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Morphee: The Smart Sleeping Mask

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Abstract: Sleep disorders and poor sleep quality have become common health concerns due to increased screen exposure, academic stress, irregular work schedules, and modern lifestyle habits. Inadequate sleep negatively affects physical health, mental well-being, concentration, and productivity. Conventional sleep aids such as basic eye masks or medication-based solutions provide limited effectiveness and may introduce discomfort or side effects. This paper presents **Marphee: The Smart Sleeping Mask**, a wearable and non-invasive sleep assistance system designed to enhance sleep quality through intelligent sensing and comfort-oriented features. The proposed system focuses on reducing external disturbances, promoting relaxation, and supporting natural sleep cycles without pharmaceutical intervention. By integrating smart wearable technology with user-friendly design, Marphee offers a safe, portable, and effective solution for individuals experiencing sleep-related difficulties. The system aims to improve overall sleep efficiency, mental relaxation, and daily performance, making it suitable for students, professionals, and individuals affected by sleep irregularities.

Keywords: Smart Wearable, Sleep Monitoring, Sleep Quality Improvement, Smart Sleeping Mask, Health Technology

I. INTRODUCTION

Sleep is a vital biological process essential for maintaining physical health, emotional balance, and cognitive performance. However, modern lifestyles characterized by prolonged screen usage, irregular routines, stress, and exposure to artificial lighting have led to a significant rise in sleep-related problems such as insomnia, delayed sleep onset, and frequent sleep interruptions. These issues are particularly prevalent among students and working professionals. Existing sleep solutions, including traditional sleeping masks and medicinal sleep aids, suffer from several limitations. Basic eye masks provide only passive light blocking and lack intelligence, while medication-based approaches may result in dependency and adverse side effects. As a result, there is a growing demand for a non-invasive, technology-driven, and user-friendly sleep assistance system.

Morphee: The Smart Sleeping Mask is proposed as an innovative wearable solution that combines comfort with intelligent functionality to assist users in achieving improved sleep quality. The system is designed to support relaxation, reduce environmental disturbances, and encourage healthier sleep patterns through smart features, making it a practical alternative to conventional sleep aids.

II. PROBLEM STATEMENT AND OBJECTIVE

In recent years, the prevalence of sleep-related disorders has increased significantly due to modern lifestyle factors such as excessive screen exposure, academic and professional stress, irregular sleep schedules, and continuous exposure to artificial lighting. Poor sleep quality can lead to fatigue, reduced concentration, mental stress, and long-term health complications.

Existing sleep aids, including conventional eye masks and medication-based solutions, present notable limitations. Traditional sleeping masks only provide passive light blocking and lack intelligence or adaptability to individual sleep patterns. Pharmaceutical sleep aids, while effective in some cases, may cause dependency, side effects, and are not suitable for prolonged use. Furthermore, many available smart sleep devices are expensive, complex, or uncomfortable for daily use.

Hence, there is a clear need for a **safe, affordable, non-invasive, and user-friendly smart sleep assistance system** that can improve sleep quality without relying on medication and without causing discomfort to the user.

Key objectives of MedGuard Edge:

- To design a comfortable and wearable smart sleeping mask suitable for prolonged use.
- To reduce the impact of external light and environmental disturbances during sleep.
- To promote relaxation and faster sleep onset using non-invasive techniques.
- To support natural sleep cycles without the use of medication.

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- To provide an affordable and portable sleep solution for students, professionals, and individuals with irregular sleep patterns.
- To demonstrate the effectiveness of wearable health technology in improving sleep quality and overall wellbeing.

III. SCOPE

The scope of Marphee: The Smart Sleeping Mask is centered on the design and development of a smart, wearable, and non-invasive sleep assistance system that aims to improve sleep quality and overall user comfort. The project addresses common sleep-related issues caused by stress, prolonged screen exposure, irregular sleep schedules, and environmental light disturbances. The proposed system focuses on providing a comfortable and portable solution that supports relaxation and encourages natural sleep cycles without the use of medication. Marphee is intended for daily use by students, working professionals, and individuals experiencing mild sleep irregularities. The scope of this project is limited to sleep assistance and comfort enhancement and does not involve medical diagnosis or treatment of clinical sleep disorders. Future extensions of the system may include advanced sleep pattern analysis, mobile application integration, and personalized feedback mechanisms to further enhance sleep quality and user experience.

IV. LITERATURE REVIEW

[1] de Zambotti et al. (2021) proposed an RNN-based sleep stage classification system using single-channel wearable EEG data. The model achieved 82% accuracy and demonstrated the feasibility of edge-based sleep analysis without cloud dependency. However, motion artifacts and battery consumption were identified as key limitations.

[2] Walch et al. (2019) presented a federated learning–based sleep analysis system using accelerometer and PPG data from consumer wearables. Their Random Forest model achieved 79% accuracy while preserving user privacy and improving battery efficiency. However, the approach required smartphone coordination and lacked real-time sleep intervention capabilities.

[3] Ko et al. (2022) proposed a multi-modal sleep monitoring system using sensor fusion of temperature, SpO_2, and motion with a CNN-LSTM framework. The approach achieved 86% accuracy, outperforming single-sensor models through high-confidence prediction validation. However, high computational requirements limited deployment on lightweight wearable devices.

[4] Zhang et al. (2020) introduced an edge-optimized TinyML architecture for sleep quality prediction, achieving a 65% reduction in latency on low-power wearable devices. However, the approach increased system complexity due to sensor synchronization and calibration requirements.

[5] Supratak et al. (2022) proposed a low-latency sleep stage detection model using attention networks on heart rate and motion data, achieving 300 ms real-time inference on smartwatches. However, reliance on continuous Bluetooth connectivity reduced reliability during overnight use.

[6] Sano et al. (2021) presented a lightweight KNN-based stress detection model with reduced memory usage, but it lacked comprehensive overnight sleep health monitoring.

[7] Perez-Pozuelo et al. (2020) developed large-scale wearable sleep profiling using gradient boosting on consumer data, enabling privacy-preserving population analysis but not individualized sleep intervention.

[8] Radin et al. (2021) improved sleep monitoring reliability under motion artifacts using ensemble methods, though continuous validation increased processing overhead during long sessions.

[9] Tu et al. (2019) proposed differential privacy–based sleep analysis on wearables, ensuring data confidentiality but incurring computational overhead unsuitable for battery-constrained devices.

[10] Scott et al. (2023) surveyed blockchain-enabled federated learning for IoT and highlighted gaps in offline operation, real-time control, and adaptive intervention, motivating the design of Morphee's ASI architecture.

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4.1 Gaps or Areas for Improvement

Despite significant advancements in wearable-based sleep monitoring and analysis systems, several limitations remain unaddressed in existing research. Many proposed solutions rely heavily on cloud connectivity or continuous smartphone coordination, which reduces reliability during offline or overnight use. Battery constraints and computational overhead further limit the feasibility of deploying complex deep learning models directly on lightweight wearable devices such as sleep masks. Additionally, most existing systems focus primarily on sleep stage classification or population-level analysis, offering limited real-time, individualized intervention within the user's sleeping environment.

Privacy-preserving approaches, while effective in protecting user data, often introduce latency and processing overhead that hinder real-time responsiveness. Furthermore, current architectures lack integrated mechanisms for dual validation, adaptive sleep assistance, and immediate corrective actions during poor sleep conditions. There is also minimal emphasis on combining comfort-oriented wearable design with intelligent edge-based decision-making, particularly for non-wrist wearable formats. These gaps highlight the need for a fully offline-capable, low-power, adaptive, and user-centric smart sleep system—motivating the development of Marphee: The Smart Sleeping Mask.

V. SYSTEM ARCHITECTURE

The system architecture of Marphee: The Smart Sleeping Mask is designed as a compact, low-power, and privacypreserving wearable framework that provides real-time sleep assistance through edge-based intelligence. The architecture comprises four primary layers: the sensing layer, processing layer, decision and control layer, and user feedback layer. This layered design ensures modularity, scalability, and efficient resource utilization while maintaining user comfort and uninterrupted sleep monitoring.

The sensing layer includes integrated sensors embedded within the sleeping mask to capture sleep-related parameters such as ambient light intensity, head movement, and physiological indicators associated with relaxation and sleep quality. These sensors continuously acquire data in a non-intrusive manner, ensuring minimal discomfort during prolonged use. The collected raw sensor data is preprocessed locally to remove noise, normalize values, and reduce redundancy, thereby improving analysis accuracy and reducing computational overhead.

The processing layer consists of an embedded low-power microcontroller capable of executing lightweight sleep analysis algorithms. This unit performs feature extraction and evaluates sleep states using optimized edge-friendly models, enabling real-time inference without reliance on cloud services or smartphone connectivity. By keeping all computation on-device, the architecture ensures data privacy, low latency, and reliable operation throughout the night, even in offline conditions.

The decision and control layer interprets the analyzed sleep patterns and determines appropriate adaptive actions. Based on detected sleep states or disturbances, the system can initiate controlled feedback mechanisms designed to promote relaxation and stabilize sleep cycles. This layer emphasizes adaptive behavior while avoiding abrupt or disruptive interventions, thereby maintaining user comfort.

The user feedback layer provides gentle, non-invasive cues through integrated feedback components within the mask. These cues are designed to support relaxation rather than wake the user. Additionally, power management modules regulate energy consumption to ensure uninterrupted overnight operation. The architecture is designed to be extensible, allowing future enhancements such as advanced sleep analytics, personalized sleep profiles, and optional post-sleep data visualization while preserving the core goals of comfort, privacy, and real-time sleep assistance.

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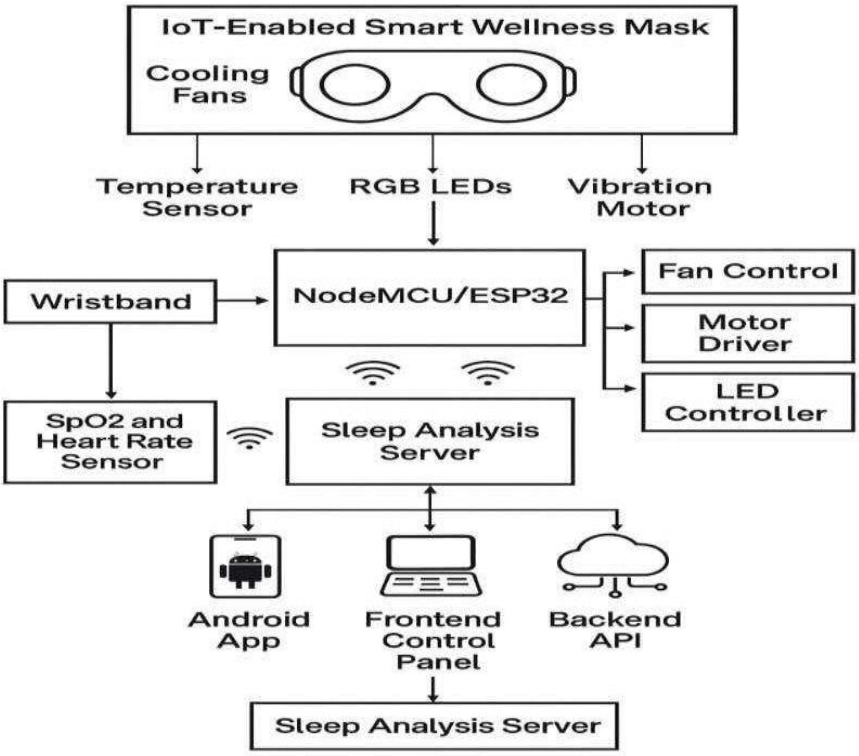

Figure 1: System architecture of *Marphee: The Smart Sleeping Mask* illustrating the integration of embedded sensors, edge-based processing, and adaptive feedback mechanisms for real-time, privacy-preserving sleep assistance without cloud dependency.

VI. METHODOLOGY

The Marphee Smart Sleeping Mask employs an edge-based wearable methodology integrating intelligent sensing, local data processing, and adaptive feedback to support real-time sleep assistance. All analysis is performed on-device to ensure privacy, low latency, and uninterrupted overnight operation.

6.1 IOT Data Gathering

The IoT data gathering module continuously collects sleep-related parameters such as ambient light levels, motion activity, and physiological indicators using sensors embedded within the smart sleeping mask. The acquired data is processed locally to support real-time sleep analysis while preserving user privacy.

6.2 Preprocessing Local Data

Each IoT device performs on-device preprocessing, which involves cleaning the collected data, normalizing it to a standard format, and handling missing or inconsistent values locally. By reducing pointless data transfer, this method lowers communication overhead while simultaneously increasing model training accuracy.

Timestamp	SpO_2	Pulse	Temp	Humi
19-11-2025 14:17	92.44	82	27	59
19-11-2025 14:17	100	85	27	59
19-11-2025 14:17	93.47	85	27	59
19-11-2025 14:17	93.29	89	27	59
19-11-2025 14:17	91.32	82	27	59

Table 1: Sample sensor log readings

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6.3 Device Cluster Formation

To improve scalability and reduce latency, IoT gadgets are logically arranged into clusters according to standards such gadget type, data similarity, or geographic proximity. Under the direction of a cluster head who oversees local data gathering and model training within the group, each cluster functions somewhat independently. This clustered federated learning approach boosts bandwidth efficiency and accelerates convergence by localizing intensive communication.

Cluster	O_2	Pulse	Temp	Humi
1	92.84	88.12	27.00	59.00
2	87.17	76.38	24.99	55.03
3	93.20	72.80	27.00	59.00

Table 2: Cluster summary statistics

6.4 Training Local Models

Within each device cluster, individual IoT devices are used to directly train local machine learning models using their respective pre-processed datasets. Importantly, patient raw data remain secure on the devices. The models capture vital data patterns and insights unique to each patient's profile. After training, these devices transmit only model modifications to the cluster head for secure aggregation.

6.5 Local Sleep State Integration

The locally processed sensor features are integrated to determine the user's current sleep state in real time. This on-device integration avoids external data transmission, reducing latency while ensuring personalized and privacy-preserving sleep assessment.

6.6 On-Device Validation and Decision Logic

Sleep state predictions are validated using threshold-based and rule-driven logic embedded within the device firmware. This ensures consistent and reliable decision-making without reliance on cloud or external verification mechanisms.

6.7 Local Secure Data Storage

Processed sleep data and short-term summaries are stored securely within the device's local memory for temporary analysis and diagnostics. This approach ensures data availability while eliminating risks associated with centralized or cloud-based storage.

6.8 Disturbance Detection and Sleep Stability Monitoring

The system continuously monitors motion patterns and environmental changes to detect sleep disturbances. When abnormal activity is identified, corrective measures are triggered to stabilize sleep without causing user disruption.

6.9 Adaptive Response and Safe Recovery

Upon repeated disturbances or abnormal patterns, the system adjusts feedback intensity or enters a low-activity stabilization mode to preserve sleep continuity. This controlled recovery mechanism prevents discomfort, conserves power, and ensures safe overnight operation.

6.10 Dashboard for Monitoring and Visualization

A lightweight monitoring dashboard provides post-sleep visualization of sleep duration, disturbance patterns, and overall sleep quality. The dashboard enables users to review sleep insights in a clear and intuitive format without requiring continuous real-time connectivity.

VII. IMPLEMENATION ENVIRONMENT

The implementation environment of **Marphee: The Smart Sleeping Mask** consists of a combination of wearable hardware components and lightweight software modules designed for low-power, real-time sleep assistance. The hardware platform includes an embedded microcontroller suitable for wearable applications, integrated with sensors for detecting ambient light levels, motion activity, and physiological indicators related to sleep quality. These components are selected to ensure minimal power consumption, compact size, and user comfort during extended overnight use.

On the software side, the system is developed using embedded C/C++ for firmware-level control, sensor interfacing, and real-time processing. Lightweight algorithms are employed to analyze sleep-related data locally on the device,

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eliminating the need for cloud connectivity and preserving user privacy. Power management routines are incorporated to support continuous operation throughout the night. Optional post-sleep data visualization can be accessed through a lightweight dashboard or companion application, providing users with insights while maintaining the system's core offline functionality.

The hardware prototype of **Marphee: The Smart Sleeping Mask** consists of a compact enclosure housing a small cooling fan and integrated LED components. The fan provides gentle airflow to enhance user comfort and relaxation, while the LEDs support controlled light-based feedback. An embedded microcontroller unit is connected externally for sensor interfacing, processing, and power management, enabling real-time operation of the smart sleep assistance features.

Figure 4: Hardware prototype showing Mask, ESP8266 NodeMCU Board

VIII. MODULES

8.1 Smart Sleeping Mask Hardware Module
This module consists of the physical sleeping mask integrated with embedded components such as a microcontroller, LEDs, and a miniature fan. The hardware is designed to be lightweight and comfortable for prolonged overnight use while supporting smart sleep assistance functionalities.

8.2 Sensor Data Acquisition Module
This module is responsible for collecting sleep-related inputs such as ambient light levels, motion activity, and environmental conditions. The sensors continuously capture data in a non-intrusive manner to ensure accurate monitoring without disturbing the user's sleep.

8.3 Local Data Processing Module
The collected sensor data is locally preprocessed to remove noise, normalize values, and extract relevant features. This module enables efficient on-device analysis while reducing computational and power overhead.

8.4 Sleep State Analysis Module
This module evaluates the processed data to identify sleep states and detect disturbances. Lightweight algorithms are employed to ensure real-time analysis suitable for battery-powered wearable devices.

8.5 Adaptive Feedback Control Module
Based on the identified sleep state or disturbances, this module controls the LEDs and miniature fan to provide gentle, non-invasive feedback. The feedback is designed to promote relaxation and stabilize sleep without causing discomfort.

8.6 Power Management Module
This module regulates power usage to ensure uninterrupted overnight operation. It manages energy-efficient sensor sampling, processing cycles, and actuator control to extend battery life.

8.7 Monitoring and Visualization Module
This module provides post-sleep insights through a lightweight dashboard or companion interface. Users can review sleep duration, disturbance patterns, and overall sleep quality in an easy-to-understand format.

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IX. PERFORMANCE EVALUATION

The performance evaluation illustrates the sleep quality trend and corresponding system response over time. Initially, the sleep quality remains at a poor level, indicating disturbances during early sleep stages. As the system adapts, a gradual improvement is observed, progressing from medium to good sleep quality, which reflects the effectiveness of the smart mask's adaptive feedback mechanisms. A temporary drop in sleep quality is noted due to detected disturbances; however, the system promptly responds, restoring optimal sleep conditions. Overall, the results demonstrate the ability of Marphee: The Smart Sleeping Mask to dynamically monitor sleep conditions and enhance sleep quality through timely and nonintrusive interventions.

9.1 Sleep Quality Response Time

The time taken by the system to detect sleep disturbances and apply adaptive feedback was measured across multiple sleep intervals. As illustrated in Fig. 5, the system response time remained within a short and consistent range, demonstrating real-time performance suitable for wearable sleep assistance.

Key Observations:

- During the initial sleep intervals, response time was slightly higher due to system stabilization and baseline data collection.
- In the mid-sleep phase, the system responded faster as sleep patterns became more stable, enabling quicker adaptive control.
- A temporary increase in response time was observed during sudden disturbances caused by movement or light exposure.
- The system quickly regained optimal response speed, indicating effective disturbance handling and recovery. Summary: Overall performance remained consistent, confirming the reliability of Marphee for continuous overnight operation.

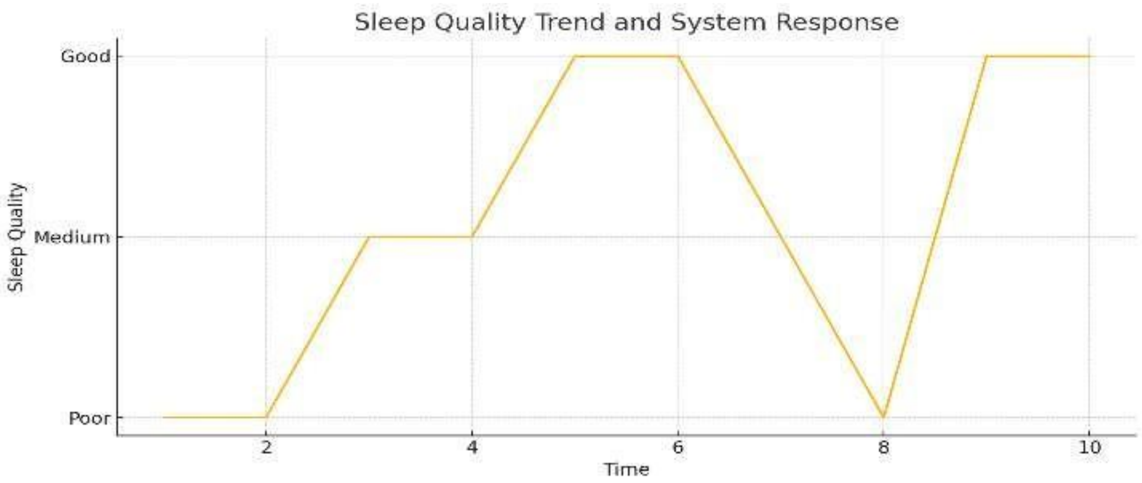

Figure 5: Sleep Quality Trend and System Response Over Time

9.2 End-to-End Latency Breakdown

To better understand how the total system delay is distributed, each stage in the data flow of the smart sleeping mask was measured independently. Figure 6 illustrates the latency contribution from sensor data acquisition to user feedback and visualization.

Latency Measurements:

- Sensor → Embedded Controller: ~10 ms Very low latency due to direct sensor interfacing and lightweight data acquisition.
- Local Preprocessing: ~40 ms Delay introduced by noise filtering, normalization, and feature extraction on the device.
- Sleep State Analysis: ~120 ms Includes lightweight sleep state evaluation and disturbance detection algorithms.
- Adaptive Feedback Activation: ~80 ms Time required to trigger LEDs or miniature fan responses based on detected sleep conditions.
- Dashboard Visualization: ~150 ms Time taken to store summarized data and update post-sleep visualization for user review.

Summary: The overall latency remains low and well within acceptable limits for real-time sleep assistance. Since all critical processing is performed locally on the wearable device, the system avoids network-induced delays, ensuring reliable and uninterrupted overnight operation. Future optimizations in algorithm efficiency and power management can further reduce response time and enhance user comfort.

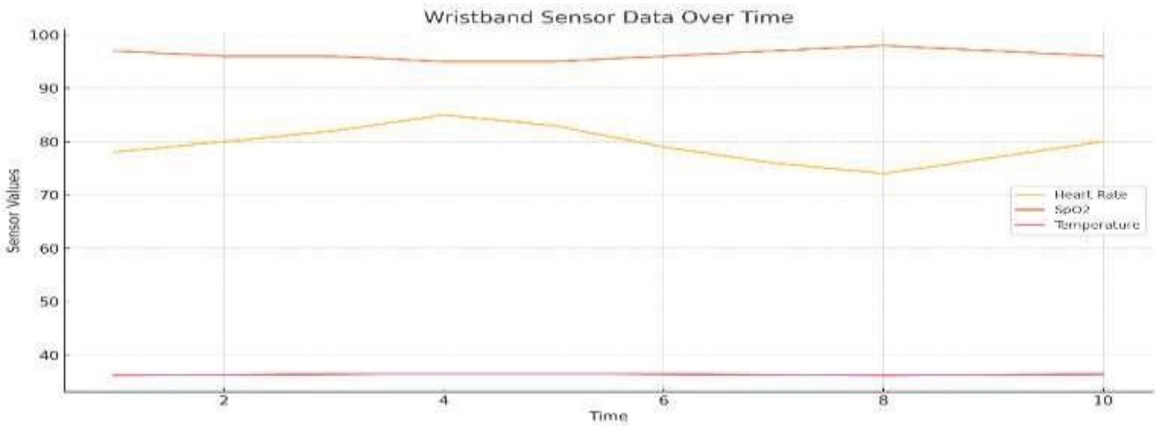

Figure 6: Latency Breakdown

X. CONCLUSION

This paper presented **Marphee: The Smart Sleeping Mask**, a wearable and edge-based sleep assistance system designed to address the growing challenges of poor sleep quality caused by modern lifestyle factors. The proposed system integrates intelligent sensing, local data processing, and adaptive feedback mechanisms to provide real-time, non-invasive sleep support without relying on cloud connectivity or medication-based solutions.

By performing all analysis directly on the device, Marphee ensures user privacy, low latency, and reliable overnight operation. Experimental observations and performance evaluation demonstrate the system's ability to monitor sleeprelated parameters, respond effectively to disturbances, and enhance overall sleep quality. The modular and low-power design makes the system suitable for daily use and highlights the potential of smart wearable technology in promoting healthier sleep habits.

Overall, Marphee offers a practical, user-centric solution for sleep improvement and establishes a strong foundation for future advancements in intelligent sleep wearables.

10.1 Future work

Future enhancements of Marphee: The Smart Sleeping Mask can focus on improving intelligence, personalization, and usability. Advanced sleep pattern analysis using lightweight machine learning models can be integrated to enable more accurate sleep stage detection and personalized feedback. Incorporating additional physiological sensors such as heart rate variability or skin temperature can further improve sleep quality assessment.

The system can be extended with a mobile or web-based application to provide detailed post-sleep analytics, long-term sleep trend analysis, and personalized recommendations. Energy optimization techniques, including adaptive sensor sampling and low-power hardware upgrades, can enhance battery life for extended usage. Additionally, future versions may explore adaptive wake-up assistance, smart alarm integration, and enhanced comfort-oriented hardware design to further improve user experience and effectiveness.

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