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Development of a Multi-Sensor IoT System for Real-Time Sleep Disorder Monitoring and Alert Generation

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ABSTRACT

Sleep apnea, snoring, and restless sleep are some sleep disorders that are dangerous to health when not diagnosed. Traditional methods of sleep monitoring, especially polysomnography (PSG), are costly, invasive and only suitable in short-term hospital research. In this paper, a smart IoT-based system is proposed that detects sleep disorders and is developed to monitor sleep in real-time and continuously and at home. The system connects SpO2, MEMS accelerator, sound and temperature sensors to an Arduino microcontroller to gather physiological and environmental sleep data. The local display of real-time values and their transmission into the Things peak cloud platform through NodeMCU provide a possibility to be visualized remotely. An alert system based on a GSM transmits instant alerts in the occurrence of abnormal sleep condition. The assessment based on experiments shows that the sensors have a high level of reliability, detect abnormal sleep disorders, and can be monitored using the cloud. The suggested system is not invasive and low cost, and an effective alternative to the conventional hospital-based sleep studies.

Keywords: IoT, Sleep Apnea, Smart Healthcare, SpO 2 Monitoring, Cloud computing, GSM Alerts.

I. INTRODUCTION

Sleep is important in ensuring physical and psychological wellbeing. Sleep apnea and snoring as well as insomnia disorders have the potential to impact cardiovascular health, cognitive and the quality of life in good ways. Sleep apnea, which is a condition that is marked by frequent interruptions in breathing whilst sleeping is normally not diagnosed since continuous monitoring facilities are not available at home [1,2]. Conventional diagnosis is based on polysomnography (PSG) in which patients are expected to follow a sleep in the controlled laboratory conditions, being attached to various sensors. Despite this fact, PSG is very costly, uncomfortable, and is not applicable in the long-term monitoring [3,4]. The latest innovation in IoT technologies has made it possible to design smart healthcare systems to facilitate continuous health monitoring with interconnected sensors and cloud platforms. This paper presents an IoT-based smart sleep disorder detection system that facilitates real-time sleep monitoring at home setting to provide comfort, cost-efficiency and give an early warning of abnormalities.

II. LITERATURE SURVEY

The problem of sleep apnea and other sleep disorders has become a critical issue of public health because it is firmly linked to cardiovascular diseases, diabetes, fatigue, and the low quality of life. Although traditional methods of diagnosis like polysomnography (PSG) are accurate, they are costly, time-

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consuming and inconvenient in the cases of continuous monitoring. Subsequently, the latest studies have drawn more attention towards the IoT-based, wearable, cloud based, and AI-enhanced sleep monitoring solutions to offer affordable, real-time, and non-invasive monitoring solutions.

Dhruba et al. [5] suggested a sleep apnea monitoring system is based on IoT and is oriented at the collection of physiological data in real-time. The system allows constant observation of sleep parameters with a series of sensors connected to them. Although it is useful in real-time monitoring, the study does not have cloud-based alerting systems and out-of-band notifications, and it is not applicable to emergency interventions and long-term analytics. Abdulmale et al. [6] have proposed a system of cloud-based IoT sleep monitoring, which is more advanced than the previous IoT solutions, as it enables the use of cloud storage and remote visualization. This system enables the professionals to get patient data in real time; hence they can diagnose and follow up better. The system, however, does not focus on predictive alerts or smart analysis but mostly on data storage and visualization.

de Zambotti et al. [7] created a wearable system of detection of sleep disorders, which is based on body-worn sensors to monitor the physiological indicators of heart rate and movement. The wearable devices are portable and easy to use and hence can be used to monitor people at home. Nevertheless, their accuracy can be influenced by compliance by the user, positioning of sensors, and motion artifacts, and therefore, the system is extremely user dependent. Osa-Sanchez et al. [8] suggested an acoustic-based system of detecting sleep apnea to overcome discomfort related to wearables. This non-invasive technique involves the use of sound signals including the snoring patterns and breathing patterns in detecting apnea events. Although the method is better in terms of user comfort and easy deployment, the method can be influenced by environmental noise and has not been multi-parameter physiologically validated.

As artificial intelligence develops, Haghighat et al. [9] proposed a machine learning system of sleep apnea detection, which is capable of significantly improving the accuracy of the diagnosis. Machine learning models are superior to traditional threshold-based approaches because they rely on the investigation of complicated physiological patterns. Nevertheless, these systems are large, high-quality datasets, and may not be able to support real-time implementation on low-power IoT devices. Recent reports are dedicated to home-based sleep apnea devices, several researchers made an attempt to decrease the patient’s lance on hospitals and enhance their comfort. These systems emphasize the move towards remote healthcare and telemedicine. Although they have their benefits, their clinical grade effectiveness and regulatory compliance are still a challenge.

III. PROBLEM STATEMENT

Sleep disorders are frequently underdiagnosed because of the absence of inexpensive and constant home-based monitoring technologies. The sleep studies conducted in hospitals are costly, uncomfortable and only offer short time data. The current wearable solutions provide little information about physiology and do not have real-time notification features. Hence, there is a need to develop a non-invasive, low-cost IoT system that would be able to constantly measure sleep parameters and send instant alarms in case of an abnormal situation.

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IV. SYSTEM ARCHITECTURE

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4.1 General System Architecture

The system architecture comprises of the architecture of all the systems where subsystems are further extended into component hierarchy. The general structure of the proposed sleep disorder detection system based on the IoT is depicted in Fig. 1. The system is created to constantly track physiological and environmental indicators concerning sleep disorders and offer real-time notifications and tele-monitoring patient results. The hardware module will consist of several sensors connected to an Arduino microcontroller to acquire and process data. The Arduino reads the raw sensor data and views the key parameters in an LCD to be observed instantly. In the case of wireless data transmission, a NodeMCU module will upload the processed data to a cloud server, which provides the opportunity of remote monitoring and long-term storage of data. To make the patient be safe, a GSM module is incorporated into the system to create alert messages in cases of abnormal sleep conditions being detected. Caregivers or medical professionals are automatically sent these alerts, which allows intervention in time. The cloud platform would store patient information in a central database and allow access using a web-based interface by the doctors and caregivers.

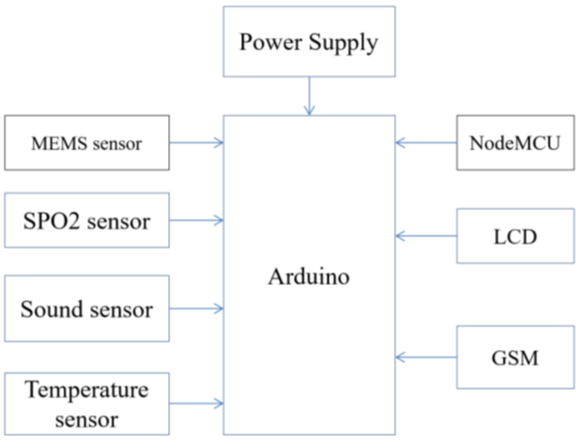

Figure 1: IoT-Based Sleep Disorder Detection System Block Diagram.

4.2 System Workflow and Interaction

The process of the system starts when the patient puts on the sleep monitoring machine. The sensor data can be respiratory activity, heart rate or other environmental parameters and is constantly monitored and sent to the Arduino controller. The analysis and preprocessing of data are followed by uploading the data to the cloud server through the NodeMCU module. Doctors and caregivers can have remote access to the sleep data of the patient through a web-based application, which is cloud-based. The system does an automatic analysis of patterns of sleep and identification of abnormalities about sleep disorders. When the abnormal conditions surpass the predetermined values, the system sends alert messages using the GSM module. It is an integrated workflow with continuous sleep tracking, remote diagnostics and emergency notifications that do not require equipment that is based at the hospital.

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4.3 Deployment Architecture

The proposed system has a distributed IoT model deployment architecture. The patient-side device is an edge node that performs the task of acquiring and preprocessing data. The cloud server is a data storage, visualization and analysis platform that is centralized. Patients and healthcare providers effectively communicate with the system using web or mobile interfaces by the end users.

4.4 Hardware Implementation

Fig. 2 demonstrates the real hardware developed in the proposed system. The proposed prototype consists of Arduino UNO, SpO 2 sensor, MEMS sensor, sound sensor, temperature sensor, NodeMCU, GSM, and LCD. With the correct wiring, data acquisition and communication are synchronized.

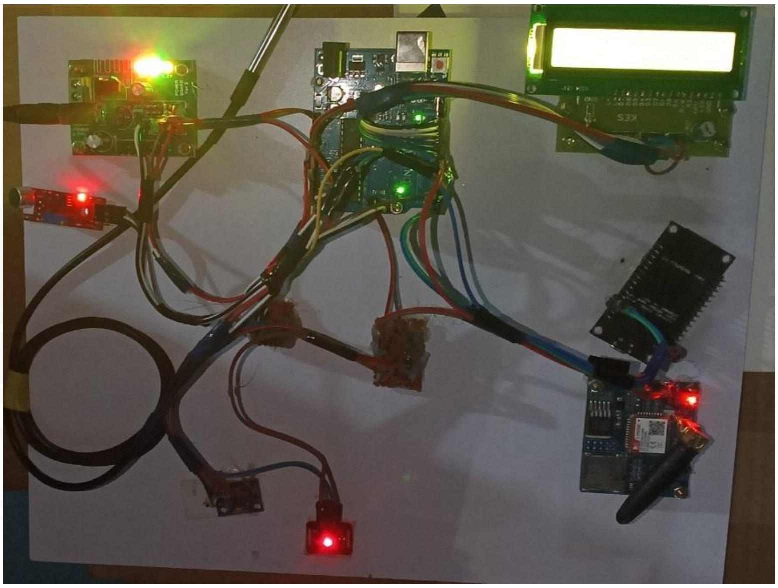

Figure 2. IoT-based Sleep Monitoring System Hardware Prototype

V. RESULTS AND DISCUSSION

The efficiency of the suggested system of detecting sleep disorders based on the IoT was assessed in real-time using various sensors, cloud visualization, and GSM alert systems. The findings indicate that the system can constantly be aware of the sleep parameters, identify the presence of abnormalities, and give early warnings.

5.1 Visualization of Sleep Data Harvested with Cloud-Based Thing Speak

Fig. 3 and Fig. 4 show the real time representation of physiological and environmental parameters of sleep in the ThingSpeak cloud platform. The sensor data obtained was also able to be sent by the NodeMCU module to the cloud via a steady Wi-Fi network that would send out the sensor data in real-time during the duration of the test. The graph of the heart rate (BPM) and the oxygen saturation (SpO2) at different periods of time are shown in Fig. 3. The parameters are important measures of respiratory wellbeing in sleep. The data that was plotted reveals some constant BPM and SpO2 values under normal sleeping conditions, whereas some significant variations could be observed when abnormal breathing patterns were present. The detection mechanism proposed in the paper is justified by the fact that a sudden decrease in SpO2 levels can signal an apnea event.

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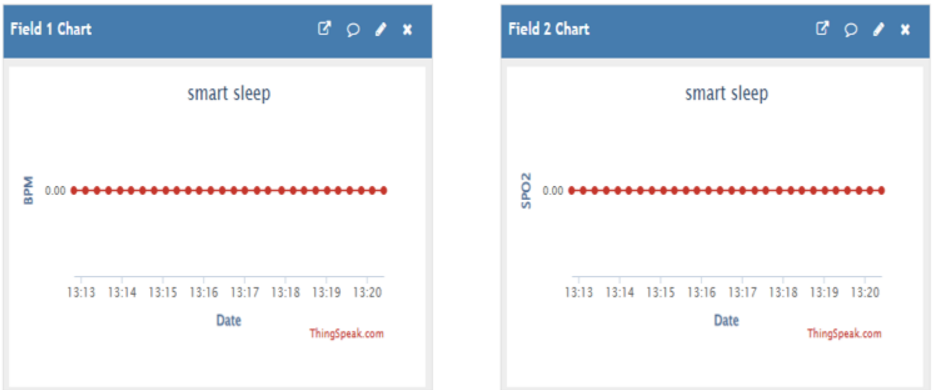

Figure 3: Smart Sleep Vs BPM and SpO2

Fig. 4 shows temperatures, counts of breaths and movement of a body based on temperature and MEMS sensors. Patterns of body movements give an insight into restless sleep or a variation in the count of breaths that assist in detecting abnormal respiration. The readings of the temperature were within normal levels, and this was an indicator that there are no drastic environmental conditions. The pattern of increased movement and abnormal count patterns of breaths were found during periods of disturbed sleep, which justifies the correct identification of sleep abnormalities. The ThingSpeak platform will also allow storing the data and analyzing the trends over a long period, which will provide caregivers and medical professionals with an opportunity to remotely monitor the historical data about sleep. This is a visualization based on clouds that enhance the cognizance of sleep behavior and promote early diagnoses via constant monitoring.

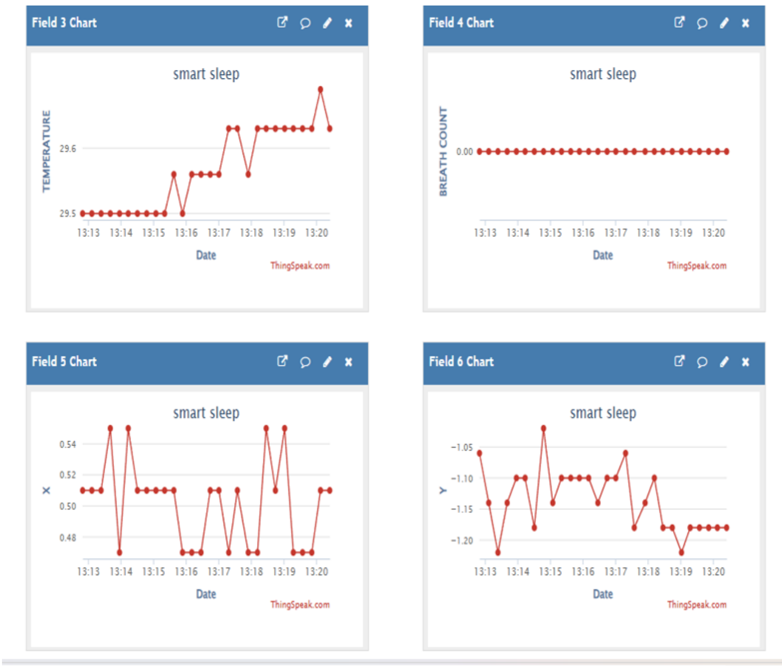

Figure 4: Temperatures, counts of breaths and movement of a body

5.2 LCD Based Notice Indication in Abnormal Conditions.

Fig. 5 illustrates the alert message on the LCD display in case the abnormal sleep conditions are detected. The LCD will offer instant on-gadget feedback, which will guarantee that caregivers or users in the vicinity are immediately notified without necessarily being connected to the cloud. When the SpO 2 level was low compared to the safe level set in the predetermined values, the system sent an alert message that showed as ALERT!! during experimentation. SpO_2 Abnormal." The system has the capacity to detect important health conditions early hence this real-time visual warning is valid. LCD alert mechanism is the primary notification mechanism and improves the usability of the system by giving direct and clear notification. This local alert display is especially used in home settings, and it enables speedy human intervention even when the internet connection is disconnected. The proposed system is more reliable and safer because of the LCD based alerts.

Figure 5: Alert message on the LCD display

5.3 GSM Based SMS Notification of Alert to Caregivers

The SMS alerts messages in GSM-based tools to alert registered mobile numbers in case of abnormal sleep parameters being detected are provided in Fig. 6. The GSM module is used to provide good communication regardless of the presence of Wi-Fi connection and therefore the alert system is very strong and reliable. In the conditions of abnormal SpO2 and BPM, SMS messages were effectively sent to the mobile devices of caregivers in real-time, e.g. "ALERT: SpO2 Abnormal and ALERT: BPM Abnormal. Such notifications allow timely behavior and immediate awareness of caregivers or medical staff, particularly during critical cases like apnea attacks. GSM based alert system would greatly promote the safety of patients since it offers a remote alerting system even in the absence of the care giver. This characteristic allows making the system extremely appropriate to the elderly patients and people with inappropriate sleep disorders who need constant attention.

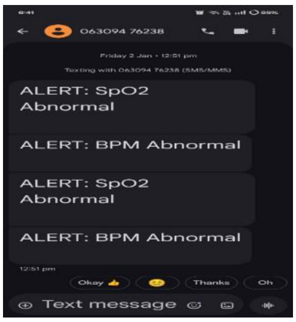

Figure 6: Alerts to registered mobile number

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5.4 Reliability and Real-Time Performance Analysis of Systems

The suggested system showed stable and continuous work during the testing period. When it came to physiological changes, all the sensors were accurate and the transmission of the data to the cloud was consistent without any significant delay. The synergistic effect of local LCD alerts and the GSM-based SMS alerts guaranteed a multi-level alert system. Combination of cloud monitoring and generation of real-time alerts ensures that the system is very effective in the detection of sleep disorders at an early stage. The findings affirm that the system works well in a real-world situation and generates accurate, timely and actionable information.

The findings of the experiment are in support of the effectiveness of the IoT-based sleep monitoring device as an alternative to a traditional polysomnography that is performed in a hospital. The combination of continuous data capture, real-time visualization of clouds, and the generation of alerts in the first place enhance early diagnosis and prevention. The system is cost effective, non-invasive and can be used at home over a long period of time as opposed to the conventional method.

VI. CONCLUSION

In this study, an IoT-based smart sleep disorder detection system has been described, which has been designed to continuously and in real-time monitor the parameters of sleep in a domestic environment. The system will include numerous non-invasive sensors such as the SpO2, MEMS accelerators, acoustic sensors, and temperature transducers to purchase complete data on physiological and behavioral sleep. The control over reliable data processing is provided by an Arduino microcontroller, whereas the process of wireless transmission is straightforward using a NodeMCU to the ThingSpeak cloud service. Live cloud dashboards can help clinicians and caregivers to track sleep patterns remotely and longitudinal trends.

The system can effectively identify the abnormal sleep conditions like the loss of oxygen, the abnormal breathing patterns, excessive body movements, and abnormal variation in heart rate. The combination of a GSM-based alarms mechanism will be used to provide prompt alerts, particularly in life-threatening situations, and increase patient safety, which will allow timely medical care to be taken. Empirical evidence shows that the systems are performing consistently, the sensors are being measured accurately, and the data is being transmitted reliably. Compared to the traditional hospital-based sleep research, the solution is cost efficient, non-invasive and suitable in long term home monitoring. In general, the system offers a viable and effective alternative to an early diagnosis of sleep disorders and helps to better sleep-health management with the help of IoT-based smart healthcare solutions.

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