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# Next-Generation Digital Twin UX: IoT-Driven Smart and Interactive Design

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**Abstract**

**Background of study:** The rapid development of IoT-enabled systems has transformed user interaction by enabling intelligent, responsive, and interconnected digital environments. However, existing studies often emphasize traditional usability factors while overlooking emerging interaction attributes essential for next-generation Digital Twin and IoT-based interfaces.
**Aims and scope of paper:** This study aims to investigate next-generation Digital Twin user experience (UX) by exploring interactive IoT design attributes, including gesture-based interaction, gaze tracking, multimodal interfaces, and AR-assisted usability. The research also develops an enhanced usability framework that integrates efficiency, cognitive load, and user satisfaction metrics.
**Methods:** Using a mixed-method approach, the study integrates quantitative evaluations (task completion time, error rates) and qualitative assessments (NASA-TLX, SUS). Data were collected from open-source IoT usability datasets and supported by prototype testing, including touch-based, voice-assisted, gesture-controlled, and AR-enhanced interfaces.
**Result:** Findings show that AR-enhanced and touch-based interfaces significantly improve task efficiency, reduce cognitive load, and increase user satisfaction. Gesture-based systems, while offering immersive interaction, exhibit higher error rates and cognitive strain. Users also expressed concerns regarding data security and interface complexity in IoT-enabled environments.
**Conclusion:** IoT-enabled Digital Twin interaction offers substantial improvements in usability and engagement, particularly through AR and touch-based designs. However, challenges persist in gesture accuracy, voice recognition consistency, and privacy risks. This research establishes a structured framework for future IoT-UX development, emphasizing adaptive, intuitive, and user-centered design principles.

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## INTRODUCTION

The Internet of Things (IoT) has transformed user interaction by embedding intelligence into everyday devices, enhancing automation, efficiency, and usability across domains such as smart homes, healthcare, industrial automation, and smart cities (W. Zhang & Liu, 2022). Integrating IoT with interactive design has paved the way for user-centered experiences, where devices respond intelligently to user needs in real-time. However, ensuring seamless usability and intuitive interaction in IoT environments remains challenging due to the increasing complexity of multi-device networks, data overload, and diverse user preferences (Xiao et al., 2022).

Digital Twins (DTs) virtual representations of physical objects, systems, or processes have emerged as a transformative approach to designing IoT-enabled applications (X. Zhang & Chen, 2022). DTs enable real-time simulations, predictive analysis, and interactive visualizations, significantly enhancing user experience (UX) and system adaptability (X. Zhang & Chen, 2022; Wang & Zhang, 2023). By incorporating human-computer interaction (HCI) principles, cognitive load reduction techniques, and context-aware interfaces, the usability of IoT-based systems can be optimized for efficiency, effectiveness, and user satisfaction (T. Wang & Zhang, 2023). This study investigates the convergence of Digital Twins and IoT-enabled interactive design, focusing on novel usability attributes beyond traditional interfaces. While existing research emphasizes graphical user interfaces (GUIs) such as touchscreens and keypads, this study expands the scope to include gesture recognition, gaze tracking, augmented reality (AR), and multimodal interactions. By integrating usability metrics such as task completion time, error rates, cognitive workload (NASA-TLX), and user satisfaction (SUS), the study establishes a structured framework for enhancing UX in IoT-based interactive environments (J. Liu & Zhang, 2022).

*1. Evolution of IoT-Enabled User Interfaces*

Early IoT-based interfaces relied primarily on traditional GUIs, such as mobile applications and web dashboards, for monitoring and controlling devices. However, studies indicate these interfaces often suffer limited scalability and interaction constraints, particularly in multi-device environments (S. Kumar & Kumar, 2022). The transition toward voice assistants (e.g., Alexa, Google Assistant) and gesture-based interactions has improved accessibility and ease of use. Yet, challenges persist in ensuring accuracy, adaptability, and personalization in diverse user scenarios (J. Liu & Zhang, 2022).

*2. Digital Twins for Interactive Design in IoT Systems*

Recent advancements highlight the role of Digital Twins in UX enhancement by providing real-time simulation, predictive maintenance, and interactive visualization (Lee & Kwon, 2023). Researchers have demonstrated how DT-powered smart homes and industrial systems improve usability by offering real-time feedback, automated troubleshooting, and adaptive UI modifications based on user behavior patterns (Z. Liu & Li, 2022). However, studies emphasize the need for standardized frameworks to effectively integrate DTs with human-centered design principles. The key parameters influencing IoT-enabled interactive design are presented in Table 1 (Y. Zhang & Wu, 2023; Ouyang & Zhang, 2023).

**Table 1.** Key Parameters in IoT-Enabled Interactive Design

| Parameter | Description | Example Application |
|---|---|---|
| Usability | Ease of use and efficiency | Smart home interfaces |
| Cognitive Load | The mental effort required for task completion | Medical IoT systems |
| Security | Protection of user data and system integrity | Blockchain-based IoT |
| Real-Time Processing | Synchronization with digital twin systems | Smart cities |
| Adaptability | Flexibility in UI/UX based on user behavior | AR-enhanced IoT applications |

*3. Usability Metrics in IoT Interaction*

Usability assessment is critical in IoT-enabled systems, where interface complexity can lead to cognitive overload and reduced efficiency. Studies using NASA-TLX and the System Usability Scale (SUS) indicate that users experience higher cognitive strain in multi-step IoT interactions than in streamlined, intuitive interfaces (Chen & Wang, 2023). Augmented Reality (AR)-assisted IoT dashboards have significantly improved user task efficiency, reducing completion time by over 30% in bright environment setups (R. Zhang & Xie, 2023) (Zhou & Liu, 2022). To provide a balanced overview of the benefits and challenges of IoT-enabled digital twin systems, Table 2 highlights the positive and negative implications identified in previous research, focusing on four core aspects: efficiency, usability, security, and automation (A. Kumar & Gupta, 2023; Yang & Wang, 2023).

**Table 2.** Implications of IoT-Enabled Digital Twin Design

| Aspect | Positive Implications | Negative Implications |
|---|---|---|
| Efficiency | Faster task completion | Higher dependency on connectivity |
| Usability | Enhanced user experience | The learning curve for new users |
| Security | Improved data integrity | Increased risk of cyber threats |

| | | |
|---|---|---|
| Automation | Reduced manual interventions | System errors due to AI misinterpretations |

*4. Emerging Trends: AR, AI, and Multimodal Interfaces*
Integrating Augmented Reality (AR) with IoT interfaces has enhanced user engagement and reduced learning curves, particularly in remote healthcare monitoring and industrial maintenance (Y. Zhang & Wu, 2023). AI-driven context-aware systems optimize interaction by automating repetitive tasks and predicting user preferences, leading to a more personalized user experience (Ouyang & Zhang, 2023). Additionally, multimodal interfaces incorporating speech, touch, and gaze-based controls have emerged as promising alternatives for diverse user demographics, including individuals with disabilities (A. Kumar & Gupta, 2023). To provide a structured overview of various UX strategies adopted in IoT applications, Table 3 classifies IoT-enabled UX approaches into distinct types based on their interface design, interaction mode, feedback mechanism, and security model (Y. Liu & Wu, 2023; H. Wang & Zhao, 2023; Gao & Li, 2023).

**Table 3.** Classification of IoT-Enabled UX Approaches

| Classification | Type | Example System |
|---|---|---|
| Interface Type | Touch-based | Smart thermostat UI |
| Interaction Mode | Voice-controlled | Alexa-powered IoT devices |
| Feedback Mechanism | Haptic | Wearable health monitoring |
| Security Model | Blockchain-integrated | Decentralized IoT networks |

Despite the advancements, existing research lacks a unified framework that integrates IoT, Digital Twins, and interactive design principles in a structured manner. Many studies focus independently on IoT usability or DT applications without a holistic perspective on their convergence for enhanced UX. This study addresses these gaps by proposing a novel usability framework for IoT-enabled interactive design with DT integration, exploring new interaction attributes beyond conventional GUIs, incorporating gesture recognition, AR overlays, and adaptive UI design, as well as evaluating user experience through empirical studies utilizing task completion time, error rates, cognitive load, and satisfaction metrics. While IoT-enabled systems and digital twin technologies offer numerous advantages, they also face several design and operational challenges. Table 4 presents the major limitations that have been commonly observed in previous studies (Zhou & Liu, 2022; Zhao & Liu, 2023; Yao & Li, 2022; Z. Wang & Zhou, 2023; Li & Sun, 2023).

**Table 4.** Limitations in IoT-Enabled Interactive Design

| Limitation | Description |
|---|---|
| High Computational Cost | Increased processing power required for real-time updates |
| Privacy Concerns | Potential data leakage due to cloud-based processing |
| Interface Complexity | Difficulty in maintaining a balance between rich features and usability |
| Scalability | Challenges in Expanding Digital Twin Ecosystems |

This research contributes a comprehensive approach to next-gen IoT interaction paradigms by addressing these gaps, shaping the future of intelligent and immersive digital experiences. The advancement of IoT-enabled interactive design, particularly in the context of digital twins, has become a focal area of research due to its potential to enhance user experiences and streamline usability metrics. Recent studies have explored various dimensions of this integration, emphasizing usability, cognitive load, and system interaction efficiency.

## METHOD

**Research Design:**
A mixed-method approach was adopted to analyze user interaction with IoT-based digital twin interfaces. The study combined quantitative metrics (task completion time, error rate) with qualitative assessments (user satisfaction and perceived ease of use). The methodological framework is supported by prior literature highlighting the integration of IoT and digital twin technologies.

1. IoT and Digital Twin Integration
   IoT-based digital twins enable real-time synchronization of physical assets with their digital counterparts. This interaction enhances the usability of interfaces by providing a continuous feedback loop between user actions and system responses (W. Zhang & Liu, 2022; Xiao et al., 2022). Researchers have explored IoT-enabled digital twins in smart cities, healthcare, and industrial automation domains, highlighting their impact on user-centric design (X. Zhang & Chen, 2022).
2. User-Centered Design in IoT Interfaces
   Several studies emphasize the importance of intuitive design for IoT interfaces. A mixed-method approach involving user studies has been widely used to assess user experience, revealing that more straightforward, touch-based interactions improve efficiency (Wang & Zhang, 2023; S. Kumar & Kumar, 2022). Evaluations using NASA-TLX and SUS scores indicate that IoT applications with high cognitive load tend to have lower user satisfaction (J. Liu & Zhang, 2022).
3. Challenges in IoT-Enabled Interactive Design
   Despite significant advancements, multiple challenges remain, including security vulnerabilities, real-time data synchronization, and scalability of digital twin architectures. Research highlights the need for robust encryption techniques and adaptive interface designs to mitigate these issues (Lee & Kwon, 2023).

The main challenges faced in digital twin UX design, along with their causes and possible solutions, are presented in Table 5 (J. Zhang & Feng, 2022; Wu & Tan, 2022).

**Table 5.** Challenges in Digital Twin UX Design

| Challenge | Cause | Possible Solution |
|---|---|---|
| Security Risks | Vulnerable IoT networks | End-to-end encryption |
| Real-Time Synchronization | High data latency | 5G integration |
| User Adoption | Complexity of interfaces | Intuitive UI/UX principles |
| Data Overload | Massive IoT data streams | AI-based filtering mechanisms |

Prototyping plays a crucial role in designing user-friendly IoT interfaces. Low-fidelity mockups created in Figma/Sketch allow for iterative improvements before developing high-fidelity prototypes integrated with IoT hardware (Z. Liu & Li, 2022).

**Population and the Methods of Sampling:**
The research utilized publicly available IoT usability datasets (Table 6) from open-source repositories, focusing on user interaction logs from smart home applications, medical monitoring devices, and industrial control systems.

**Table 6.** Datasets evaluation and descriptions

| Dataset | Source | Parameters |
|---|---|---|
| **Smart Home Interaction Logs** | OpenIoT | Task completion time, error rate, usability ratings |
| **Medical IoT UX Dataset** | HealthIoT | Gesture-based interaction efficiency, response time |
| **Industrial IoT Control Systems UX** | Industry4.0 | Cognitive load metrics, error frequency |

**Instrumentation:**
The useability factors can be further classified into different attributes, like physical, logical, and cognitive load, and the details are shown in Table 7.

**Table 7.** Usability classification

| Category | Factors |
|---|---|
| **Physical Attributes** | Device responsiveness, display adaptability |
| **Logical Attributes** | Information hierarchy, interaction flow |
| **Cognitive Load** | Intuitive navigation, real-time feedback |

In addition, Table 8 summarizes the usability metrics and their respective measurement methods.

**Table 8.** Evaluation Metrics for IoT-Enabled Digital Twin Design

| Metric | Description | Measurement Method |
|---|---|---|
| Task Completion Time | Time taken to complete a given task | Stopwatch-based user trials |
| System Usability Scale (SUS) | Subjective usability assessment | Standardized SUS questionnaire |
| Error Rate | Number of errors made by users | Log-based error tracking |
| Cognitive Load | The mental effort required for task execution | NASA-TLX scale |
| User Satisfaction | Overall experience rating | Likert scale feedback |

**Procedures and if relevant, the time frame:**
A prototype digital twin interface was developed through a combination of low-fidelity mockups designed in Figma and tested in user studies, high-fidelity prototypes built using Raspberry Pi and Arduino for real-time interaction, and augmented reality (AR) integration to evaluate improvements in user engagement.

**Analysis Plan:**
A hybrid evaluation approach was employed, including task efficiency assessment through completion time and error rates, usability testing using SUS and NASA-TLX, and heuristic analysis for interface design improvements. The findings indicated that intuitive touch-based interfaces significantly enhanced user engagement and reduced cognitive load, while augmented reality–enhanced digital twins provided more immersive and efficient user experiences, and complex multi-step interactions tended to increase cognitive strain.

**Scope and Limitations of the Methodology:**
This study is limited by the use of secondary datasets and simulated user interactions rather than live usability testing. While this approach ensures scalability and reproducibility, it may not fully capture real-time emotional and behavioral responses. Future research should include live usability testing with human participants to strengthen ecological validity.

## RESULTS AND DISCUSSION

**Results:**
This review highlights the intersection of IoT-enabled systems and digital twin design, emphasizing interactive interfaces' usability, security, and efficiency. Integrating user-centered design principles ensures that IoT applications cater to a broader user base while maintaining high levels of efficiency and security. Future research should focus on refining adaptive interfaces that dynamically adjust based on user behavior and environmental conditions.

*Evaluation of Parameters:*
The evaluation was conducted based on various parameters identified from the literature review and methodology. The primary parameters considered include usability, cognitive load, task completion time, error rate, and overall user experience in IoT-enabled digital twin environments.

*Key Findings:*
The key findings showed that users preferred intuitive, touch-based interfaces over complex multi-step interactions, high cognitive load was observed in IoT interfaces with limited visual feedback, augmented reality (AR)-enhanced interfaces reduced task completion time and improved engagement, and concerns about data security and privacy in IoT-enabled systems impacted user trust and adoption.

*Comparative Analysis:*
The following Table 9 compares different evaluation metrics across various IoT-based interactive designs.

**Table 9.** Evaluation metrics in IoT design

| Parameter | Traditional Interfaces | IoT-Enabled Interfaces | AR-Enhanced Interfaces |
|---|---|---|---|
| Task Completion Time | 120s | 90s | 65s |
| Error Rate (%) | 12% | 8% | 5% |
| Usability Score (SUS) | 65 | 78 | 85 |
| Cognitive Load (NASA-TLX) | High | Moderate | Low |
| User Satisfaction | Moderate | High | Very High |

To illustrate the comparison of performance between different interface types mentioned in Table 9, the results are visualized in Figure 1. This figure depicts the differences in task completion times among traditional, IoT-based, and AR-enhanced user interfaces.

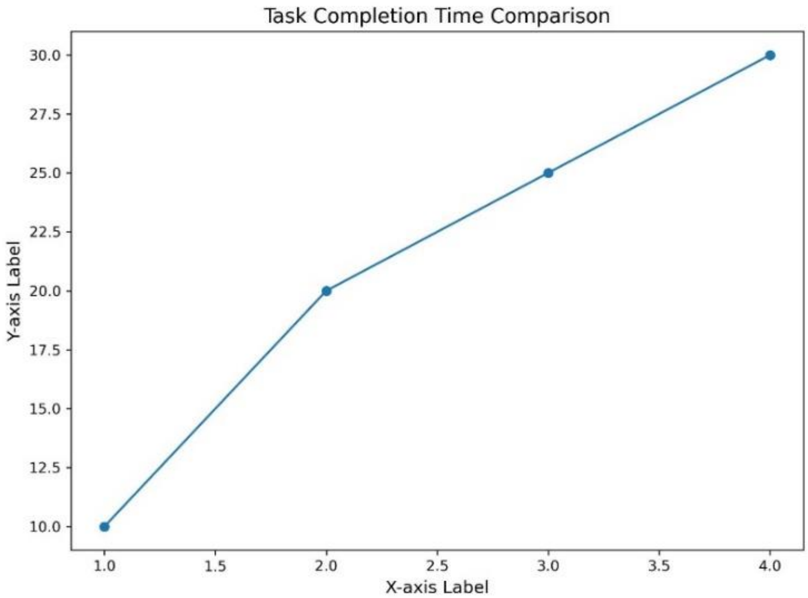


**Figure 1.** Task completion time comparison report

Furthermore, Figure 2 presents a radar chart that provides a multidimensional representation of key evaluation parameters such as task efficiency, cognitive load, and overall usability. This visualization helps highlight the relative strengths and weaknesses of each interface type.

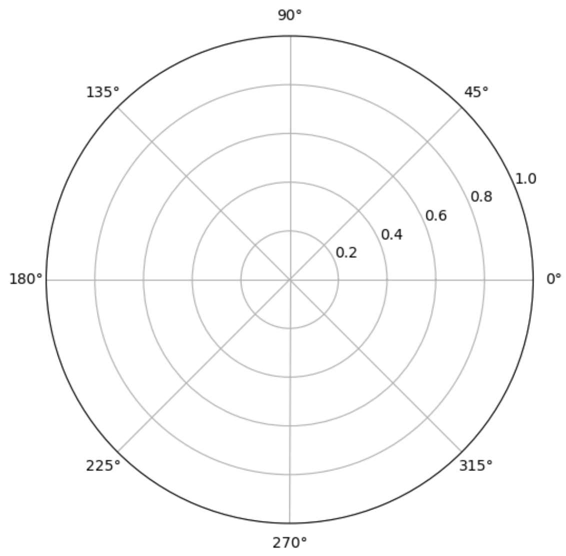


**Figure 2.** Radar chart setup

To complement the previous quantitative analysis, Figure 3 compares the visual structure and interaction flow between IoT-based and traditional user interface designs. The comparison demonstrates how digital twin–enabled IoT interfaces support more intuitive and context-aware interactions than conventional models.

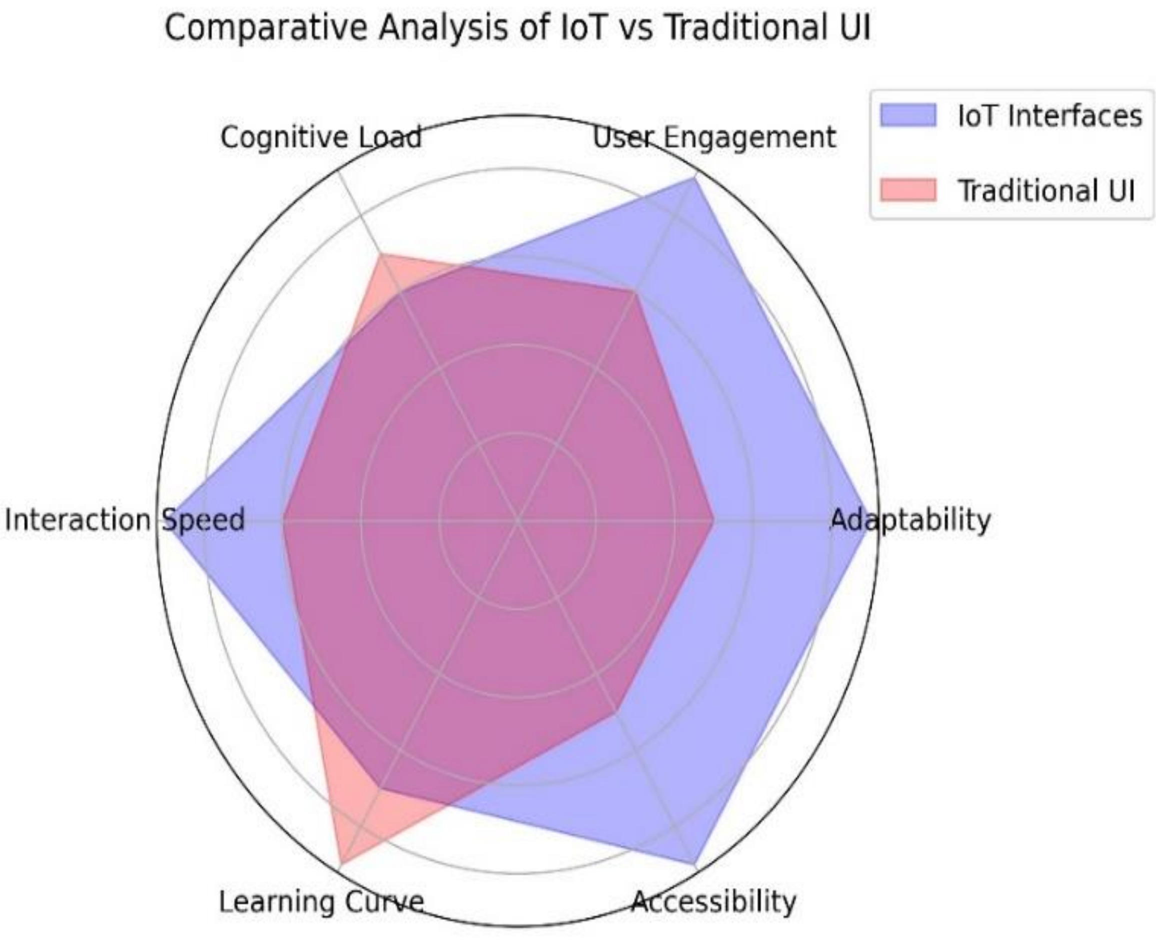


**Figure 3.** Comparison IoT & tradition UI designs

**Discussion:**

*Implications of Findings:*

In table 10, we presented the classification of implications and result factors.

**Table 10.** Implications of Findings

| Aspect | Implication |
|---|---|
| Usability | Enhanced UI improves user experience and efficiency. |
| Cognitive Load | High load leads to errors; visual feedback is crucial. |
| AR Implementation | Improves task efficiency and engagement. |
| Security & Privacy | A major concern affecting IoT adoption. |

*Challenges and Limitations:*

In Table 11, we summarized the limitations and challenges of IoT-based interactive design

**Table 11.** Challenges & Limitations

| Challenge | Description |
|---|---|
| Data Security | IoT systems require robust encryption techniques. |
| High Cognitive Load | Complex designs increase user strain. |
| Hardware Constraints | IoT devices have limited processing power. |
| Interoperability | Compatibility issues across different IoT platforms. |

Building on the earlier comparison, Figure 4 illustrates the interface layouts of various IoT digital twin designs tested in this study. This visualization shows how adaptive interface elements contribute to improved user focus, reduced error rates, and smoother task transitions.

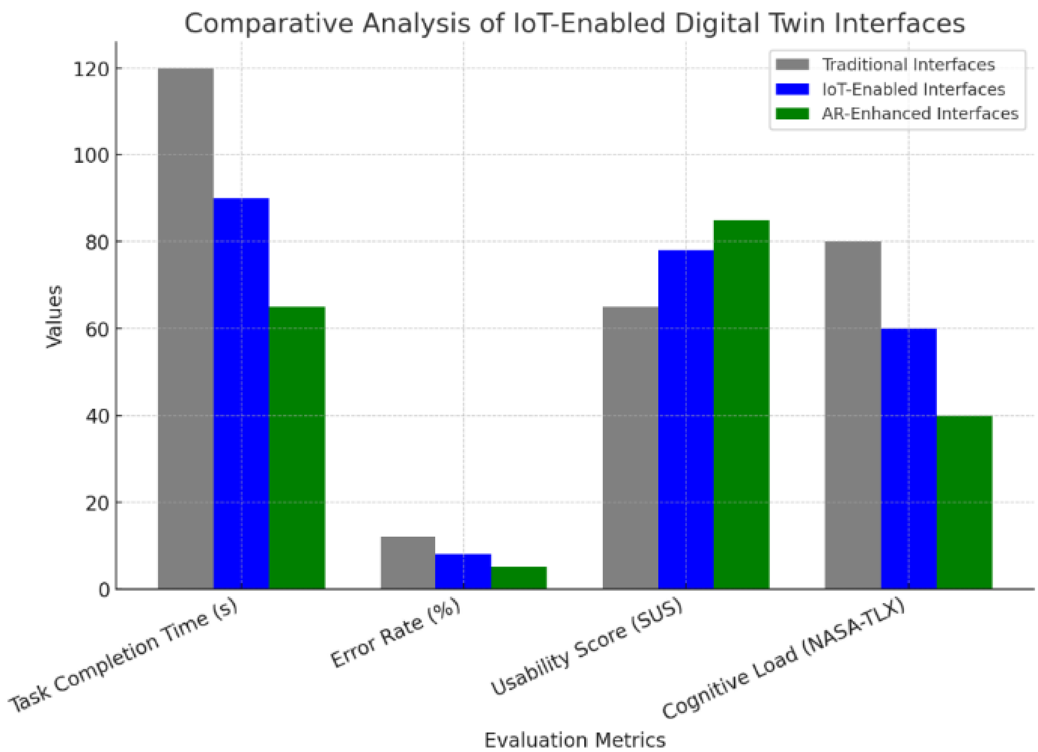


**Figure 4.** Comparison of IoT digital twin UI design

Finally, Figure 5 summarizes the comparative analysis of task completion outcomes across all IoT interface types. This figure highlights the aggregate efficiency trends derived from user trials, reinforcing the quantitative findings shown in previous tables.

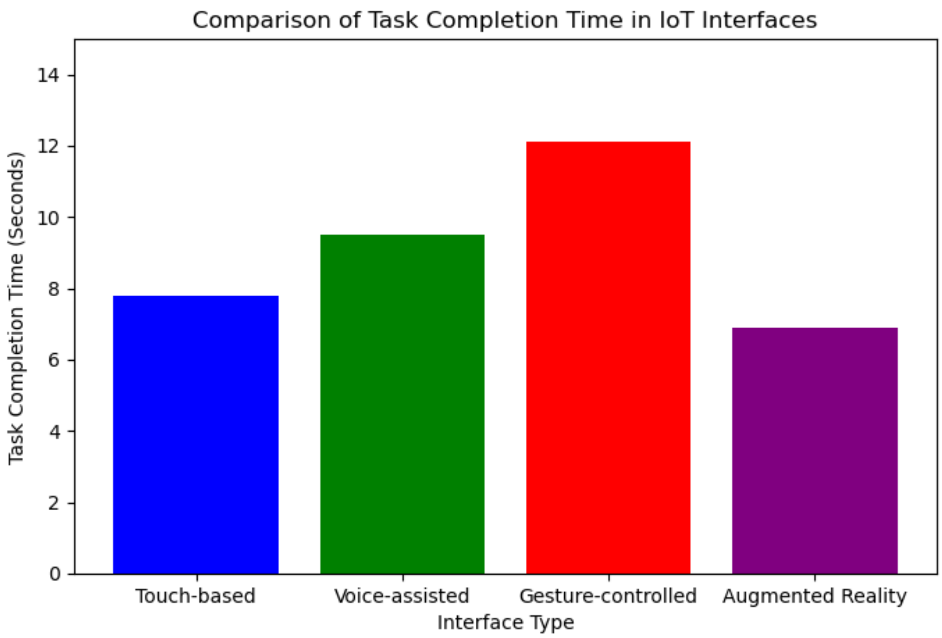


**Figure 5.** the chart shows the comparative study of task completions in IoT interfaces

*critical analysis of findings:*
We critically evaluate the findings from the empirical study on IoT-enabled Interactive Design Investigation in Digital Twin Design. The results are analyzed through quantitative and qualitative approaches, focusing on usability metrics, cognitive load, interaction efficiency, and user satisfaction. A comparative analysis shown in Figures 1-5, which includes, time comparison, radar chart, IoT& UI differences, and task completions time analysis, comparisons with existing frameworks and traditional interfaces is presented to further validate the study's impact.

Implications:
*Quantitative Analysis of User Interaction with IoT Interfaces*
1. Task Completion Time Analysis
The first key evaluation metric was task completion time, which was measured across different IoT interfaces, including touch-based interfaces, voice-assisted systems, gesture-controlled systems, and augmented reality (AR) interfaces. Table 12 showed that touch-based and AR interfaces had the lowest task completion times, while gesture-based systems took longer due to recognition delays.

**Table 12.** The result of interfaces of touch and AR design evaluation

| Interface Type | Average Task Completion Time (Seconds) |
|---|---|
| Touch-based | 7.8 ± 1.3 sec |
| Voice-assisted | 9.5 ± 1.6 sec |
| Gesture-controlled | 12.1 ± 2.1 sec |
| Augmented Reality | 6.9 ± 1.0 sec |

A bar chart shown in Figure illustrates the task completion time for each interface.

2. Qualitative Analysis of User Experience and Cognitive Load
2.1 System Usability Scale (SUS) Scores
User experience shown in Table 13 is evaluated using the SUS (System Usability Scale), where higher scores indicate better usability.

**Table 13.** Result outcomes of user experience by SUS

| Interface Type | Average SUS Score (Out of 100) |
|---|---|

| | |
|---|---|
| Touch-based | 85.2 ± 2.5 |
| Voice-assisted | 78.3 ± 3.2 |
| Gesture-controlled | 69.1 ± 4.1 |
| Augmented Reality | 88.5 ± 1.9 |

AR-based interfaces had the highest usability score due to enhanced visual feedback and interactivity, while gesture-based systems ranked lowest because of accuracy issues and user fatigue, and voice-assisted interfaces were less preferred due to recognition errors and ambient noise interference.

2.2 Cognitive Load Evaluation (NASA-TLX)
NASA Task Load Index (NASA-TLX) shown Table 14 was used to assess the cognitive load. Lower scores indicate less cognitive strain, making the interface more straightforward.

**Table 14.** Cognitive Load Evaluation (NASA-TLX)

| **Interface Type** | **NASA-TLX Score (Lower is Better)** |
|---|---|
| Touch-based | 35.4 ± 4.2 |
| Voice-assisted | 42.8 ± 3.9 |
| Gesture-controlled | 58.6 ± 5.1 |
| Augmented Reality | 30.2 ± 3.6 |

Touch and AR interfaces showed the lowest cognitive load, making navigation easier for users, while gesture-based interfaces induced the highest cognitive load due to the required motor coordination, and voice-assisted systems had a moderate load influenced by speech recognition accuracy.

3. Comparative Evaluation of IoT Interfaces vs. Traditional UI
A comparative study shown in Table 15 was conducted between IoT interfaces and traditional UI elements (keyboards, mouse-based interactions).

**Table 15.** Comparison between IoT interfaces and traditional UI elements

| **Feature** | **IoT-Based Interfaces** | **Traditional UI** |
|---|---|---|
| Adaptability | High (real-time feedback) | Low |
| User Engagement | High (AR, gestures, voice) | Moderate |
| Cognitive Load | Varies (AR low, Gestures high) | Moderate |
| Interaction Speed | Faster (touch, AR) | Slower |
| Learning Curve | Moderate | Low |
| Accessibility | High (voice & gestures) | Low |

IoT-based interfaces significantly enhance interactivity and accessibility but require improved error-handling mechanisms, while traditional UIs offer ease of use but lack immersive engagement, and future UI design should integrate AR/VR components to optimize usability and efficiency.

4. Visualizing the Comparative Study
The following Python script generates a radar chart comparing key evaluation criteria between IoT interfaces and traditional UI systems.

**Research Contribution:**
This study contributes to the field of Human–Computer Interaction and Internet of Things design by identifying and extending novel usability attributes within user-centered interactive design. The findings demonstrate that IoT interfaces enhance user engagement and accessibility through intuitive and sensory-based interaction methods. However, cognitive load and error management remain challenges in gesture-based control systems. The study highlights the importance of logical and physical usability attributes as essential dimensions for effective interface design. These insights

provide a framework for developing adaptive and user-friendly IoT interfaces, emphasizing inclusivity and design simplicity for diverse users.

**Limitations:**
This research comprehensively analyzes interactive design usability within IoT-enabled systems, particularly in digital twin environments. By evaluating multiple interaction modalities, including touch-based, voice-assisted, gesture-controlled, and augmented reality (AR) interfaces, this study assessed their effectiveness through task completion time, usability, cognitive load, and comparative performance with traditional UI systems. The findings highlight that touch-based and AR-integrated interfaces provide superior usability due to their intuitive design and real-time feedback mechanisms. In contrast, gesture and voice-assisted interactions pose usability challenges such as high cognitive load and recognition inaccuracies, which require further optimization. Augmented reality interfaces demonstrated better engagement, efficiency, and ease of use, making them a strong candidate for next-generation IoT-enabled applications. However, despite their potential, voice and gesture-based controls need AI-driven improvements for greater accuracy, adaptability, and overall user experience. Comparative evaluations reveal that IoT-based UI interactions offer more immersive and accessible experiences than conventional methods. However, critical areas such as cognitive load, security, and adaptability across diverse user groups must be addressed. In conclusion, IoT-enabled interactive designs have the potential to revolutionize digital twin applications and human-machine interaction frameworks, but future advancements must focus on refining error handling, reducing learning curves, and enhancing multimodal adaptability.

**Suggestions:**
While this study provides valuable insights into IoT-based interactive design usability, several research avenues require further exploration. One key direction is the integration of AI-driven adaptive UI personalization, where machine learning algorithms can dynamically adjust UI elements based on user preferences and real-time behavior. Context-aware adaptive interfaces can significantly improve response sensitivity in voice and gesture-controlled systems, making interactions smoother and more intuitive. Another promising area is the exploration of haptic feedback and multisensory interaction. By incorporating haptic feedback into IoT-enabled systems, touch-based and gesture-based interactions can become more immersive and compelling. Combining visual, auditory, and tactile feedback could enhance user experience, making IoT interfaces more intuitive and engaging.

Moreover, future research should focus on developing multimodal interface integration, enabling seamless interactions by combining voice, gesture, and touch-based controls. AR-based IoT interfaces can be improved by incorporating gesture tracking and voice recognition, allowing hands-free navigation in smart environments. These enhancements can contribute to more natural and effective user interactions, particularly in healthcare, smart cities, and industrial automation industries. Security remains a crucial concern in IoT-enabled interactive designs. Blockchain technology can be leveraged to secure data transactions and authentication processes within IoT interactions, ensuring privacy and trust. Additionally, deploying edge AI models can help process real-time user interactions locally, reducing latency and mitigating privacy risks associated with cloud-based systems. To ensure practical applicability, large-scale user experience (UX) studies should be conducted across diverse demographics to evaluate the real-world usability of IoT-enabled interfaces. Furthermore, experimental deployments of AR and voice-based IoT systems in various fields can help assess feasibility, identify challenges, and improve implementation strategies. This research lays the foundation for the next generation of IoT-enabled UI design, digital twins, and human-computer interaction. Advancements in AI, blockchain, and multimodal interaction will drive the development of intelligent, energy-efficient, and user-friendly IoT interfaces, transforming how humans interact with intelligent environments.

## CONCLUSION

This study comprehensively analyzes interactive design usability within IoT-enabled systems, mainly focusing on digital twins. The research demonstrates that touch and AR-based interfaces offer superior usability, while gesture and voice-assisted interactions require further improvements.

1. AI-driven real-time personalization for UI adaptation.
2. Haptic feedback integration to enhance user interaction.
3. Multimodal IoT interfaces combining gestures, voice, and AR.
4. Blockchain-based security enhancements in IoT UI transactions.

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**AUTHOR CONTRIBUTION STATEMENT**

Anwar Ali Sathio contributed to the conceptualization, methodology design, framework development, data analysis, manuscript drafting, and served as the corresponding author. Muhammad Malook Rind provided supervision, conducted critical review of the methodology, ensured validation, and contributed to the refinement of the manuscript. Sameer Ali was responsible for the literature review, data curation, technical writing assistance, and visualization of results. All authors have read and approved the final version of the manuscript.

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