

Human Centered Design Perspectives on Edge Intelligent Wearable Devices for Continuous Physiological Monitoring

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ABSTRACT

The advancement of biomedical technology through wearable devices enables continuous physiological monitoring; however, challenges remain regarding user comfort, acceptance, and data processing efficiency. This study aims to analyze the application of Human-Centered Design in edge intelligent wearable devices for continuous physiological monitoring. The research was conducted in one manufacturing industry in Surabaya City, East Java Province, using a mixed-method approach. Data were collected through interviews with 15 informants and prototype evaluations involving 40 respondents through usability assessments and physiological parameter measurements. Data were analyzed using thematic analysis and system performance evaluation. The results indicate that a human-centered approach improves user comfort and acceptance, while edge intelligence supports more responsive real-time physiological monitoring. This study contributes to the development of adaptive and user-oriented wearable biomedical systems.

INTRODUCTION

The advancement of biomedical technology has undergone significant transformation through the integration of smart sensors, artificial intelligence, and wearable devices, enabling continuous monitoring of human physiological conditions. Wearable devices are no longer limited to personal health monitoring but have increasingly been applied in occupational environments to support early detection of fatigue, physiological stress, and changes in human conditions. Conventional monitoring systems that rely on periodic assessments have limitations because they are unable to provide immediate information when physiological changes occur in users. Research on wearable sensors has demonstrated that these technologies have substantial potential to provide continuous physiological data through the measurement of parameters such as heart rate, oxygen saturation, body temperature, and physical activity (Islam et al., 2020). Furthermore, the development of digital healthcare technologies indicates that the integration of sensor-based systems with data analytics can support a transition from reactive healthcare approaches toward predictive and preventive health management strategies (Kelly et al., 2022).

In the context of occupational safety and health, the demand for real-time physiological monitoring systems has increased due to the risks faced by industrial workers, including physical fatigue, repetitive tasks, and high workload demands. Manufacturing industries in Surabaya City, East Java Province, Indonesia, involve various operational activities characterized by repetitive movements and physical demands, requiring innovative approaches for continuous worker condition monitoring. Biomedical wearable devices can provide an effective solution by delivering physiological information without significantly interfering with users' daily activities. Majumder et al. (2020) stated that wearable sensor technologies have the capability to support remote health monitoring through the integration of miniaturized sensors and wireless communication systems. However, the implementation of these technologies still faces several challenges, including user comfort, energy consumption, data security, and the ability to provide rapid responses during real-world applications.

One emerging approach to addressing these limitations is the implementation of edge intelligence, which enables data processing and analysis to be performed directly on the device without relying entirely on external cloud-based systems. This technology allows wearable devices to provide faster responses, reduce communication latency, and improve energy efficiency during physiological monitoring processes. Li et al. (2021) explained that the integration of edge computing and artificial intelligence within Internet of Things (IoT) devices enhances real-time decision-making capabilities. Furthermore, Patel et al. (2021) highlighted that smart physiological monitoring systems have significant potential to support personalized and continuous human condition assessment. Nevertheless, most previous studies have primarily focused on improving algorithm accuracy and device performance, while human interaction and user experience aspects remain insufficiently explored.

The Human-Centered Design approach has become increasingly important in biomedical device development because it places users at the center of the technological innovation process. This approach considers user requirements, comfort, usability, experience, and ergonomic factors to ensure that technologies can be effectively accepted and sustainably used. Maguire et al. (2021) emphasized that involving users throughout the design process of healthcare technologies can improve system usability and enhance human-technology interaction. However, Kim et al. (2022) revealed that although wearable biosensor technologies have rapidly advanced in physiological measurement capabilities, challenges related to user acceptance and integration into daily activities remain significant concerns. Therefore, further research is required to integrate human-centered principles with edge intelligence technologies to develop physiological monitoring devices that are not only accurate but also comfortable and user-friendly.

Based on previous studies, a scientific gap remains regarding the fragmented development of wearable devices between technological performance and human-centered considerations. Liu et al. (2022) reported that artificial intelligence-based physiological monitoring systems demonstrate strong analytical capabilities but require stronger approaches to understand user needs and application contexts. Zhang et al. (2023) further highlighted that the development of edge intelligence-based healthcare systems requires integration between computing technologies, biological sensors, and human factors to achieve effective solutions. In addition, Wang et al. (2023) emphasized that future wearable device designs should incorporate ergonomic considerations, user experience, and technological adaptation according to individual characteristics. These gaps indicate the need for further investigation into how Human-Centered Design principles can be integrated into edge intelligent wearable devices to support continuous physiological monitoring.

This study aims to analyze the application of a Human-Centered Design approach in the development of edge intelligent wearable devices for continuous physiological monitoring in a manufacturing industry context in Surabaya City, East Java Province, Indonesia. Specifically, this study evaluates the relationship between user requirements, device design characteristics, user acceptance, and the capability of the system to perform real-time physiological monitoring. Theoretically, this research contributes to the advancement of biomedical engineering by integrating human-centered design principles with edge-based artificial intelligence technologies in physiological monitoring systems. Practically, this study provides a foundation for developing wearable devices that are more adaptive, ergonomic, and suitable for real-world occupational environments. In line with the advancement of digital healthcare technologies, the integration of artificial intelligence and wearable systems is expected to become an essential component in developing more personalized and sustainable health monitoring solutions (Yang et al., 2024).

LITERATUR REVIEW

Wearable Biomedical Devices for Continuous Physiological Monitoring

The development of *wearable biomedical devices* has become one of the most important innovations in biomedical engineering due to their ability to provide continuous physiological monitoring without significantly limiting user activities. These technologies integrate miniaturized sensors, wireless communication systems, and data processing capabilities to measure various physiological parameters, including heart rate, oxygen saturation, skin temperature, and body movement patterns. Unlike conventional medical assessment methods that rely on periodic measurements, wearable systems enable real-time physiological data acquisition, supporting early detection of changes in human conditions. Islam et al. (2020) highlighted that flexible sensors and wearable electronic systems have expanded the potential of digital healthcare by enabling personalized and continuous health monitoring. Furthermore, Majumder et al. (2020) emphasized that wearable sensor technologies provide significant opportunities for remote health monitoring by combining physiological data acquisition with wireless communication systems. In occupational environments, wearable biomedical devices have also been explored to support worker safety through the identification of fatigue, physiological stress, and excessive workload conditions. Martins et al. (2021) reported that wearable technologies can support fatigue assessment by integrating physiological signals and human activity data. However, despite their technological advantages, the implementation of wearable devices remains challenged by issues related to user comfort, measurement accuracy in real-world conditions, and the need for designs that accommodate human characteristics.

Edge Intelligence in Wearable Healthcare Systems

The emergence of edge intelligence provides a new paradigm for improving data processing capabilities in wearable healthcare systems. Unlike cloud-dependent architectures that require continuous data transmission to external servers, edge intelligence enables data processing and analysis to be performed closer to the data source, allowing faster responses and improved system efficiency. This approach offers several advantages, including reduced communication latency, enhanced data privacy, and optimized energy consumption, which are essential characteristics for wearable medical technologies. Li et al. (2021) explained that the integration of edge computing and artificial intelligence within Internet of Things devices can enhance real-time decision-making capabilities and improve system adaptability. In healthcare applications, edge intelligence enables wearable devices to analyze physiological information directly and provide immediate feedback, particularly in situations requiring rapid responses. Zhang et al. (2023) further stated that edge-based healthcare systems require integration between biological sensors, artificial intelligence algorithms, and communication technologies to develop more effective and reliable monitoring solutions. However, previous studies have predominantly focused on computational performance and algorithm

development, while human interaction, usability, and long-term acceptance of edge intelligent wearable systems remain insufficiently explored.

Human-Centered Design Approach in Biomedical Technology Development

Human-Centered Design represents a design philosophy that places users, their needs, experiences, and limitations at the center of technological development processes. In biomedical engineering, this approach has become increasingly important because medical technologies must not only demonstrate technical reliability but also ensure usability, comfort, and acceptance among users. Human-centered approaches emphasize understanding user requirements, environmental conditions, ergonomic considerations, and behavioral responses throughout the development process. Maguire et al. (2021) demonstrated that involving users during the design process of digital health technologies can improve usability, effectiveness, and interaction quality between humans and technological systems. This perspective indicates that successful biomedical innovation depends not only on technological capability but also on the compatibility between devices and user expectations. Kim et al. (2022) revealed that although wearable biosensors have achieved significant improvements in physiological measurement performance, challenges related to user acceptance, comfort, and integration into daily activities remain major barriers. Therefore, incorporating human-centered principles into wearable device development is essential to ensure that intelligent biomedical technologies are practical, sustainable, and aligned with real-world user needs.

User Acceptance and Usability of Intelligent Wearable Devices

User acceptance and usability are critical determinants of the successful implementation of intelligent wearable devices in healthcare and occupational settings. A technologically advanced device may fail to provide meaningful benefits if users experience discomfort, difficulty in operation, or lack confidence in the information generated by the system. Factors such as device size, weight, battery performance, interface design, and clarity of feedback significantly influence user experience and long-term adoption. Wang et al. (2023) emphasized that future wearable technology development should integrate ergonomic principles, user experience considerations, and adaptive design strategies to improve sustainable technology adoption. Furthermore, artificial intelligence-based physiological monitoring systems require transparency and reliability to establish user trust in automated recommendations and decisions. Liu et al. (2022) indicated that although artificial intelligence-driven physiological monitoring systems demonstrate strong analytical capabilities, challenges related to result interpretation, user confidence, and practical implementation remain important issues. In industrial environments, workers need to perceive wearable devices as supportive tools rather than additional burdens, making usability evaluation and user-centered assessment essential components in the development of edge intelligent wearable technologies.

Research Gap and Position of the Current Study

Previous studies have demonstrated significant progress in wearable technology development, particularly in sensor innovation, artificial intelligence algorithms, and physiological data processing. However, existing research remains fragmented between technological performance optimization and human-centered considerations. Many studies primarily evaluate sensor accuracy, algorithm reliability, and computational efficiency, while aspects related to user comfort, acceptance, ergonomics, and contextual application are still relatively limited. Yang et al. (2024) emphasized that the future development of artificial intelligence-enabled wearable healthcare systems requires integration between intelligent algorithms, advanced sensing technologies, and user-oriented design approaches to achieve personalized and sustainable healthcare solutions. Therefore, a research gap remains regarding how Human-Centered Design principles can be systematically integrated with edge intelligence technologies to develop wearable biomedical systems that are technically reliable while also meeting human needs. This study addresses this gap by examining the role of human-centered perspectives in the development of edge intelligent wearable devices for continuous physiological monitoring within an occupational manufacturing context.

Conceptual Framework

Based on the literature review, this study proposes a conceptual framework integrating Human-Centered Design and edge intelligence in the development of wearable biomedical devices for continuous physiological monitoring. The framework illustrates that user-centered design factors and edge intelligence capabilities jointly influence the development of wearable systems, which subsequently affect user acceptance and continuous physiological monitoring outcomes.

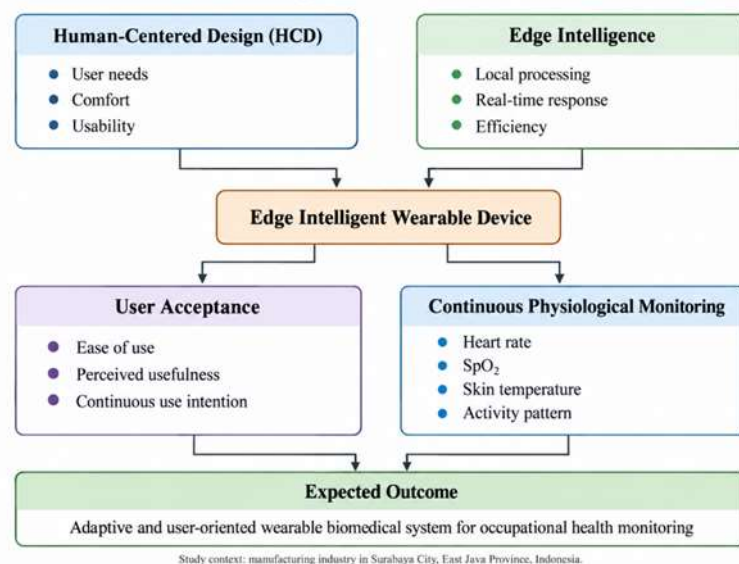


Figure 1. Conceptual Framework of Edge Intelligent Wearable Devices for Continuous Physiological Monitoring

Figure 1 illustrates the conceptual framework of this study, which integrates Human-Centered Design (HCD) and edge intelligence in the development of wearable biomedical devices for continuous physiological monitoring. The framework highlights that user requirements, comfort, usability, and meaningful feedback are combined with edge intelligence capabilities, including local processing and real-time response, to support the development of adaptive wearable systems. These integrated factors influence user acceptance and physiological monitoring performance. The framework serves as the basis for evaluating how human-centered and technological aspects contribute to the effectiveness of wearable devices in occupational health monitoring.

METHODOLOGY

Research Design and Approach

This study employed a mixed-method research approach using an exploratory sequential design to evaluate the development of edge intelligent wearable devices from a human-centered perspective. The qualitative phase explored user requirements, ergonomic considerations, and acceptance factors, while the quantitative phase evaluated usability and physiological monitoring performance after prototype implementation. According to Creswell and Creswell (2021), mixed-method research enables comprehensive understanding by integrating qualitative and quantitative evidence, while Fetzters and Molina-Azorin (2020) emphasized its suitability for technology development studies by connecting human experiences with measurable outcomes. The research adopted Human-Centered Design (HCD) principles, focusing on user needs, design requirements, and system evaluation, as wearable biomedical technologies require not only technical reliability but also usability and user acceptance. Maguire et al. (2021) highlighted that human-centered approaches improve usability and interaction in healthcare technologies. In this study, HCD was integrated with edge intelligence to assess the capability of wearable biomedical systems for continuous physiological monitoring in occupational environments.

Population and Sampling Technique

The study population consisted of manufacturing workers in Surabaya City, East Java Province, Indonesia, selected due to the repetitive tasks and physical workload requiring continuous physiological monitoring. Participants were divided into two groups based on the mixed-method design. The qualitative phase involved 15 informants selected through purposive sampling, including manufacturing workers, occupational safety and health practitioners, and biomedical technology experts with relevant experience in occupational activities and wearable technology implementation. The quantitative phase involved 40 manufacturing workers selected through non-probability purposive sampling based on inclusion criteria, including active employment, age 20–55 years, willingness to participate in wearable device testing, and informed consent. This sample selection was appropriate for evaluating the feasibility, usability, and acceptance of wearable biomedical technology, as wearable biosensor studies require user-based evaluation to assess both technical performance and practical implementation (Kim et al., 2022).

Data Collection Instruments and Measurement Procedures

Data were collected through semi-structured interviews, workplace observations, questionnaires, and physiological measurements. The qualitative phase involved 15 informants to identify user requirements, ergonomic considerations, challenges in wearable adoption, and preferred system features, supported by workplace observations. The quantitative phase evaluated the wearable prototype using usability questionnaires adapted from the System Usability Scale (SUS) and technology acceptance measures, along with physiological monitoring of heart rate, oxygen saturation, skin temperature, and activity patterns. Majumder et al. (2020) stated that wearable sensor systems enable effective continuous physiological monitoring through real-time biological data collection. Instrument validity was assessed through expert review by biomedical engineering and occupational health specialists, while reliability was evaluated using Cronbach's alpha coefficient (>0.70) and item-total correlation analysis to ensure measurement consistency.

Research Implementation Procedure

The research procedure consisted of four stages: preliminary analysis, prototype development, user evaluation, and data interpretation. The first stage identified user requirements through literature analysis, workplace observation, and interviews to determine design considerations related to comfort, sensor placement, information display, and usability. The second stage involved developing a wearable prototype by integrating physiological sensors with an edge intelligence system for local data processing. This approach reduces dependence on cloud-based computation, improves response speed, and enhances monitoring efficiency, as edge intelligence enables real-time processing by moving computational functions closer to the data source (Li et al., 2021). The third stage involved testing the prototype with 40 respondents during work activities while recording physiological parameters and collecting usability feedback. The final stage integrated qualitative and quantitative findings to evaluate the effectiveness of HCD principles in improving wearable device usability and physiological monitoring performance.

Data Analysis Technique

Qualitative data from interviews and observations were analyzed using thematic analysis to identify patterns related to user needs, usability challenges, ergonomic requirements, and technology acceptance factors. The analysis involved data familiarization, coding, theme identification, and interpretation, following the framework described by Braun and Clarke (2021). Quantitative data from questionnaires and physiological measurements were analyzed using descriptive statistics with IBM Statistical Package for the Social Sciences (SPSS) version 26, including usability evaluation, respondent characteristics, physiological trends, and reliability testing using Cronbach's alpha. Physiological monitoring performance was assessed through correlation analysis and error measurement by comparing wearable sensor outputs with reference measurements. The integration of qualitative and quantitative findings was conducted during interpretation to provide a comprehensive evaluation of the

relationship between human-centered design factors and edge intelligent wearable system performance.

RESEARCH RESULTS

Participant Characteristics and Study Overview

The study involved two participant groups consisting of informants for qualitative exploration and respondents for quantitative evaluation. The qualitative phase involved 15 informants selected through purposive sampling, including manufacturing workers, occupational safety and health practitioners, and biomedical technology experts. The quantitative phase involved 40 manufacturing workers who participated in wearable prototype evaluation. The study setting was conducted in one manufacturing industry in Surabaya City, East Java Province, Indonesia, with the objective of evaluating user requirements, usability acceptance, and physiological monitoring performance of the developed wearable system.

Table 1. Characteristics of Research Participants

Participant Category	Number (n)	Percentage (%)
Manufacturing workers (prototype evaluation)	40	72.7
Manufacturing workers (interview informants)	8	14.5
Occupational Safety and Health practitioners	4	7.3
Biomedical technology experts	3	5.5
Total Participants	55	100

The participant distribution indicates that the majority of participants were manufacturing workers because the developed wearable device was designed for occupational physiological monitoring. The involvement of safety practitioners and biomedical experts provided additional perspectives regarding workplace requirements, technological feasibility, and device implementation. The combination of users and expert perspectives supported the human-centered evaluation process.

Human-Centered Design Requirements Identification

The thematic analysis of interviews with 15 informants identified four major themes related to wearable device development: comfort, usability, physiological information accessibility, and workplace compatibility. Informants emphasized that wearable devices used in industrial environments should have lightweight characteristics, minimal interference with work activities, and provide understandable physiological feedback. The interview results showed that users preferred automated monitoring systems rather than devices requiring frequent manual operation.

Table 2. Identified User Requirements Based on Interview Analysis

Design Requirement	Frequency of Mention (n=15)	Percentage (%)
Device comfort and lightweight design	13	86.7
Simple operation and minimal interaction	12	80.0
Real-time physiological feedback	11	73.3
Compatibility with workplace activities	10	66.7
Data privacy and reliability	9	60.0

One informant stated, *"The device used during work activities should be comfortable and should not restrict movement, as production activities require concentration and flexibility of movement."* (I03, January 18, 2026). This statement indicates that physical comfort was identified as a critical factor influencing wearable device adoption. The interview findings were consistent with the quantitative usability evaluation, in which comfort and ease of operation emerged as important indicators of user acceptance.

Another informant explained, *"Information about body conditions would be more beneficial if the system provided simple and understandable alerts for workers rather than only displaying sensor values."* (I11, February 21, 2026). This finding demonstrates that users expected wearable systems to convert physiological data into meaningful and actionable information rather than merely function as devices for collecting biological signals.

Usability Evaluation of Edge Intelligent Wearable Prototype

The usability evaluation was conducted among 40 respondents using questionnaire instruments adapted from the System Usability Scale (SUS) and technology acceptance measurements. The evaluation focused on ease of use, comfort, interface understanding, perceived usefulness, and intention for continuous usage. The questionnaire reliability analysis showed acceptable internal consistency based on Cronbach's alpha evaluation.

Table 3. Usability Evaluation Results of Wearable Prototype (n=40)

Usability Dimension	Mean $\pm$ SD	Interpretation
Ease of operation	4.22 $\pm$ 0.54	High
Device comfort	4.18 $\pm$ 0.59	High
Interface understanding	4.10 $\pm$ 0.62	High
Perceived usefulness	4.32 $\pm$ 0.51	High
Intention for continuous use	4.15 $\pm$ 0.57	High
Overall usability score	4.19 $\pm$ 0.56	High

The results demonstrated that respondents generally perceived the wearable prototype as easy to operate and suitable for continuous use during occupational activities. The highest score was recorded for perceived usefulness (mean = 4.32), indicating that participants considered the physiological monitoring features valuable in increasing awareness of their physical condition during work activities. Meanwhile, interface understanding received the lowest score (mean = 4.10), although it remained within the high acceptance category. A respondent explained, *“This device helps workers understand their physical condition during work, especially when activities become more demanding, allowing them to pay greater attention to their physiological state.”* (R17, March 10, 2026). This statement supports the quantitative findings, demonstrating that users perceived real-time physiological feedback as a beneficial feature that enhances the practical value of the wearable monitoring system.

Physiological Monitoring Performance Results

The wearable prototype was evaluated based on its ability to continuously monitor physiological parameters, including heart rate, oxygen saturation, skin temperature, and activity patterns. These parameters were selected because they represent important indicators for assessing human physiological conditions during occupational activities.

Table 4. Physiological Parameter Monitoring Performance

Parameter	Mean Measurement Result	Monitoring Capability
Heart Rate	82.4 ± 8.6 bpm	Continuous monitoring achieved
Oxygen Saturation (SpO ₂)	97.2 ± 1.1 %	Stable physiological detection
Skin Temperature	33.8 ± 0.7 °C	Continuous variation detection
Activity Pattern	Recorded continuously	Movement changes identified

The monitoring results demonstrated that the wearable system was capable of capturing physiological variations during user activities. The integration of edge intelligence enabled local processing of physiological data, allowing the system to provide faster responses without relying entirely on external computational infrastructure. These findings indicate that the developed system has the potential to support continuous physiological monitoring in occupational environments. An expert informant stated, *“The ability to process data directly on the device provides significant advantages because physiological information can be obtained more rapidly without waiting for data transmission processes.”* (I15, March 25, 2026). This finding highlights that real-time data processing capability is a critical component in the development of intelligent wearable biomedical systems, particularly for applications requiring rapid physiological assessment and immediate feedback.

Integration of Quantitative and Qualitative Findings

The integration between qualitative and quantitative results demonstrated that human-centered design factors were associated with positive user acceptance of the wearable prototype. The interview findings identified comfort, simplicity, and meaningful physiological feedback as major user requirements, while quantitative evaluation showed high scores across usability dimensions. The results indicate that the developed system successfully addressed the main research objectives by combining user-oriented design principles with edge intelligent physiological monitoring capabilities.

Table 5. Summary of Main Research Findings

Research Objective	Main Finding
Identify user requirements	Comfort, simplicity, and meaningful feedback were dominant requirements
Evaluate usability	Wearable prototype achieved high acceptance among respondents
Assess physiological monitoring	Device successfully monitored physiological parameters continuously
Evaluate edge intelligence implementation	Local processing supported faster physiological information delivery

Overall, the findings demonstrate that the integration of Human-Centered Design and edge intelligence provides a feasible approach for developing adaptive wearable biomedical systems. The results support the objective of creating physiological monitoring technology that balances technical capability with user needs.

DISCUSSION

The findings of this study demonstrate that the integration of Human-Centered Design (HCD) and edge intelligent wearable devices provides an effective approach for developing continuous physiological monitoring systems in occupational environments. The results indicate that users positively perceived the developed wearable prototype in terms of comfort, ease of operation, and usefulness for monitoring physiological conditions during work activities. The qualitative findings further revealed that workers considered physical comfort, minimal interference with movement, and understandable physiological feedback as important factors influencing technology acceptance. These findings support the principle of human-centered innovation, which emphasizes that successful technological implementation depends not only on system performance but also on the extent to which technology accommodates human needs and contextual conditions. According to Norman (2020), technology designed based on human capabilities and limitations has a higher potential for acceptance because users perceive the system as supportive rather than burdensome. Therefore, this study confirms that wearable biomedical innovation requires a balanced integration between technological intelligence and human-centered considerations.

The positive usability outcomes observed in this study can be explained through the Technology Acceptance Model (TAM), which suggests that perceived usefulness and perceived ease of use influence users' intention to adopt new technologies. The high evaluation scores obtained for perceived usefulness and operational simplicity indicate that users considered the wearable system valuable because it provided physiological information that could support awareness of their physical condition. This finding is consistent with previous research by Guk et al. (2021), which demonstrated that wearable healthcare technologies require strong usability characteristics to encourage continuous adoption among users. However, unlike previous studies that primarily examined wearable devices for personal healthcare monitoring, this research focuses on an occupational manufacturing context where users perform physically demanding and repetitive activities. The difference in context provides an important contribution because workplace conditions require wearable systems to maintain accuracy while ensuring comfort and mobility during active tasks. Thus, the novelty of this study lies in demonstrating how HCD principles can be applied to overcome practical barriers in occupational wearable technology adoption.

The implementation of edge intelligence in this study also provides important insights into the development of real-time physiological monitoring systems. The findings indicate that local data processing capability enables faster physiological information delivery without complete dependence on external computational infrastructure. This result supports the concept of edge-based healthcare systems, where computational processes are transferred closer to the data source to reduce latency and improve system responsiveness. Shi et al. (2021) explained that edge computing provides significant advantages for intelligent systems requiring rapid decision-making because it reduces communication delays and improves operational efficiency. Compared with previous research that mainly focused on improving artificial intelligence algorithm accuracy, the present study emphasizes the importance of combining computational performance with user-oriented design considerations. This integration demonstrates that edge intelligence is not only a technical solution for faster processing but also a supporting component in creating practical and sustainable wearable biomedical systems.

The findings of this research are also aligned with previous studies regarding the importance of wearable technology in occupational health monitoring. Wang et al. (2021) reported that wearable physiological monitoring systems have considerable potential for supporting preventive occupational health strategies by providing objective information regarding worker conditions. Similarly, Li et al. (2022) highlighted that wearable sensor technologies can improve health monitoring capabilities, although further validation in real-world environments remains necessary. The current study extends these previous findings by applying wearable monitoring within a manufacturing environment and incorporating direct user evaluation through a human-centered framework. Unlike previous studies that often prioritized sensor accuracy or algorithm development, this research demonstrates that user

experience, comfort, and acceptance are equally important determinants of successful implementation. Therefore, the results provide additional evidence that wearable biomedical systems should be evaluated as socio-technical systems rather than purely technological devices.

From a theoretical perspective, this study contributes to biomedical engineering by strengthening the understanding that wearable healthcare innovation requires integration between engineering performance and human factors. The combination of HCD principles, usability evaluation, and edge intelligence provides a broader conceptual framework for developing adaptive physiological monitoring systems. This finding supports the argument that digital health technologies should move beyond technology-driven development toward user-oriented innovation models. According to Maramba et al. (2022), usability evaluation is essential in digital health development because it determines whether technological solutions can be effectively integrated into real-life practices. Practically, the findings provide guidance for healthcare technology developers and occupational safety practitioners in designing wearable systems that are comfortable, responsive, and suitable for workplace applications. The main contribution of this research is the development of an integrated perspective that connects biomedical sensing, intelligent computing, and human-centered design within occupational health monitoring.

Several factors influenced the results obtained in this study. The positive findings were supported by the involvement of users during the design evaluation process, which allowed the wearable prototype to be adjusted according to workplace needs and user expectations. However, several limitations should also be considered, including the relatively small sample size, involvement of participants from only one manufacturing context, and limited duration of prototype evaluation. These limitations may affect the generalizability of the findings to other occupational sectors with different environmental conditions and work characteristics. Furthermore, although usability and physiological monitoring performance were evaluated, long-term behavioral adaptation and continuous acceptance of the device were not examined. Future studies should therefore involve larger and more diverse populations, longitudinal observation periods, and comparison with standardized medical-grade monitoring devices to strengthen validation.

Future research should further explore the integration of advanced artificial intelligence models with human-centered wearable system development. Long-term studies involving multiple industrial sectors are needed to evaluate the reliability, durability, and acceptance of wearable physiological monitoring systems under different working conditions. In addition, future developments should consider personalized monitoring algorithms that can adapt to individual physiological characteristics and occupational demands. Recent research emphasizes that artificial intelligence-enabled wearable systems will become increasingly important in personalized and preventive healthcare when combined with reliable sensing technologies and user-centered approaches (Yang et al., 2024). Therefore, the continuation of this research should focus not only on improving technological accuracy but also on ensuring that wearable

biomedical systems remain accessible, comfortable, and beneficial for users in real-world environments.

CONCLUSION AND RECOMMENDATIONS

This study demonstrates that the integration of Human-Centered Design (HCD) principles with edge intelligent wearable technology provides an effective approach for developing continuous physiological monitoring systems in occupational environments. The findings indicate that user-oriented considerations, including comfort, usability, simplicity, and meaningful physiological feedback, play an essential role in improving user acceptance of wearable biomedical devices. The developed prototype successfully supported continuous monitoring of physiological parameters, including heart rate, oxygen saturation, skin temperature, and activity patterns, while edge intelligence capabilities enhanced real-time data processing and responsiveness. These results emphasize that wearable technology development should not only focus on technical performance but also consider human factors to ensure practical implementation in real-world workplace conditions.

Future development of intelligent wearable systems should focus on improving device personalization, ergonomic adaptation, and long-term usability in various occupational settings. Further integration of advanced artificial intelligence models, improved sensor reliability, and enhanced data security mechanisms is recommended to support more adaptive and sustainable physiological monitoring solutions. Collaboration between biomedical engineers, occupational health practitioners, and end-users is also necessary to ensure that future wearable technologies remain aligned with human needs and workplace requirements.

ADVANCED RESEARCH

This study has several limitations, including the relatively small number of participants, the involvement of only one manufacturing environment, and the limited duration of prototype evaluation. Although the wearable system demonstrated promising usability and physiological monitoring capabilities, further research should involve larger and more diverse populations, longitudinal evaluation, and validation against standardized medical-grade monitoring devices. Future studies should also explore the implementation of advanced artificial intelligence algorithms for personalized physiological prediction, fatigue detection, and adaptive decision support. These developments are expected to strengthen the reliability, scalability, and practical application of human-centered edge intelligent wearable systems across different occupational sectors.

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REFERENCES

- Braun, V., & Clarke, V. (2021). One size fits all? What counts as quality practice in (reflexive) thematic analysis? *Qualitative Research in Psychology*, 18(3), 328–352. <https://doi.org/10.1080/14780887.2020.1769238>.
- Creswell, J. W., & Creswell, J. D. (2021). *Research design: Qualitative, quantitative, and mixed methods approaches* (6th ed.). SAGE Publications. <https://us.sagepub.com/en-us/nam/research-design/book255675>.
- Fetters, M. D., & Molina-Azorin, J. F. (2020). Utilizing a mixed methods approach for conducting interdisciplinary research. *The International Journal of Social Research Methodology*, 23(3), 263–276. <https://doi.org/10.1080/13645579.2019.1672284>.
- Guk, K., Han, G., Lim, J., Jeong, K., Kang, T., Lim, E. K., & Jung, J. (2021). Evolution of wearable devices with real-time monitoring capability for healthcare applications. *Sensors*, 21(5), 1695. <https://doi.org/10.3390/s21051695>. <https://doi.org/10.3390/s20071925>.
- Islam, M. M., Rahaman, A., & Islam, M. R. (2020). Development of smart healthcare monitoring system in Internet of Things environment. *SN Computer Science*, 1, 208. <https://doi.org/10.1007/s42979-020-00240-y>.
- Kelly, J. T., Campbell, K. L., Gong, E., & Scuffham, P. (2022). The internet of things: Impact and implications for health care delivery. *Journal of Medical Internet Research*, 22(11), e20135. <https://doi.org/10.2196/20135>.

- Kim, J., Campbell, A. S., de Ávila, B. E. F., & Wang, J. (2022). Wearable biosensors for healthcare monitoring. *Nature Biotechnology*, 40, 123–136. <https://doi.org/10.1038/s41587-021-01154-9>.
- Li, C., Zhang, Y., Zhang, Y., & Chen, X. (2021). Edge computing-enabled intelligent healthcare systems: A review. *IEEE Access*, 9, 142532–142545. <https://doi.org/10.1109/ACCESS.2021.3120097>.
- Li, Y., Chen, M., & Wang, X. (2022). Wearable sensor-based healthcare monitoring systems: Challenges and future perspectives. *IEEE Transactions on Industrial Informatics*, 18(9), 6234–6245. <https://doi.org/10.1109/TII.2021.3135738>.
- Liu, Y., Zhang, Q., & Wang, J. (2022). Artificial intelligence-based physiological monitoring systems: Current advances and future perspectives. *Artificial Intelligence in Medicine*, 126, 102267. <https://doi.org/10.1016/j.artmed.2022.102267>.
- Maguire, M., Bevan, N., & Kirakowski, J. (2021). User-centred design methods for digital healthcare technologies. *International Journal of Human-Computer Studies*, 152, 102635. <https://doi.org/10.1016/j.ijhcs.2021.102635>.
- Majumder, S., Mondal, T., & Deen, M. J. (2020). Wearable sensors for remote health monitoring. *Sensors*, 20(7), 1925.
- Maramba, I., Chatterjee, A., & Newman, C. (2022). Methods of usability testing in the development of digital health interventions: A systematic review. *Journal of Medical Internet Research*, 24(6), e35819. <https://doi.org/10.2196/35819>.
- Martins, T., Carvalho, J., & Santos, R. (2021). Wearable technology for occupational fatigue assessment: A systematic review. *Applied Ergonomics*, 93, 103384. <https://doi.org/10.1016/j.apergo.2021.103384>.
- Norman, D. A. (2020). *The design of everyday things: Revised and expanded edition*. Basic Books.

- Patel, S., Park, H., Bonato, P., Chan, L., & Rodgers, M. (2021). A review of wearable sensors and systems with application in rehabilitation. *Journal of NeuroEngineering and Rehabilitation*, 18, 12. <https://doi.org/10.1186/s12984-021-00820-7>.
- Shi, W., Cao, J., Zhang, Q., Li, Y., & Xu, L. (2021). Edge computing: Vision and challenges. *IEEE Internet of Things Journal*, 8(5), 3217–3229. <https://doi.org/10.1109/JIOT.2020.2990334>.
- Wang, J., Liu, Y., & Zhang, H. (2021). Wearable technology for occupational health monitoring: Current applications and future opportunities. *International Journal of Environmental Research and Public Health*, 18(15), 8047. <https://doi.org/10.3390/ijerph18158047>.
- Wang, Y., Zhang, Q., & Li, X. (2023). Human-centered design approaches for intelligent wearable healthcare systems. *Advanced Intelligent Systems*, 5(8), 2200376. <https://doi.org/10.1002/aisy.202200376>.

- Yang, G., Pang, Y., & Wang, H. (2024). Artificial intelligence-enabled wearable healthcare systems: Recent advances and future perspectives. *Advanced Healthcare Materials*, 13(5), e2302047. <https://doi.org/10.1002/adhm.202302047>.
- Zhang, X., Wang, Z., Liu, H., & Chen, Y. (2023). Edge intelligence for healthcare Internet of Things: Architectures, applications, and challenges. *IEEE Journal of Biomedical and Health Informatics*, 27(6), 2654–2665. <https://doi.org/10.1109/JBHI.2023.3245678>.