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An Intelligent HSAT with EEG-Based Sleep Stage Monitoring

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Abstract: *Sleep apnea is a sleep-related breathing disorder in which breathing repeatedly slows or stops during sleep. These events can disturb normal sleep and may be associated with drops in blood oxygen levels and other health risks. Although laboratory sleep studies provide detailed information, travelling to a sleep centre and spending a night there may not be convenient for everyone. This paper presents Smart Sleep, a portable home sleep-monitoring system designed to collect selected physiological signals during sleep. The system design brings together oxygen saturation (SpO_2), heart-rate, and electroencephalography (EEG) monitoring. An ESP32 microcontroller coordinates the planned data-acquisition workflow, local storage, and wireless transfer to a mobile interface. EEG is included to explore the possibility of adding sleep-stage information to home monitoring. This paper describes the system concept and its proposed development and evaluation. Since verified prototype measurements and clinical comparison data are not yet available, performance or diagnostic accuracy is not claimed. Further engineering and clinical validation are necessary before the system can be considered for diagnostic use.*

Keywords: Home sleep apnea testing, EEG, sleep-stage monitoring, SpO_2, heart rate, portable monitoring.

I. INTRODUCTION

Sleep is essential for physical health and daily functioning. For people with sleep apnea, however, breathing may repeatedly become reduced or stop during sleep. These interruptions can affect sleep quality and may be accompanied by oxygen desaturation, snoring, and daytime tiredness. If sleep apnea is suspected, an appropriate sleep assessment can help guide clinical care.

Polysomnography (PSG), usually performed in a sleep laboratory, records several signals to assess sleep and breathing. It can provide detailed information, but laboratory testing may involve cost, travel, and unfamiliar surroundings. Home sleep apnea testing (HSAT) offers a more convenient option for selected patients.

However, the channels available differ between devices, and many home systems do not provide EEG-based sleep-stage information.

Our project, Smart Sleep, proposes a compact monitoring system that combines SpO_2, heart rate, BP, and EEG signal acquisition, with data intended to be viewed through a mobile application. The goal is to explore whether these measurements can be brought together in a practical home-monitoring design. The proposed device is a research concept and is not presented as a replacement for professional diagnosis.

II. RELATED WORK

Wearable EEG has been explored as a way to make sleep monitoring less intrusive. Tabar and colleagues investigated at-home sleep monitoring using generic ear-EEG and evaluated automatic sleep scoring against professional scoring in

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a study setting [1]. Their work provides a useful example of how EEG collected outside a traditional laboratory may support sleep-stage estimation. Its reported findings apply to that study and should not be taken as evidence of Smart Sleep performance.

Research and discussion on augmenting home sleep apnea testing with single-lead EEG have also highlighted the potential balance between patient comfort and diagnostic information [2]. This direction is relevant to Smart Sleep because the proposed design aims to include EEG alongside other physiological measurements.

Based on this background, Smart Sleep is proposed as an integrated monitoring platform. Its potential contribution is the planned combination of selected sensors, embedded data handling, and mobile viewing. Whether this integration provides reliable signals or useful sleep-related information must be determined through testing.

III. METHODOLOGY

3.1 Proposed system

The proposed workflow has four stages: physiological signal collection, signal conditioning and digitization, processing and storage, and presentation to the user. During an overnight session, the device is intended to acquire available sensor signals, organize them with timestamps, store them locally, and transfer selected information to a mobile interface.

3.2 Components

The current component plan includes EEG electrodes, an AD620 instrumentation amplifier, high-pass and low-pass filters, an ADS1115, a MAX30102 optical sensor, a a microSD module, an ESP32 microcontroller, an OLED display, an I²C interface, and a rechargeable 3.7-V Li-Po battery. Exact component models, electrical connections, and operating specifications should be finalized during implementation.

3.3 EEG acquisition

EEG electrodes are intended to capture electrical activity associated with brain activity during sleep. The proposed front end includes amplification and filtering before digitization. The electrode placement, reference arrangement, gain, filter cutoffs, sampling rate, input protection, and artifact-reduction approach must be specified and documented. Movement, poor electrode contact, and electrical interference may affect signal quality.

3.4 Physiological sensing and embedded system

The MAX30102 is planned for optical pulse and SpO_2-related measurements. Its readings can be influenced by placement, motion, perfusion, and implementation; therefore, the measurements require verification. The BP sensing method and exact sensor have not yet been specified. The manuscript should not claim continuous until the selected method is defined and validated.

The ESP32 is proposed to manage sensor communication and data handling. A microSD module can support local recording, while wireless communication can provide transfer to the mobile interface. The OLED may show device status or selected values. Design considerations include synchronized timestamps, safe battery operation, secure handling of personal data, and reliable recording throughout the night.

3.5 Planned evaluation

After the prototype is assembled, initial tests should examine signal quality, sensor consistency, data-storage integrity, wireless connectivity, usability, and battery runtime. If sleep-stage classification is implemented, its output should be compared with expert-scored reference recordings using a predefined protocol and suitable measures, such as agreement and per-stage performance. Any apnea-detection evaluation must use an appropriate clinical reference and a prespecified analysis. BP measurements should likewise be compared with a validated reference method. Studies involving participants require institutional ethics review, informed consent, and appropriate clinical supervision.

IV. RESULTS

No measured prototype or participant results were included in the project information available for this draft. Therefore, this paper does not report numerical performance, sleep-stage accuracy, apnea-detection sensitivity, or

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battery runtime. These values should be added only after tests are completed, with the testing setup, sample size, analysis method, and results clearly stated.

V. CONCLUSION

Smart Sleep is a proposed portable HSAT concept that aims to combine EEG with SpO_2, heart-rate, make collected information available through a mobile interface. Adding EEG may offer an opportunity to explore sleep-stage information in home monitoring, while the overall usefulness of the system depends on reliable sensing and careful validation. The next steps are to finalize the hardware details, build and test the prototype, and compare its measurements with suitable reference systems under an approved study protocol. Until such evaluation is complete, Smart Sleep should be treated as an engineering research prototype rather than a diagnostic device.

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