial conditions.

According to Budihartono et al. (2022), training that combines theory and direct practice can significantly improve participant understanding. Hands-on learning approach through intensive workshops has proven to help participants understand IIoT concepts better than theory-based learning alone. Similarly, Sanchez and Kataria (2022) add that training involving real devices such as Arduino or Raspberry Pi can strengthen technical capabilities while accelerating adaptation to industrial technology. Thus, interactive IIoT training based on real experience becomes important so that participants not only understand technical aspects, but also the context of its application in the workplace. This is where Augmented Reality (AR) technology has great potential to enrich conventional training methods to become more immersive and realistic.

2.2. Quality Function Deployment (QFD)

Quality Function Deployment (QFD) is a structured method used to translate user needs into product technical specifications. QFD was first developed by Yoji Akao in the 1960s and has been widely used in various industrial sectors (Han, 2016; Mankins, 2009). The core of QFD is the House of Quality (HoQ), which is a matrix that connects Voice of Customer (VoC) with technical attributes that must be met by the product. In the context of technology-based training media development, QFD functions to ensure that application features truly reflect user needs, such as ease of use, visual clarity, and interactivity. The QFD process is carried out through several main stages:

- 1) User needs identification, conducted through surveys or interviews.
- 2) Mapping needs to technical attributes, such as user interface, data visualization, and system performance.
- 3) Development priority determination, based on importance level and relationships between attributes.

With this approach, developers can design training solutions that are not only technologically innovative, but also functionally relevant to participant needs.

2.3. Augmented Reality (AR)

Augmented Reality (AR) is technology that combines digital elements into the real world interactively. In IIoT training, AR can be used to display sensor data visualization, system components, and industrial process simulations in real-time in a real environment (Rauschnabel et al., 2022). This technology provides a more intuitive and profound learning experience compared to conventional learning media. According to Mitrovic et al. (2021), the application of AR in technical training can increase participant engagement, accelerate knowledge transfer, and reduce work accident risks because participants can practice virtually without touching high-voltage physical equipment. Additionally, research by Bologna et al. (2020) shows that AR-based training can reduce operational costs while increasing learning effectiveness up to 80%. In its implementation, AR can be developed using platforms such as Unity 3D with ARCore support for integration on Android devices. The development process includes 3D model design stages, user interface (UI/UX) design, to testing for stability and visualization accuracy. The use of AR in IIoT training enables more flexible, efficient, and immersive learning, in accordance with the needs of the industrial digital era.

2.4. Previous Research

Several previous studies have proven AR effectiveness in industrial training. Bologna et al. (2020) developed an AR platform for industrial device calibration training and found that this technology increased learning effectiveness up to 82%. Papakostas et al. (2021) examined

user experience toward AR and concluded that the level of interactivity and personalization are the main factors in the acceptance of this technology. Meanwhile, Han (2016) integrated the QFD approach in AR application development for the tourism sector, showing that QFD can help identify user needs and translate them into appropriate technical specifications. Based on these studies, this research occupies a unique position by combining AR technology and QFD approach in the context of Industrial IoT training at automation system companies, which has not been widely studied before. This approach is expected to produce a new training model that is more interactive, effective, and in accordance with current industry needs, while providing practical contributions to improving human resource competence in the industry 4.0 era.

3. Methods

This research was conducted through several interrelated main stages. The process begins with user needs identification (Voice of Customer), then translated into technical attributes using the Quality Function Deployment (QFD) approach. The needs analysis results are used as the basis for Augmented Reality (AR) application development using the Agile SCRUM method. Research stages include:

- 1) User needs identification through surveys and interviews.
- 2) Mapping needs into the House of Quality (HoQ) matrix to determine feature priorities.
- 3) Backlog preparation and AR application development sprint planning.
- 4) Application implementation using the SCRUM method.
- 5) Application testing by training instructors.
- 6) Quantitative and qualitative data collection.
- 7) Data analysis using the QFD approach.
- 8) Discussion of results and research conclusions.

This approach ensures that each development stage is iterative, based on user feedback, and oriented toward improving IIoT training effectiveness at automation system companies.

3.1. Data Collection

Research data was collected through questionnaires and direct observation of lecturers, instructors, and students who had participated in IIoT training at the automation system company. Questionnaires were distributed twice, before and after AR media use to measure effectiveness and user perception toward ease, satisfaction, functionality, and learning effectiveness. The questionnaire instrument was prepared using a Likert scale with a range of 1-6, where higher values indicate more positive perception. Questions were designed to identify main need aspects, such as ease of use, data visualization, interactivity, and user engagement during training.

3.2. AR Development

Augmented reality application development was carried out using the Agile SCRUM method with steps as in Figure 1 below. First is Planning, second is analyzing needs. Third is designing the system to subsequently develop the augmented reality application. In this development stage there are several sprints namely prototype, object tracking, and IIoT visualization. After development is complete, testing is conducted to assess whether the developed augmented reality application is in accordance with needs and is feasible. Finally, if there are deficiencies during the testing stage, improvements will be made so that the final result can match current needs.

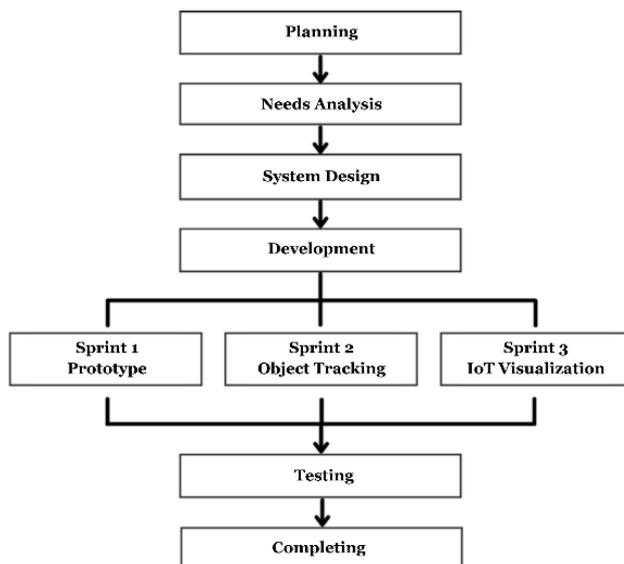


Figure 1. Augmented Reality Development Flow

3.3. Data Analysis Method

The data analysis method using Quality Function Deployment (QFD) through surveys involves data collection from trainers, lecturers, and students who have participated in training at PT XYZ. The survey was designed to identify their needs and expectations toward training technology, including experience with demo boxes and potential development of augmented reality applications. Quantitative data was collected using a Likert scale to assess the importance level of needs and satisfaction level toward existing technology. In addition, open-ended questions were included to obtain qualitative insights.

Survey results were analyzed by entering importance weights (importance rating) into the HoQ matrix, which connects customer needs with technical attributes such as system stability or interactive visualization. Relationship weights are given to show the relevance level between user needs and technical attributes, producing priority scores that indicate the most important features to be developed. Normalization is carried out to identify the contribution of each attribute to overall customer needs.

4. Results and Discussion

4.1. Research Results

4.1.1. Respondent Characteristics

All This research involved 110 respondents consisting of students, training instructors, lecturers, and industry professionals who participated in Industrial Internet of Things (IIoT) training at the automation system company. The majority of respondents (86.4%) were students, while 8.2% were lecturers/teachers, 3.6% trainers, and 1.8% industry professionals.

The dominance of participants from students shows that IIoT-based learning media is widely used in higher education and vocational contexts. This emphasizes the importance of learning media that is easy to understand, interactive, and contextual. Meanwhile, the presence of respondents from professionals provides additional perspective on media relevance to real industry needs.

The Demo Box user group is generally already familiar with physical device-based training. However, visual space limitations make it difficult for them to understand data communication flow between components. Conversely, participants who used Augmented

Reality (AR) could understand the system more quickly because 3D visualization helped them see the relationships between components comprehensively.

4.1.2. Survey Results and Needs Analysis

Table Based on surveys of Demo Box users, it is known that this media is effective in introducing physical components and basic working principles of IIoT systems. However, limited interactivity and lack of internal visualization cause the learning process to tend to depend on instructors.

To overcome these limitations, user needs identification (Voice of Customer) was carried out, which was then grouped into four main aspects:

- 1) Ease of use: media must be intuitive and easy to learn.
- 2) Learning effectiveness: helps understanding of the complete IIoT system flow.
- 3) System functionality: integrated with IIoT devices in real-time.
- 4) User satisfaction: provides an interesting and efficient learning experience.

These needs were then mapped into technical attributes using Quality Function Deployment (QFD) through the House of Quality (HoQ) matrix. The mapping results show that the highest priority features are interactive simulation, 3D visualization, visual guidance, and intuitive user interface (UI). The translation of user requirements into technical specifications was carried out using the House of Quality (HoQ) matrix, as shown in Figure 2.

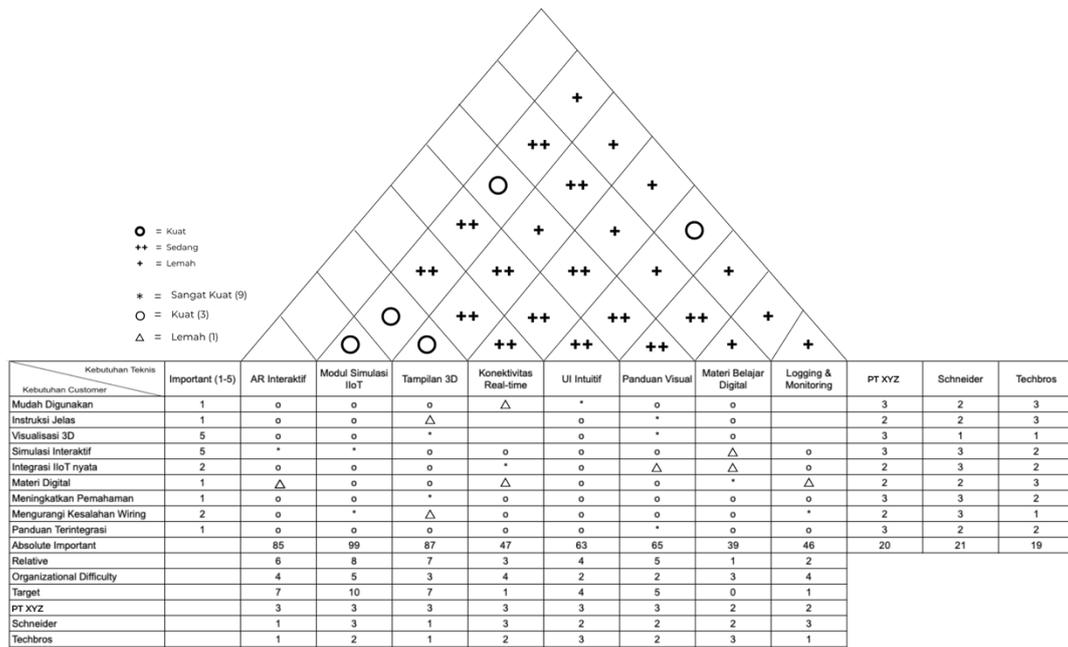


Figure 2. House of Quality Matrix

Figure 2 presents the House of Quality (HoQ) matrix used in this study to translate customer requirements into technical characteristics of the Augmented Reality-based IIoT training media. Customer needs, such as ease of use, interactivity, real-time visualization, and digital learning materials, were first identified and weighted based on their level of importance. These needs were then mapped against technical requirements, including interactive AR features, 3D visualization, real-time connectivity, intuitive user interfaces, and system monitoring capabilities. The relationship matrix illustrates the strength of association between customer needs and technical attributes, while the priority scores help determine which technical features should be emphasized during development. By applying the HoQ

matrix, this study ensures that the AR training system design is systematically aligned with user expectations and industry needs, supporting a user-centered and structured development process.

4.1.3. Augmented Reality-Based Learning Media Implementation

Based on needs analysis results, Augmented Reality (AR)-based learning media was developed that functions as a complement, not a replacement for Demo Box. AR was implemented to provide digital twin visualization of IIoT systems, so participants can see the system structure transparently, understand relationships between components, and perform industrial process simulations interactively. This AR application is integrated with IIoT devices through MQTT protocol, which enables real-time display of sensor and actuator data. In training, participants can observe conveyor movement, monitor motor temperature, belt speed, and production output directly through digital displays. Additionally, an emergency mode notification feature was added to display abnormal production system conditions as part of troubleshooting training simulation. Thus, AR not only clarifies conceptual understanding, but also trains participants' analytical abilities toward actual industrial situations.

4.1.4. AR-Based Learning Media Evaluation: Comparison of Learning Results Before and After AR Use

Comparison between training results using Demo Box and Augmented Reality shows significant improvement in almost all learning aspects:

Table 1. Demo Box and AR Comparison Results

Aspect	Demo Box (Mean)	Demo Box (SD*)	Augmented Reality (Mean)	Augmented Reality (SD*)	Improvement (Mean)
Ease of Use	4,17	0,93	4,17	0,72	+1,28
User Satisfaction	4,41	0,88	4,41	0,81	+0,91
System Functionality	4,25	0,95	4,25	0,79	+1,15
Learning Effectiveness	4,30	0,90	4,30	0,86	+1,08

*= Standard Deviation

From the table 1, it can be seen that AR media consistently obtained higher average values with lower standard deviation, indicating increased positive perception and more uniform learning experience among participants. Overall, AR-based learning media proved to be more effective, interactive, and easier to use compared to Demo Box. This technology improves concept understanding, learning independence, and strengthens training participants' visual experience. AR also functions as an ideal complement to Demo Box, creating more immersive learning relevant to industry needs in the industry 4.0 era.

4.2. Discussion

These research results strengthen previous findings indicating that the integration of Augmented Reality (AR) and Quality Function Deployment (QFD) is an effective approach for designing industrial technology learning media. Prior studies have reported that AR-based learning environments can enhance visualization, learner engagement, and conceptual understanding in technical and industrial education settings (Latif et al., 2024; Suhail et al., 2024). Similar to the findings of Mokmin et al. (2024), this study demonstrates that AR reduces cognitive load and increases learning motivation by allowing learners to interact directly with virtual representations of complex systems .

In contrast to earlier works that primarily focused on AR as a standalone replacement for conventional training tools, the present study emphasizes AR as a complementary medium to the Demo Box, thereby combining physical hands-on experience with immersive digital visualization. Furthermore, while previous studies have highlighted usability and engagement benefits of AR, this research extends existing literature by integrating the QFD approach to systematically translate user needs into technical features, ensuring alignment between learner expectations and system design. This integration differentiates the current findings from earlier AR-based training studies and supports the conclusion that AR-based learning media, when developed using a user-centered design framework, has strong potential for broader implementation in industrial training, vocational education, and technical certification environments.

5. Conclusion

This research aims to develop Augmented Reality (AR)-based learning media to improve Industrial Internet of Things (IIoT) training effectiveness at automation system companies. Research results show that conventional training media such as Demo Box still has limitations in terms of visualization and interactivity, so participants find it difficult to understand the system comprehensively. Through Quality Function Deployment (QFD) application, user needs were successfully translated into main features in the form of 3D visualization, interactive simulation, visual guidance, and intuitive interface.

The AR application developed with Agile SCRUM method is able to display digital twin of IIoT systems in real-time through MQTT protocol, so participants can learn industrial processes in a more interactive and profound way. Based on evaluation results, AR media showed significant improvement in ease of use aspects (4.17 → 5.45) and learning satisfaction (4.41 → 5.32). Thus, AR-based learning media proved to be able to improve concept understanding, learning independence, and participant interactivity, as well as being an effective complement to Demo Box in supporting industrial training in the industry 4.0 era.

For further development, it is recommended that AR media be developed with additional simulation modules and multi-sensor data integration to be more comprehensive. Further evaluation involving participants from various backgrounds also needs to be conducted to expand the application of this media. In addition, integration with Learning Management System (LMS) and training for instructors will support optimal AR adoption. With these steps, AR-based learning media is expected to continue to be developed as an interactive, efficient, and sustainable industrial learning innovation.

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