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IoT Powered Wearable Sleep Apnea Monitoring and Holistic Patient Monitoring

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***Abstract*—Sleep plays a vital role in maintaining both cognitive and physiological health. Poor sleep quality, especially due to conditions like sleep apnea, poses serious health risks and may lead to fatal outcomes during rest. To address the limitations of existing systems that lack real-time monitoring, this research introduces an IoT-based sleep apnea detection system. It utilizes sensors to continuously monitor vital parameters such as ECG, heart rate, SpO_2, pulse rate, skin response, and body motion throughout sleep. Data is transmitted via a NodeMCU to a ThingSpeak for real-time analysis and alerts. The system is user-friendly and designed for diverse populations. Testing across multiple individuals confirmed its effectiveness in identifying sleep anomalies without disturbing the user. This work contributes to early detection and awareness of sleep apnea, aiding in timely intervention and prevention.**

***Index Terms*— Sleep Apnea, Heart rate Sensor, ECG Sensor, Spo_2 Sensor, Skin Response Sensor, Strain Sensor.**

I. INTRODUCTION

Sleep apnea represents a pathological state that is intricately associated with both the respiratory apparatus of humans and neurological processes. This disorder indicates an obstruction to the mechanisms of respiration and the dynamics of breathing during the state of slumber. Sleep apnea can be classified into two primary variant central sleep apnea (CSA) and obstructive sleep apnea (OSA). In certain scenarios, both variants may present simultaneously a phenomenon termed complex sleep apnea, nevertheless. This occurrence is regarded as too uncommon to justify its designation as a distinct type of apnea. Obstructive sleep apnea (OSA) is fundamentally defined by the blockage of the upper airway. This condition results from the relaxation of pharyngeal musculature, leading to a shortfall in oxygen traversing the nasal and pharyngeal conduits, which induces respiratory distress and may lead to serious health repercussions. Conversely, central sleep apnea is less common but presents a more significant concern than Obstructive sleep apnea. The human brain functions as the central regulatory nexus for all bodily operations, as each organ and system functions under its directive signals, thereby

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rendering central sleep apnea notably critical. Central sleep apnea manifests when the brain fails to deliver essential signals to the mechanisms governing respiration. In such circumstances, neuronal pathways may stop transmitting impulses to the respiratory muscles, resulting in the cessation of breathing for extended intervals, potentially approaching ten seconds [1]. In rare occurrences, both forms may coexist. Constituting a critical medical emergency and inciting considerable concern.

Ongoing medical and clinical research is being undertaken regarding this health concern, with several alarming discoveries necessitating heightened awareness. Sleep apnea is associated with a plethora of physical consequences and pathological conditions, including cerebrovascular incidents, hypertension, cardiac arrhythmias, and mood disorders such as depression [2] Empirical research suggests that roughly 3 to 7% of the male demographic and 2% to 5% of the female demographic are afflicted by sleep apnea. This aggregates to an estimated global prevalence surpassing 100 million individuals, including adolescents. The prevalence of the condition fluctuates across various demographic parameters, distinguishing affected individuals from those who are not 13, 41. A variety of complications or risk factors associated with identifying this disorder include excessive body weight or Obesity, alcohol consumption, nasal obstruction, neck circumference, male gender (with a heightened risk), tobacco usage, familial history, and comorbid conditions such as hypertension, type 2 diabetes, and pulmonary or other respiratory disorders. Individuals diagnosed with conditions such as Parkinson's disease or those recovering from strokes face an elevated risk of developing central sleep apnea. The consequences of sleep apnea can result in a range of health complications and in the most severe cases, mortality Typical symptoms of sleep apnea include pronounced snoring, continual fatigue, excessive daytime sleepiness, bodily weakness, and impaired focus. Hypertension arising from insufficient sleep and lowered oxygen levels may further increase the risk of myocardial infarction. Patients with sleep apnea are three times more likely to experience a cerebrovascular accident. The pulmonary system may be adversely impacted in a more significant manner when Sp02 levels are compromised. Respiratory impairment due to hypoxemia is a prevalent yet critically alarming outcome of sleep apnea. Approximately 43% of individuals with mild sleep apnea present with hypertension. Research indicates that this apnea condition accounts for 15% of traffic-related incidents and contributes to approximately 1,000 fatalities annually in the United States. More than 38000 individuals in the United States decease every year due to the consequences of sleep apnea, primarily influenced by cardiovascular complications [5]. Therefore, this issue demands increased awareness, as it has yet to receive sufficient attention or exposure, however, through our research initiatives, we aim to enhance the detection of this disorder to ensure that individuals are not left undiagnosed and can lead lives unencumbered by significant health risks.

The essential parameters related to sleep apnea-health concerning comprises of apnea-hypopnea index (AHI), blood oxygen saturation (SpO2), heart rate quantified in beats per minute (BPM), body mass index (BMI), total sleep duration, rapid eye movement (REM) sleep, blood glucose concentrations, cholesterol levels and age [6]. Numerous investigations have suggested that these parameters are scrutinized through a medical research perspective. Generally, such studies evaluate medical information relevant to individual subjects or groups, thereby clarifying the resultant findings. The primary devices employed comprise polysomnography (PSG), electrocardiography (ECG), and other clinical instruments. Nonetheless, the costs associated with these devices render them unaffordable for personal use. Significant progress in sleep apnea research has been documented historically. Wearable e-textile sensors [7] utilizing an Internet of Things (IoT) framework were deployed to collect real-time information on sleep patterns and respiratory rates. An analogous approach is detailed in [8], where respiratory data were gathered from sensor-integrated mattresses, frequently employed in surgical settings. A polysomnography (PSG) system is integrated with a polyvinylidene fluoride (PVDF) sensor to determine periodic AHI statistics [9]. The authors utilized the “peripheral arterial tonometry” (PAT) technique to accurately diagnose sleep apnea, ultimately leading to the innovation of the Watch PAT apparatus, which captures pulse waveforms from a finger to derive sleep-related metrics [10]. In [11], a three-dimensional camera was utilized to observe abdominal muscle movements, which were then juxtaposed with the obstructive sleep apnea (OSA) detection process. The auditory detection mechanism employed in [12] enables the precise measurement of sounds at elevated frequencies. Furthermore, extensive studies have been undertaken analyzing real-time ECG monitoring in conjunction with pre-existing ECG datasets, incorporating machine learning methodologies. The authors [13] described the devising of an microcontroller based pulse monitoring system, utilizing a single sensor to gauge human heart rate. An IoT device [14] was designed to extract ECG data from users and evaluate results employing a support vector machine (SVM)-based classification model, termed the “Apnea Med Assist Service.” In references [15–17], researchers employed deep learning and machine learning techniques for identifying apnea using clinical datasets.

II. Methodology

This section clarifies the strategies, components, and mechanisms utilized to attain the specified goal. The primary aim of the system is to thoroughly monitor the complete duration of sleep experienced by an individual suffering from sleep disorders. This microcontroller-based framework for the surveillance of sleep apnea in patients with sleep-related ailments is designed with three separate tiers. The core tier encompasses a microcontroller unit that acts as a conduit linking the input tier to the output tier. Within the input tier, it incorporates four distinct sensors that relay analog signals to the Arduino UNO, thereby enabling the assessment of various metrics related to sleep conditions. The output tier consists of two elements, namely a ThingSpeak and serial monitor of the Arduino UNO, which collectively display the digital data that has been processed by the microcontroller. Figure 1 depicts the block diagram illustrating.

the entire system which includes I/O pins, power and microcontroller system as depicted in Figure 2.

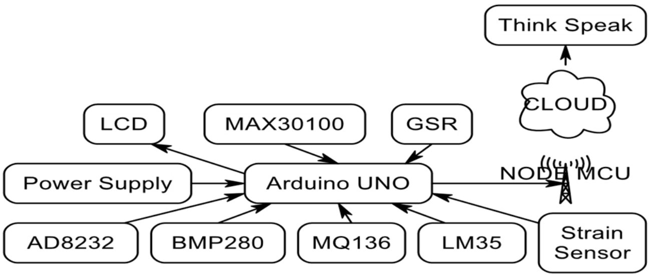

Figure 1. Full system block diagram by which the system works successfully

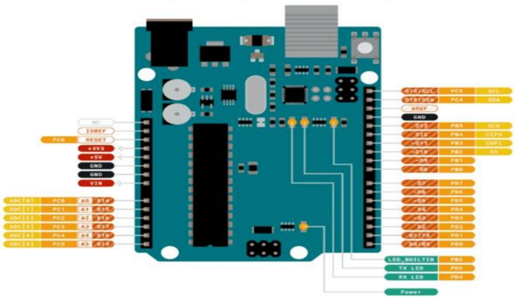

Figure 2. Arduino UNO Pinout

Microcontroller is connected to the output, interfacing with the serial communicator of the Arduino board and ThingSpeak, linked via a NodeMCU to present the estimated measurements to the user the essential operational workflow of the system. Arduino receives data from the sensors concurrently, which subsequently transmits the digitized information to the Arduino Integrated Development Environment (IDE) serial monitor, while simultaneously connecting through NodeMCU to the ThingSpeak Via Cloud. The system comprises an array of distinct components, each executing specific roles within the overall framework. Certain components are assigned for input functions, others for output roles, while some facilitate the interconnection between outputs and inputs. Arduino UNO is adept at interfacing with a variety of sensors or computers, rendering it applicable for diverse projects. It is equipped with 2 KB of SRAM and 32 KB of flash memory. A decreased heart beat may occur as a result of inadequate oxygenation within the body. This situation can arise when an individual's breathing ceases due to unforeseen circumstances. In contrast, an increased heart rate may also arise from sleep apnea, Factors such as hypertension and psychological stress can contribute to an elevated heart rate. Moreover, this condition frequently disrupts an individual's normal sleep patterns. It is a major contributor to the risk of cardiac failure during sleep. To monitor sleep apnea effectively, a wearable system was developed incorporating various sensors to track key physiological parameters throughout sleep. These include a heart rate sensor, SpO2 sensor, ECG sensor (AD8232), GSR sensor, pulse sensor, and sound sensor. The heart rate and ECG sensors detect abnormalities like increased or decreased heartbeat, which are indicative of sleep apnea-related stress or oxygen deficiency. The SpO2 sensor (MAX30102) evaluates blood oxygen saturation, where a drop below 95% may indicate hypoxemia. GSR sensors measure skin conductance to reflect emotional stress levels, which often vary with hypertension or disturbed sleep. A sound sensor identifies snoring intensity— a primary symptom of obstructive sleep apnea. All sensors transmit analog signals to an Arduino UNO, where data is processed and digitized. The system uses a NodeMCU to wirelessly transmit this data to ThingSpeak, a cloud-based IoT platform for real-time visualization. Data is collected every second and shared for further analysis. The setup was designed using circuito.io, and the circuit integrates all sensor modules with appropriate analog or digital pins on the Arduino. This system offers a compact, continuous, and real-time solution for early detection and monitoring of sleep apnea through cloud-based data visualization.

III. WORKING

The system operates using an Arduino UNO microcontroller as the central processing unit that interfaces with multiple biomedical and environmental sensors. The setup begins with a power supply unit that ensures the microcontroller and connected modules receive stable voltage for proper operation. The MAX30100 sensor captures heart rate and SpO_2 levels, providing crucial insights into the patient's cardiovascular and respiratory status during sleep. The AD8232 ECG sensor records the electrical activity of the heart, helping identify cardiac irregularities that may be associated with sleep apnea.

To monitor environmental and physiological stressors, the GSR sensor measures skin conductance, indicative of emotional and physical arousal levels. The BMP280 sensor tracks ambient pressure and temperature, while the LM35 delivers precise body temperature readings. Air quality is assessed using the MQ136 gas sensor, detecting harmful gases that could influence breathing quality. Additionally, a strain sensor is used to detect chest or abdominal movements related to respiration.

All sensor data is collected and processed by the Arduino UNO, which sends the information to the NodeMCU module for wireless transmission. Through this module, the processed data is uploaded to ThingSpeak, an IoT-based cloud platform, where it is visualized in real-time. The LCD module displays critical sensor readings locally for immediate feedback. This integrated system offers a comprehensive, realtime health monitoring solution that enables early detection of sleep apnea and related complications.

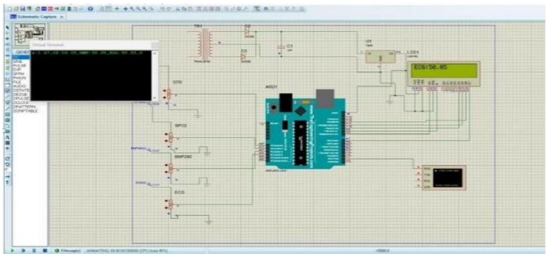

Figure 3. Stimulation of the Proposed Method

IV. RESULT AND DISCUSSION

The designed system offers an integrated approach to tracking vital signs and environmental conditions that may influence the onset or severity of sleep apnea. Using an Arduino UNO microcontroller, it connects to a variety of biomedical sensors to gather and process real-time data. The MAX30100 sensor continuously monitors heart rate and blood oxygen levels, both of which are essential for identifying irregular breathing patterns typical of sleep apnea. Significant drops in oxygen saturation accompanied by elevated heart rates during certain periods suggest potential apnea events. The AD8232 sensor records the heart's electrical signals, helping detect irregular cardiac activity linked to low oxygen or physiological stress. Additionally, the GSR sensor measures skin conductivity, offering insights into the user's stress levels— steady readings reflect relaxed states, while sudden spikes may indicate disturbances. The LM35 and BMP280 sensors measure body and environmental temperatures respectively, helping assess the impact of thermal conditions on sleep quality. The MQ136 gas sensor detects the presence of harmful gases that could interfere with respiratory function, while a strain sensor captures chest movement data, directly reflecting breathing patterns. Data from all sensors are processed by the Arduino and shown on an LCD for local viewing. A NodeMCU module provides wireless connectivity, uploading the sensor data to the ThingSpeak cloud platform for continuous, remote health monitoring. The system exhibited consistent performance and accurately captured physiological changes linked to sleep disturbances, making it a practical, affordable tool for real-time detection and monitoring of sleep apnea.

V. CONCLUSION

The proposed IoT-based sleep apnea monitoring system demonstrates a reliable and efficient approach for continuous real-time health surveillance during sleep. By integrating a suite of biomedical and environmental sensors with the Arduino UNO and leveraging wireless data transmission via NodeMCU, the system effectively captures vital parameters such as ECG, heart rate, SpO_2, skin response, body motion, and environmental conditions. The real-time data visualization through ThingSpeak enhances remote monitoring capabilities, allowing for early identification of abnormal sleep patterns and potential apnea events. The system's low cost, portability, and user-friendly design make it accessible for personal and clinical use, especially in underserved areas where traditional diagnostic tools are unavailable or unaffordable. Experimental validation confirms its ability to detect physiological irregularities without disturbing the user, positioning this work as a valuable contribution toward early intervention and better management of sleep-related disorders. Future enhancements may include AI-based pattern recognition for improved diagnostic accuracy.

Figure 4. Hardware

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