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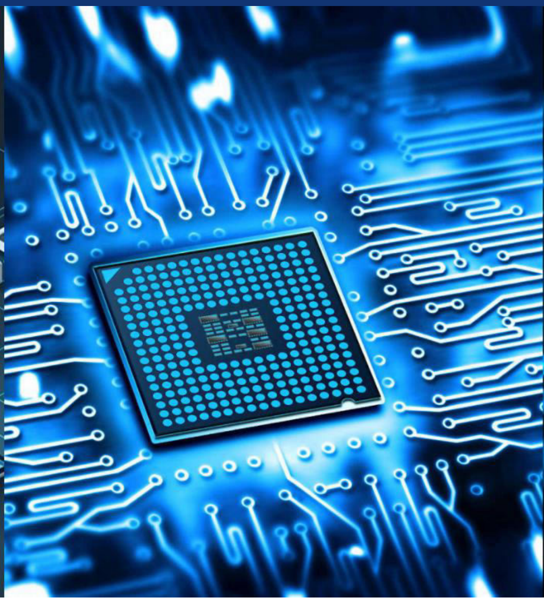

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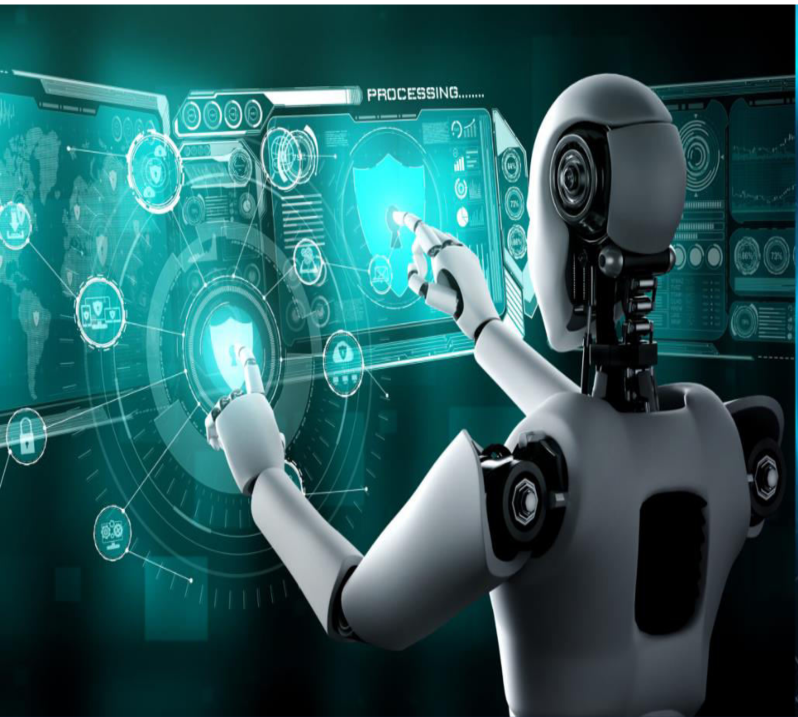

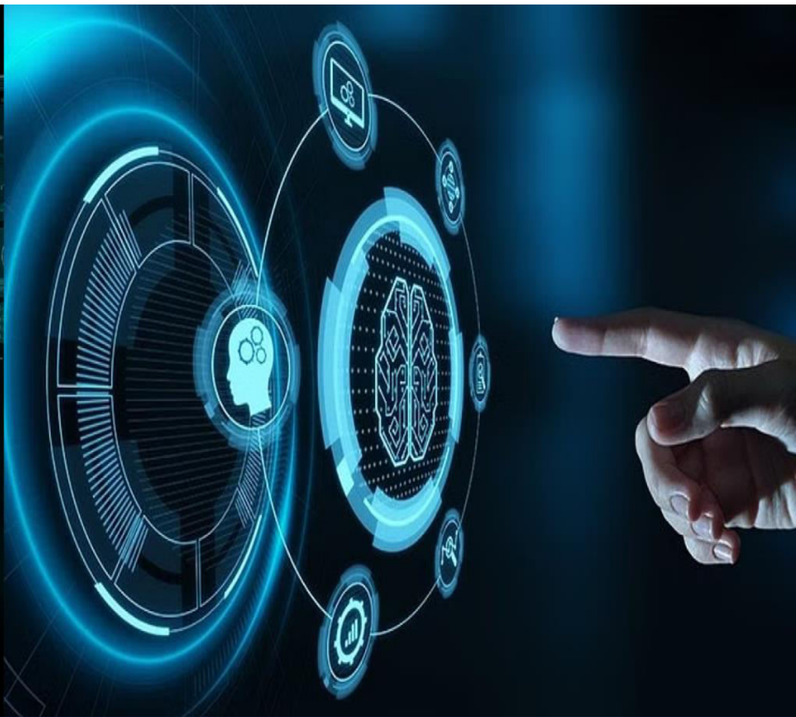

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AI-Enabled Wearable Menstrual Health Monitoring System with Closed-Loop Biofeedback and Emotional Intelligence

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ABSTRACT: Wearable healthcare technologies are transforming personal health monitoring; however, existing menstrual health solutions largely depend on manual inputs and lack real-time physiological analysis and adaptive intervention. This paper presents an AI-enabled wearable menstrual health monitoring system with closed-loop biofeedback and emotional intelligence for continuous and personalized healthcare support. The proposed system captures physiological signals, including Heart Rate Variability (HRV), Electrodermal Activity (EDA), and skin temperature, using integrated wearable sensors. These signals are processed through artificial intelligence algorithms to assess stress levels, pain intensity, and emotional states in real time. Based on the analysis, the system delivers adaptive therapy using vibration and thermal modules through a closed-loop biofeedback mechanism for effective pain management. Additionally, an emotional intelligence-based chatbot provides psychological support to help users manage stress and anxiety during the menstrual cycle. The system also performs long-term data analysis to identify menstrual patterns and detect irregularities for early diagnosis of potential hormonal imbalances. Experimental results indicate that the proposed system enhances monitoring accuracy, enables real-time intervention, and provides a comprehensive platform integrating sensing, analysis, therapy, and emotional support, thereby improving both physical comfort and emotional well-being.

KEYWORDS: Wearable healthcare, menstrual health monitoring, artificial intelligence, biofeedback system, HRV, EDA, closed-loop therapy, emotional intelligence, IoT, smart healthcare

I. INTRODUCTION

Menstrual health is a vital component of women's overall well-being, yet it remains inadequately addressed in current healthcare systems due to limited real-time monitoring and lack of personalized intervention strategies. Many individuals experience a range of physiological and psychological symptoms during the menstrual cycle, including pain, stress, mood fluctuations, and hormonal imbalances. Conventional approaches for menstrual health management primarily rely on self-reporting through mobile applications or manual tracking methods, which are often subjective, inconsistent, and incapable of capturing real-time physiological changes. This creates a significant gap in providing timely and effective healthcare support.

With the rapid advancement of wearable healthcare technologies and artificial intelligence (AI), there is a growing opportunity to develop intelligent systems capable of continuous health monitoring and adaptive intervention. Wearable devices equipped with physiological sensors can capture real-time biosignals such as Heart Rate Variability (HRV), Electrodermal Activity (EDA), and skin temperature, which are closely associated with stress levels, pain perception, and emotional states. However, most existing wearable systems focus primarily on data collection and lack integrated mechanisms for real-time analysis, feedback, and therapeutic response.

To address these limitations, this paper proposes an AI-enabled wearable menstrual health monitoring system with closed-loop biofeedback and emotional intelligence. The proposed system continuously acquires physiological signals and utilizes AI-based algorithms to analyze and interpret the user's physical and emotional conditions in real time.

Based on this analysis, the system delivers personalized therapy through vibration and heat modules, forming a closed-loop biofeedback mechanism that dynamically adjusts treatment according to the user's condition. Furthermore, an emotional intelligence-based chatbot is incorporated to provide psychological support, helping users manage stress and anxiety during different phases of the menstrual cycle.

In addition to real-time monitoring and intervention, the system performs long-term data analysis to identify menstrual patterns and detect abnormalities, enabling early detection of potential health issues. By integrating sensing, intelligent analysis, adaptive therapy, and emotional support into a unified platform, the proposed system aims to provide a comprehensive and user-centric solution for menstrual health management.

The main contributions of this work are as follows: (i) development of a multimodal wearable system for continuous physiological monitoring, (ii) implementation of AI-based real-time emotional and pain assessment, (iii) design of a closed-loop biofeedback mechanism for adaptive therapy, and (iv) integration of an emotional intelligence chatbot for enhanced user support. The proposed approach significantly improves the effectiveness, reliability, and user experience of menstrual health management systems.

II. RELATED WORK

Recent advancements in wearable healthcare systems and artificial intelligence have significantly contributed to real-time physiological monitoring and personalized healthcare solutions. Several researchers have explored the integration of wearable sensors, AI algorithms, and menstrual health tracking systems.

Hirayama et al. (2025) proposed a wearable-based approach for detecting menstrual pain using biometric signals collected from wristwatch devices. Their study demonstrated that physiological parameters can effectively identify pain conditions; however, the system was limited to detection and did not provide real-time therapeutic intervention.

Liu et al. (2024) presented a comprehensive review of wearable sensors and AI techniques for health monitoring, particularly in maternal and reproductive healthcare. Their work highlighted the importance of multimodal physiological sensing and AI-driven analysis but emphasized the need for integrated systems capable of adaptive feedback and personalized care.

Zainab et al. (2024) investigated the integration of artificial intelligence with wearable devices for continuous health monitoring. Their study demonstrated that AI-based systems can improve diagnostic accuracy and enable real-time monitoring; however, their work primarily focused on cardiovascular health and lacked emotional or hormonal context-specific applications.

A systematic review on menstrual health monitoring using wearable technologies reported that physiological parameters such as heart rate, heart rate variability (HRV), and skin temperature vary significantly across different phases of the menstrual cycle. However, most existing systems rely on passive monitoring without incorporating intelligent feedback or intervention mechanisms.

Further studies on HRV-based monitoring indicate that heart rate variability is a reliable indicator of autonomic nervous system activity and stress levels, which fluctuate during the menstrual cycle. Despite advancements in wearable-based HRV measurement, challenges remain in ensuring accuracy under real-world conditions and integrating these insights into actionable healthcare solutions.

Recent research by **Rajesh (2025)** introduced an AI-powered menstrual cycle prediction system using multimodal biosensing and federated learning. While the approach improved prediction accuracy and ensured privacy, it primarily focused on prediction rather than real-time intervention or emotional regulation.

Similarly, **Rajadhyaksha and Koli (2025)** proposed a multimodal wearable biosensor framework incorporating hormone monitoring and physiological signals for menstrual cycle prediction in PCOS patients. Although the system enhanced prediction capabilities, it lacked closed-loop biofeedback and real-time therapeutic support.

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In addition, studies on stress monitoring using wearable sensors have shown that combining physiological signals such as HRV and electrodermal activity (EDA) with machine learning models can effectively predict stress levels in real-world environments. However, these systems typically do not include adaptive intervention mechanisms or domain-specific applications such as menstrual health management.

III. EXISTING SYSTEM

Existing menstrual health monitoring systems primarily rely on mobile applications, wearable devices, and basic physiological tracking technologies. These systems have contributed significantly to understanding menstrual cycles; however, they still exhibit several limitations in terms of real-time intelligence, adaptability, and therapeutic support.

Traditional menstrual tracking applications depend heavily on manual input of symptoms and cycle dates, which often leads to inaccurate predictions due to subjective reporting and irregular user engagement. To overcome this, recent research has focused on integrating wearable sensors for continuous physiological monitoring.

Jasinski et al. (2024) demonstrated that wearable devices can capture variations in physiological parameters such as heart rate, skin temperature, and respiratory rate across menstrual cycle phases. Their work highlighted the capability of wearables to detect cycle-related physiological changes, but the system was limited to data analysis without real-time intervention.

Similarly, Sides et al. (2023) analyzed physiological signals including heart rate, inter-beat intervals, and electrodermal activity (EDA) using wearable sensors. Their study showed that these signals exhibit periodic patterns corresponding to menstrual phases and can be used for prediction models. However, the system primarily focused on signal analysis and prediction rather than personalized healthcare support.

In another study, Hirayama et al. (2025) proposed a wearable-based system to detect menstrual pain using biometric signals obtained from wristwatch devices. Although the approach demonstrated the feasibility of objective pain detection, it relied on limited datasets and lacked adaptive feedback or therapeutic mechanisms.

Earlier work on wearable technologies for menstrual cycle tracking showed that parameters such as heart rate variability (HRV), skin temperature, and respiratory rate can be used to predict fertile windows with high accuracy. For instance, a study using wearable bracelets achieved nearly 90% accuracy in detecting fertile phases using machine learning techniques. However, these systems mainly focused on prediction rather than real-time emotional or pain management.

Recent reviews on digital health tools indicate that wearable devices such as smartwatches and rings can estimate HRV and other physiological parameters with high accuracy, making them suitable for long-term monitoring. Nevertheless, these systems often operate as standalone monitoring tools without integration of intelligent decision-making or intervention strategies

IV. PROPOSED SYSTEM

The proposed system presents an AI-enabled wearable menstrual health monitoring framework integrated with closed-loop biofeedback and emotional intelligence to provide continuous, real-time, and personalized healthcare support. The system is designed to overcome the limitations of conventional menstrual health solutions by incorporating intelligent sensing, adaptive intervention, and psychological assistance within a unified architecture.

The system consists of four primary components, namely the physiological sensing unit, AI-based data processing and analysis unit, closed-loop biofeedback control unit, and emotional intelligence support module. The physiological sensing unit employs wearable sensors to continuously acquire key biosignals such as Heart Rate Variability (HRV), Electrodermal Activity (EDA), and skin temperature. These parameters are closely associated with autonomic nervous system activity, emotional arousal, and hormonal variations during the menstrual cycle. The collected data is transmitted in real time to the processing unit using low-power wireless communication protocols, ensuring efficient and uninterrupted monitoring.

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The acquired physiological signals are subjected to preprocessing techniques, including noise filtering and artifact removal, to enhance signal quality. Subsequently, feature extraction methods are applied to obtain relevant statistical and temporal features from the raw data. These features are then analyzed using artificial intelligence algorithms, such as machine learning or deep learning models, to classify the user's physiological and emotional state. The system is capable of identifying stress levels, pain intensity, and emotional conditions with high accuracy through real-time inference, enabling timely detection of abnormal patterns.

Based on the analytical outcomes, the closed-loop biofeedback control unit generates appropriate therapeutic responses. The system incorporates vibration and thermal actuation modules to provide non-invasive pain relief and comfort. The feedback mechanism continuously adjusts the intensity and duration of therapy in response to dynamic physiological changes, thereby forming a closed-loop system that ensures personalized and adaptive treatment. This real-time feedback significantly enhances the effectiveness of intervention compared to static or manual approaches.

In addition to physical health management, the proposed system integrates an emotional intelligence-based chatbot to support psychological well-being. The chatbot utilizes natural language processing techniques to interact with users, providing emotional reassurance, stress management guidance, and coping strategies during different phases of the menstrual cycle. This module enhances user engagement and addresses mental health aspects that are often neglected in existing systems.

Furthermore, the system performs long-term data storage and analysis to identify menstrual cycle patterns and detect irregularities. By leveraging historical data, the system can predict future cycle phases and provide early warnings for potential hormonal imbalances or health issues. This predictive capability enables proactive healthcare management and informed decision-making.

Overall, the proposed system offers a comprehensive and intelligent solution by integrating multimodal sensing, AI-driven analysis, adaptive biofeedback therapy, and emotional support within a single platform. The system significantly improves monitoring accuracy, enables real-time intervention, and enhances user experience, thereby providing an effective and holistic approach to menstrual health management.

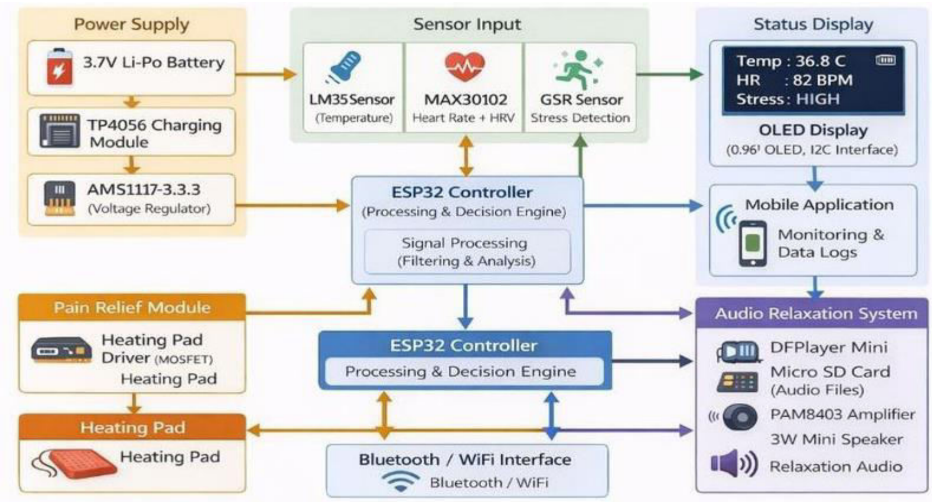

Fig 1 – Block Diagram

Proposed algorithm

The proposed algorithm is designed to perform real-time acquisition, analysis, and adaptive regulation of physiological and emotional states using an AI-enabled closed-loop biofeedback mechanism. The algorithm integrates multimodal sensor data processing, machine learning-based classification, and dynamic therapeutic control to ensure personalized menstrual health management.

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The overall workflow of the algorithm consists of signal acquisition, preprocessing, feature extraction, state classification, and adaptive feedback generation. Initially, physiological signals such as Heart Rate Variability (HRV), Electrodermal Activity (EDA), and skin temperature are continuously acquired from wearable sensors. The collected raw signals are then preprocessed to remove noise and motion artifacts using appropriate filtering techniques.

Following preprocessing, relevant features are extracted from the signals, including time-domain and frequency-domain parameters for HRV, conductance levels for EDA, and temperature variations. These extracted features are then fed into a trained artificial intelligence model, which classifies the user's condition in terms of stress level, pain intensity, and emotional state.

Based on the classification results, the system dynamically determines the appropriate therapeutic response. The closed-loop biofeedback mechanism activates vibration and thermal modules with optimized intensity and duration. The system continuously monitors the user's response through sensor feedback and updates the therapy parameters accordingly, ensuring adaptive and effective intervention. Additionally, the emotional intelligence module interacts with the user through a chatbot interface to provide psychological support and stress management guidance.
The detailed steps of the proposed algorithm are presented as follows:

Algorithm 1: AI-Based Emotional and Pain Regulation Using Closed-Loop Biofeedback
Input: Physiological signals (HRV, EDA, Skin Temperature)
Output: Adaptive therapy control (Vibration, Heat) and emotional support
Step 1: Initialize wearable sensors and establish communication with processing unit.
Step 2: Continuously acquire physiological signals (HRV, EDA, Temperature).
Step 3: Preprocess the acquired signals using noise filtering and artifact removal techniques.
Step 4: Extract relevant features from each signal:

- HRV → time-domain and frequency-domain features
- EDA → skin conductance level and response
- Temperature → baseline variation

Step 5: Input extracted features into the trained AI model.
Step 6: Classify the user's condition into:
(a) Stress level (Low / Medium / High)
(b) Pain intensity
(c) Emotional state
Step 7: Evaluate the classification output and determine the required intervention.
Step 8: Activate biofeedback modules:
(a) Apply vibration therapy for pain relief
(b) Apply thermal therapy for muscle relaxation
Step 9: Monitor real-time feedback from sensors after therapy activation.
Step 10: Adjust therapy parameters (intensity, duration) dynamically based on feedback (Closed-loop control).
Step 11: Activate emotional intelligence chatbot to provide psychological support if stress level exceeds threshold.
Step 12: Store physiological and response data for long-term analysis and pattern prediction.
Step 13: Repeat Steps 2–12 continuously for real-time monitoring and adaptive regulation

V. RESULT AND DISCUSSION

The proposed system demonstrates significantly improved performance when compared to traditional menstrual health monitoring solutions. One of the major advantages observed is the ability to perform continuous physiological monitoring, which provides accurate and real-time data without relying on manual user input. This reduces errors, inconsistencies, and delays associated with conventional tracking methods. The integration of wearable sensors ensures that important parameters such as Heart Rate Variability (HRV), Electrodermal Activity (EDA), and skin temperature are captured continuously, enabling precise assessment of the user's physical and emotional condition.

The implementation of a closed-loop biofeedback mechanism plays a crucial role in enhancing the effectiveness of the system. Unlike traditional open-loop devices, the proposed system dynamically adjusts therapy based on real-time physiological responses. This ensures that the therapy provided is neither insufficient nor excessive, resulting in improved pain management and increased user comfort. The adaptive nature of vibration and heat-based therapy contributes to more efficient and personalized treatment outcomes.

The incorporation of artificial intelligence further strengthens the system by enabling accurate classification of stress levels, pain intensity, and emotional states. Machine learning algorithms analyze both real-time and historical data to detect patterns and predict potential health conditions. This capability allows the system to identify irregular menstrual cycles and early signs of hormonal imbalance, thereby supporting preventive healthcare. Over time, the AI model improves its performance by learning individual user patterns, making the system more personalized and reliable.

In addition to physical health monitoring, the emotional intelligence chatbot significantly enhances user engagement and overall experience. The chatbot provides real-time psychological support, offering relaxation techniques, motivational messages, and stress management guidance. This feature addresses the often-neglected emotional aspect of menstrual health, contributing to holistic well-being.

Furthermore, long-term data analysis enables users to track trends and gain insights into their menstrual health patterns. This helps in better understanding of cycle irregularities and supports timely medical consultation when necessary. The integration of mobile application interfaces ensures easy access to data visualization, alerts, and system interaction, improving usability and convenience.

Overall, the proposed system improves the accuracy of health monitoring, enhances the effectiveness of therapy through adaptive control, and provides a comprehensive user experience by combining physical and emotional support. The results indicate that the system is efficient, reliable, and capable of delivering a smart and personalized healthcare solution for menstrual health management.

VI. CONCLUSION AND FUTURE WORK

The proposed AI-based wearable menstrual health monitoring system presents a comprehensive and innovative solution by integrating real-time physiological monitoring, intelligent data analysis, adaptive therapy, and emotional support into a single platform. By utilizing wearable sensors to continuously track parameters such as Heart Rate Variability (HRV), Electrodermal Activity (EDA), and skin temperature, the system ensures accurate and reliable health assessment. The incorporation of artificial intelligence enables effective classification of stress, pain, and emotional states, allowing the system to provide personalized and timely interventions. The closed-loop biofeedback mechanism further enhances the system by dynamically adjusting therapy based on real-time physiological responses, ensuring optimal pain management and user comfort. Additionally, the inclusion of an emotional intelligence chatbot addresses the psychological aspects of menstrual health, offering guidance and support to improve overall well-being. Compared to existing solutions, the proposed system overcomes key limitations such as dependency on manual input, lack of real-time monitoring, and absence of adaptive therapy, thereby delivering a more efficient, reliable, and user-centric healthcare solution.

Future work can focus on enhancing the system's performance and expanding its capabilities. Improvements in sensor technology can increase accuracy and reliability under different environmental and usage conditions. Expanding the dataset used for training AI models will enable more accurate predictions and better personalization for diverse user groups. Integration of cloud-based analytics can facilitate large-scale data processing, advanced pattern recognition, and remote healthcare monitoring. Furthermore, the system can be extended to monitor additional health conditions such as stress disorders, cardiovascular health, and general wellness, making it a versatile and scalable smart healthcare solution for broader applications.

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