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The IoT-enabled Interactive Design Investigation in User-Centered Design

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Abstract

Background of study: IoT enabled systems such as mobile phones, smart homes, and medical applications play a significant role in improving convenience and usability in everyday life. The combination of IoT networks with graphical user interface designs, including websites and online applications, continues to grow rapidly. Despite this progress, interactive usability challenges remain, especially in aligning IoT technologies with human centered interaction principles.
Aims and scope of paper: This study explores the usability of interactive design and identifies new attributes that contribute to improving user experience in IoT enabled systems. It aims to classify logical and physical attributes that influence usability and to propose new interactive dimensions for IoT based design.
Methods: The study uses a descriptive and analytical approach based on a review of relevant literature and conceptual analysis. Logical and physical usability attributes were examined to understand their roles in interactive design and user experience across IoT environments.
Result: The results reveal that two major factors, logical and physical attributes, are fundamental to interactive design. These attributes can guide new rules for IoT based usability, expanding human computer interaction beyond traditional interfaces such as keyboard, mouse, and screen, and including motion, gaze, and posture as part of new interaction mechanisms.
Conclusion: This study focuses on interface usability to help developers create more attractive and user friendly designs. The findings open new research areas in interactive IoT systems and contribute to the development of adaptive, efficient, and human oriented interface design principles for future IoT applications.

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INTRODUCTION

People ought to uncover more classified information than in recent memory as data innovation advances, which aligns with the standards of the current innovation climate. This way, as innovation improves, our trust in the security of our private information doesn't develop and may even decrease. A few insurance questions emerge inexplicable and accidental data deliveries can detrimentally affect clients. Customers' privacy is a lot of data and practices, like telephone numbers, web looking through action, IoT gadget setups, and individual inclinations. Recollect that modern advanced devices can track and store every development connected to Human-Computer Interaction. The consumer's data confidentiality affects the behaviors, cell numbers, browsing data activity, IoT system configuration secrecy, personal information, etc., as some software track and guides the users' moods and sentiments through HCI user-centered design approach Bevan (2001), Gittins (1986), Nuamah & Seong (2017). A few of the critical challenges include connectivity across IoT system modules based on variable burdens and switching restrictions. Even before the goal of IoT development becomes a fact of life, several issues and limitations regarding HCI in IoT systems

Nuamah & Seong (2017), must be tackled, and both technical and digital threads must be untangled. Critical problems include achieving collective benefit among IoT sensors and providing systems with a top standard of intelligence by supporting their adaptability and essential foreign while maintaining customer confidence, access, and protection. Furthermore, Human-Computer Interaction in the Internet of Things system will introduce a slew of new difficulties relating to asset efficiency in moderate commodity gadgets Nuamah & Seong (2017). This system aims to assist people with regular exercise and maintain a solid lifestyle. The significant point of any HCI strategy in IoT is to help the improvement of systems Vilar (2010) and Mao et al., (2005). While recognizing people's insight and capabilities and the intricacies of everybody's conduct, the accomplishment of these advances depends upon the information accumulated adequately reliant on the current structure given by the designer, and it assists with limiting inconveniences. The different objective of this strategy is to offer responses to hardships, including methodologies that depend on trademark demonstrating, context-oriented, and UI bunch dynamic that can assist with IoT framework fire-up challenge (Zhao & Alabama, 2016).

A few examination studies have examined different Internet of Things components, such as mechanical hardships, affordances, frameworks, and interface thoughts. Innovative affordances are, obviously, a fundamental component. A few IoT scholarly analysts are presently zeroing in on gas pedals (empowering agents) for a conversation about IoT frameworks and shrewd frameworks that exist under both genuine (physical) and virtual (advanced) worlds (Shackel, 2009; Yagmur, 2016). A few innovative affordances have been assembled with assistance from cell phone programs (applications). Fibaro Smart Facility 2, Smartphones Devices, Smart Displays, and Chrome Wave are only a few choices. Having one more apparatus to oversee circumstances isn't generally the best choice, particularly for straightforward interlinked like turning a gadget on and off. This requires the client to pick up the telephone, open it, find the applications, begin it, find the gadget, and finally have the option to work it. In any case, such projects help perform more mind-boggling arrangements. The human-computer interaction interface and cooperation plan exploration ought to perceive the substantial dependence of individual credits on the current innovation setting. When looking at the problem of client experience, dependability, helpfulness, and passive consent, the shortfall of a comprehensive view in sensitive sensors is one part liable for the low development of such methods. Among IoT-based drives and HCI, there is, yet a significant space for research. A mobile based application has been utilized to produce an assortment of strategies. Fibaro Smart Facility 2, Smartphones Devices, Smart Displays, and Chrome Wave are only a few choices.

In the literature, IoT technology has many elements Paternò (2005), including affordance, system, interface, in-reality, and virtual world specification. The innovative phone applications and the affordances made the technology easy and appealing. The IoT systems will review the HCI interface and interactive design with user experiences, usefulness, reliability, and acceptance (Banavar & Bernstein, 2002; Siricharoen, 2011; Nielsen, 1993). In the emerging field of IoT, Artificial Intelligent IoT (AIIoT) and Medical Artificial Intelligent IoT (MAIIoT) are still a big gap for HCI researchers. In this field of study, HCI and IoT will be widely established with wireless, connectionless, augmented worlds gadgets exploring the new dimension of a research study (Oyomno et al., 2013).

This research study aims to enhance perfect design quality by integrating IoT systems, as IoT-based systems or network designs play a vital role in sensor-based system design. The design will help to answer the difficulties in the interactive IoT-based user-centered design, modeling, context, and interfaces applied in the interactive design (Mao et al., 2005; Silva et al., 2011; Perera et al., 2014; and Sundmaeker & Saint-exupéry, 2010). The goal of IoT systems in Human-Computer Interaction communicability is for the customers to comprehend the ideas, intents, and choices by interacting with the IoT sensors (Perera et al., 2014). The primary goal of the collaboration between Human-Computer Interaction and IoT systems is to create better-networked products that uphold human abilities, expertise, and flexible usage patterns. This is significant since it minimizes the time required to comprehend the information and enables customers to respond more quickly and correctly. When attempting to combine sensors from multiple vendors into a unified system interface, the limits of IoT development in Human-Computer Interaction became apparent. Even though IoT-based systems with sensors in HCI advanced technology offer several potential opportunities in various domains and address various issues in multiple sectors, they face various protection difficulties and restrictions. It has many flaws that legacy methods have difficulty dealing with effectively. Since the Internet of Things is such a powerful platform, IoT systems with sensors have many limits, including battery life, power output, and processor ability (Silva et al., 2011; Alturki & Gay, 2019; Jokela et al., 2003).

METHOD

Research Design:
This study employed a descriptive and analytical design to explore the role of Human-Computer Interaction (HCI) within Internet of Things (IoT) systems. The research focuses on analyzing the integration of user-centered design, interactive modeling, and sensor-based communication systems. Through qualitative and conceptual analysis, this study investigates how HCI principles contribute to the improvement of IoT design quality and usability, providing a structured understanding of communicability and human adaptability within interconnected environments.

Instrumentation:
The study utilized secondary data derived from existing scholarly works, models, and frameworks related to IoT-based systems and HCI design principles. The instruments included literature synthesis, model comparison, and contextual analysis of user-centered design approaches and their integration into IoT environments. These sources provided essential data for evaluating connectivity challenges, interface affordances, and system interaction limitations.

Procedures and Time Frame:
The research procedure involved three main stages: (1) identifying key elements of IoT–HCI integration from previous studies, (2) classifying challenges and technological constraints in sensor-based system interactions, and (3) interpreting the effectiveness of user-centered frameworks in addressing IoT communication gaps. The research was conducted within an analytical timeframe focused on conceptual understanding rather than experimental implementation.

Scope and Limitation:
This study is limited to theoretical and conceptual interpretations of HCI and IoT frameworks rather than empirical experimentation. The absence of direct participant involvement and real-time data collection limits the generalizability of findings. However, the analysis provides foundational insights for future empirical research in enhancing IoT usability and human-centered interaction designs.

RESULT AND DISCUSSION

Results:

Design Principles & Its Justification in the Design

Our project (IoT) is new but not an invention because it has already been working on it (i.e., smart home) has already been done. We have added some new features for dumb people; for example, one clap means the sensor will understand that and open the light automatically, and two claps will indicate the sensor to close the light. Three claps suggest opening the door, and with four claps, the door will be shut. Perceived affordance describes an action that a user perceives to be possible or happen, just as our project, which is mainly based on sensory activity so dumb people can easily understand or perceive what to do (Gandy et al., 2003; Seffah & Metzker, 2004; Issa & Isaias, 2022). Our IoT project contains an entirely natural mapping that is too dumb, so people do not need labels, ambiguity, or learning. But it must be remembered because it's all about sensory action. Dumb people easily control the system, and the step will be performed immediately by the IoT system (Holzinger et al., 2008; Juristo et al., 2007; Bevan , 1995; and Quiñones et al., 2018). We have added some new features for dumb people; for example, one clap means the sensor will understand that and open the light automatically, and two claps will indicate the sensor to close the light. Three claps suggest opening the door, and with four claps, the door will be shut. Our system is sensory, so when a user acts (claps), the system will understand and perform the task. As mentioned above, when a user acts, the result will be displayed after a mini-second. There is no delay in it. There could be a slip error. For instance, a user wants to open the light with one clap but mistakenly claps twice, so the light remains closed. When a user (dumb) claps according to their need, the IoT system will respond to their action; accordingly, otherwise, the system can't give results to the user. socialization and user experience relieve heavily on thought processes mental model. They are founded on perc;eption instead of being a real idea and pertain to how a person views the world about them. Cognitive processes are a type of belief phenomenon. They are a customer's perceptions about a specific technology or relationship. In most cases, the idea will mirror the professional photo. This is significant since users will use their thought (mental) processes to plan and anticipate future behaviors inside a technology.

User-Centered Design

User-centered design is based on the user's needs, abilities, context, work, and task (Peters et al., 2015; Bevan, 2001; and Nielsen, 1992). The design of any IoT-based system is user-centered because the project is based on or surrounded by the user's requirements. Our system's primary purpose or goal is to provide facilities to individuals who are dumb. Using our system, they can fulfill their needs or requirements to make life more manageable. The design of technological projects where a user can easily interact with the IoT system (Bevan, 2001; Nuamah & Seong, 2017; Perera et al., 2014; and Nielsen, 1992).

Usability Engineering Model (Six Usability Attributes):

The following are key usability attributes (Yagmur, 2016);

a. Effectiveness: This project focuses on providing facilities to the dumb, and by using this system, they can quickly fulfill their desires or needs.
b. Learnability: This system is user-friendly and easy to understand and implement.
c. Efficiency: This system can make less effort and more outcomes.
d. Memorability: Repeatedly for average or casual consumers, the device is convenient for its user.
e. Errors: There could be a chance of errors occurring.
f. Satisfaction: If their need is fulfilled, customers will be satisfied.

Design Dimensions:

a. Use: Where there is a need, a system will be installed at the specific place, and the sensors will be fitted in the instruments. Just as (doors, lights, switch sockets)
b. Useful: to makes the task easier for dumb people.
c. Useable: The target audience (those who could not perform their task) includes dumb people and those who want to save time.
d. Adoption: It provides the facility to save time and fulfill the desire.
e. Appropriate: It is suitable for the dumb because they can use the IoT system without saying anything by making hand motion (Hall & Llinas, 1997; Hall, D. L., & Llinas, 2017; Nuamah & Seong, 2017; Perera et al., 2014; Zhao & Alabama, 2016).

Proposed classified modeled list of attributes applicable for User-Centered-Design (UCD) (UCD) in IoT-enabled GUI interactive design and in Fig. 1 shows the domain area of HCI in the design for the GUI, while in Fig.2 describes the main actors of User-Centered-Design (UCD). In Fig.3, it shows the key factors explored in the UDC area.

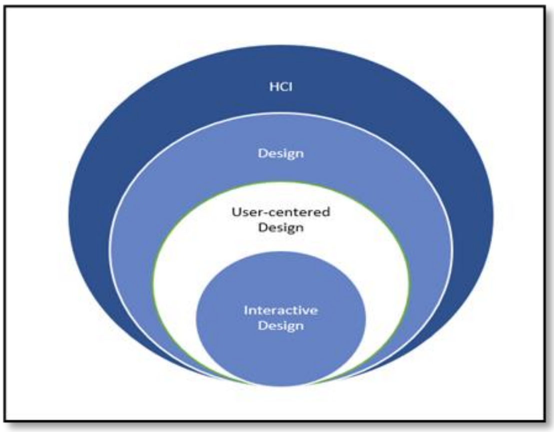

Figure 1. Describe the domain areas of design

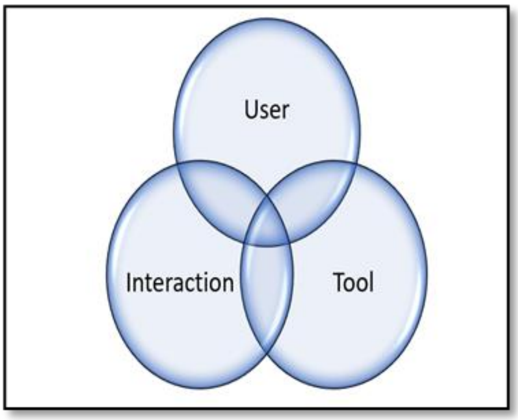

Figure 2. Critical components in the User-centered design in the GUI environment

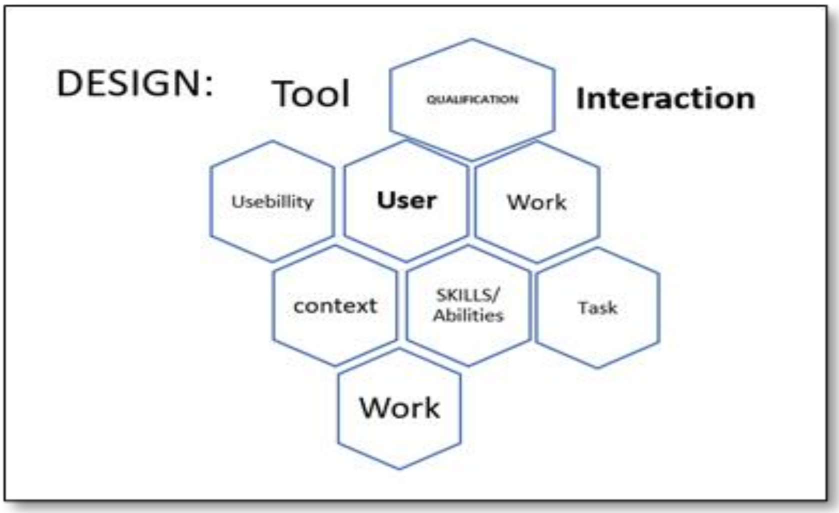

Figure 3. Describes the User's factors in UDC.

Users' attributes for the interactive-centered design development process

The six basic usability principles introduced in literature, but there are some others also exists, are very important, listed below, and need to be considered when the design of any interface (Mao et al., 2005; Medhi, 2007; Silva et al., 2011; Jokela et al., 2003; Shackel, 2009; and Sundmaeker & Saint-exupéry, 2010).

a) **Measurement:** How do we measure all these attributes related to design?
b) **Navigation:** Simple mapping and navigation between the components can be easy.
c) **CMN:** Consistency, mapping, and navigation between all interactive levels in a consistent way.
d) **EVU:** Effectiveness, validation, and updating the current and upcoming versions smoothly.
e) **Transitional Action:** The action transition is efficient, and there is a minimal time stamp.
f) **Sustainability:** Sustaining the required needs of users shall be fulfilled
g) **Learnability:** every user can learn the whole system without training or help, just like in games.
h) **Memorability:** processes shall be short, simple, and easy to remember a long time once used.
i) **User-friendly:** every type of user can interact with the design
j) **Simple labeling:** used names shall be small, simple, and visible
k) **Simplicity:** the design shall be simple through usability, look, and functionality
l) **Structure outlook**: design structures, themes, windows, and navigation 7-panels are well planned.
m) **Flexible across-the-board interface**: that is adjustable for all environmental changes, from mobile to desktop.
n) **Tolerable**: handles the situation when any error occurs, smooth interaction and functionality

o) **Reusability:** This is an excellent capability to enhance the usability features and minimize costs.
p) **With low mental work**: users do not need to think much about making decisions.
q) **Feedback/Review**: It shall be considered for further improvements when the user identifies the errors.
r) **Easy mechanism of usage**: all systems and interactions shall be by the user's needs and surrounding environment.
s) **Information presentation& Display**: It shall be according to local and international standards based on culture, tradition, and civic rules.
t) **Easy help:** this functionality helps the user raise trust and satisfaction levels.
u) **Error ratio:** When the design is simple, error lessness means minimizing the error ratio.
v) **Cost-effective:** the lowest cost level is a key factor in the design.
w) **Freedom of choice:** The user can use all components and navigate anywhere.
x) **Freedom of exit:** when users get tired, they may leave the interface without restriction (Yagmur, 2016; Paternò, 2005; Oyomno et al., 2013; Seffah & Metzker, 2004; and Holzinger et al., 2008).

In Fig. 4 shows the factors of the Tool, which describes and measures these attributes using qualitative and quantitative methods to analyze any GUI interface design. In Fig. 5, we describe the components used to assess any GUI design.

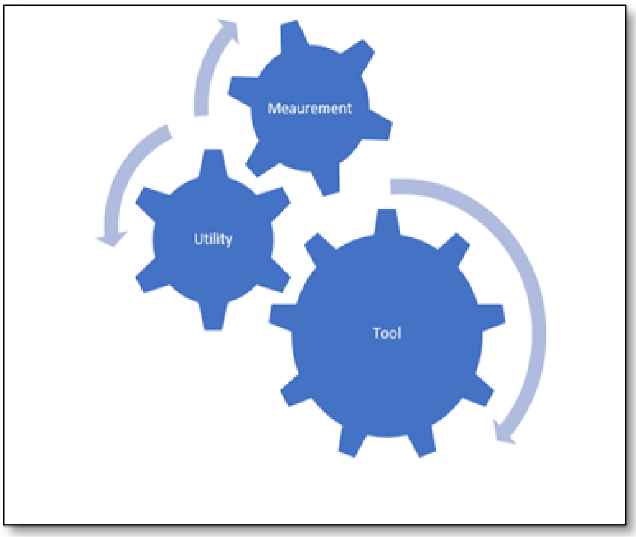

Figure 4. Describe the Factor Tool and related components.

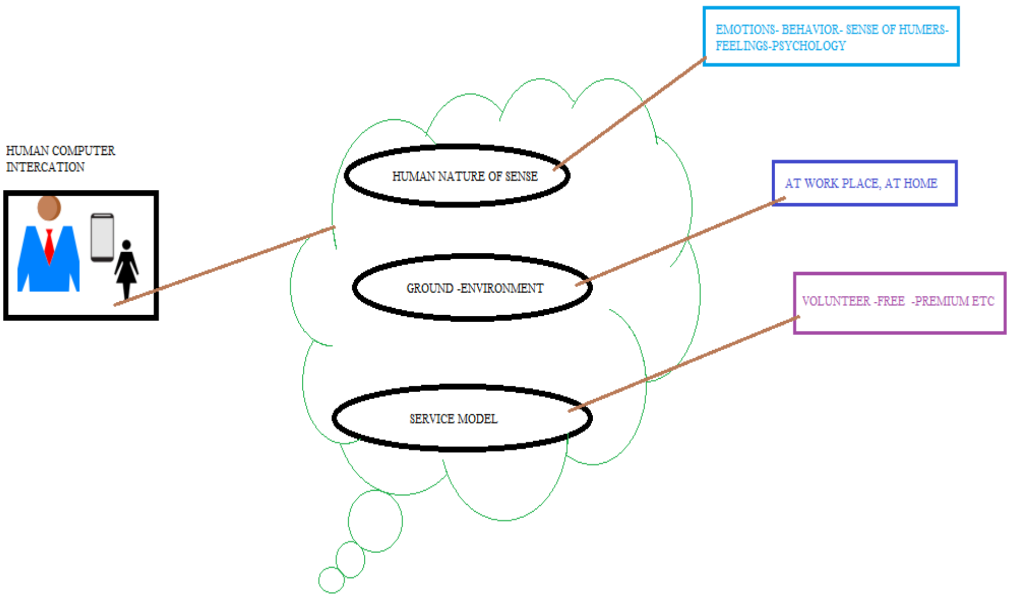

Figure 5. Describes the Interaction factors and usability metrics for interactive design

User-centered Design of interactive attributes

Several researchers have contributed to the understanding and development of user-centered design principles, including Juristo et al., (2007), Gandy et al., (2003), Perera et al., (2014), Mao et al., (2005), Medhi (2007), Silva et al., (2011) and Jokela et al., (2003). Based on their studies, interactive user-centered design attributes can be classified into three main categories: user attributes, tool attributes, and interaction attributes.

A. User attributes description

The user attributes can be justified as logical and physical attributes.

1. The Logical Attributes:
   The basic concept of logical attributes is essential for measuring the degree and relationships with physical attributes. Many tools and techniques have been introduced to measure user behavior, understand it, and improve design.
2. The Physical attributes:
   The ultimate concept of these attributes is to measure the interactive response capability, how these attributes we can measure and use for improvements

B. Tool attributes description

1. Logical Attributes: active, fast, accurate.
2. Physical Attributes: low cost, available, accessible.

C. Interaction attributes description

1. Logical Attributes: emotion, attitude.
2. Physical attributes: work, home.

Discussion:

The study explored novel attributes important in interactive user-centered design for IoT-enabled creation. In previous research studies, there were only six attributes. We explored the new characteristics and dimensions of the IoT-enabled system and interactive design. This will contribute to and enhance the design perfection for an emerging field.

1. Exploration of Novel Attributes in Interactive Design

i. Existing research studies focused on six core attributes related to interactive design. However, our study identified additional attributes that significantly enhance the usability and functionality of IoT systems.
ii. Including these new dimensions can enhance the scope of design considerations, addressing gaps in prior research. Attributes such as motion tracking, posture-based interactions, and gaze detection align with advancements in Human-Computer Interaction (HCI) and adaptive systems.
iii. Scholarly frameworks, such as Norman's "The Design of Everyday Things," emphasize the importance of user-centered design, which aligns with the study's approach to improving interaction dynamics for IoT systems.

2. Contribution to Emerging IoT-Based Interactive Systems:

i. IoT-enabled systems, such as wearable health monitors and smart home devices, depend highly on user-centric designs to ensure adoption and usability.
ii. The study explores novel attributes associated with a paradigm shift towards ambient intelligence, where devices seamlessly interact with users. This contributes to improving interaction paradigms in both domestic and professional contexts.
iii. Existing studies, such as Nielsen (1992), highlight the role of usability testing and consumer feedback in refining system interfaces. The integration of the novel attributes proposed a benchmark for emerging IoT applications.

3. Logical and Physical Attributes as Design Foundations

i. Logical attributes, such as data flow, information architecture, and user feedback mechanisms, underpin the structural usability of interfaces. These aspects ensure efficient interaction and reduce cognitive load, as outlined in research on cognitive ergonomics.

ii. Physical attributes, including tactile input methods, device ergonomics, and environmental adaptability, are critical for IoT systems in diverse scenarios, such as healthcare and smart cities.
iii. The proposed logical and physical integration require further research to establish their impact on user engagement and task completion efficiency.

Implications:
The study supports the Usability Engineering Lifecycle by emphasizing the iterative development of user-centered designs. We focus on key principles, such as requirement gathering, prototyping, and evaluation, which are critical to refining IoT interfaces. Such as consumer requirements, particularly for novice users, must remain at the forefront to ensure inclusivity.

Research Contribution:
The research provides a strong foundation for interface-specific usability studies, which are vital in reducing the learning curve for novice users, a critical factor in Human-Computer Interaction. The study contributes to understanding how convenience, openness, and client experience can be integrated into IoT design to enhance efficiency and adaptability. These insights also establish a theoretical base for future empirical work focused on human-centered IoT development.

Limitations:
The study explicitly focuses on user interface (UI) design for IoT-based systems, omitting critical areas such as back-end system integration, network efficiency, and security. The research provides a strong foundation for interface-specific usability studies, which are vital in reducing the learning curve for novice users a critical factor in HCI, convenience, openness, and client experience are critical variables studies.

Suggestions:
In the study, we still need to evaluate the proposed attributes using empirical methods, including usability testing frameworks like SUS (System Usability Scale) or UTAUT (Unified Theory of Acceptance and Use of Technology), for further investigations. The development of standardized measuring tools for assessing the proposed attributes will be vital. Such tools could assess how well gaze tracking improves task efficiency in IoT systems compared to traditional inputs. We should explore the potential of integrating AI to dynamically adjust interactive design elements based on user behavior, creating adaptive and predictive systems. The study findings apply to IoT domains, including smart home systems, healthcare monitoring, and industrial IoT. Wearable health monitors can be utilized for such applications, highlighting how novel attributes can enhance user satisfaction and operational efficiency. Developers can use these insights to streamline the design process, ensuring faster time to market and reduced development costs.

CONCLUSION

The purpose of this study was to compose the roadmap of interactive user-centered design and how we develop the best interactive interface for IoT-based systems. We explored the novel attributes and their relationship with different vital components. These logical and physical attributes may need further investigation. This study is restricted only to the User interface design of IoT-based systems. These proposed design principles help control the design factors and manage the development process in time. In the future, these attributes shall be investigated to learn the existing and suggested measuring tools and techniques. These tools will help measure every interface's degree of usability and ease. The design dimensions play a vital role in allowing us to create efficient and practical designs that fulfill all users' requirements. Novice use is a critical factor in the user dimension of HCI. According to usability engineering, lifecycle's basic principles, in which consumer requirements have been focused on. We classified the user's context of IoT-based features and characteristics. Our primary examples are innovative home security systems and wearable health monitors.

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AUTHOR CONTRIBUTION STATEMENT

Muhammad Malook Rind contributed to the conceptualization of the study, supervision, and critical evaluation of the research framework. Anwar Ali Sathio, as the corresponding author, was responsible for methodology design, data analysis, manuscript drafting, and overall coordination of the research. Shafique Ahmed Awan supported the validation, review, and refinement of the manuscript. Ghulam Ahmed assisted in literature review, data curation, and preparation of supporting materials. All authors have read and approved the final version of the manuscript.

DECLARATIONS

The authors received no specific funding for this research. They declare that there are no conflicts of interest regarding the publication of this paper. Since the study did not involve human participants, animals, or sensitive data, ethical approval and consent to participate were not applicable. All authors consent to the publication of this manuscript. The study utilizes open-source datasets, and all materials used and/or analyzed are publicly available; additional resources are available from the corresponding author upon reasonable request.

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