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Artificial Intelligence Powered Smart Pillow Health Analytics Platform

[1]SAtheeshkumar S , [2]Priyadharshini P , [3]Swetha S, [4]Thirisha K

[1] Associate Professor, Paavai Engineering College, Pachal, Namakkal
[2,3,4] UG Student, Paavai Engineering College, Pachal, Namakkal
Email: [1]sskv89@gmail.com, [2]palaniyoga7@gamil.com

ABSTRACT:

A restful night's sleep is crucial for overall health, and monitoring vital signs like body temperature and sweat patterns during sleep can provide valuable insights for clinical diagnosis. However, traditional methods of tracking physiological changes during sleep can be cumbersome and intrusive. To address this challenge, a smart pillow has been developed, equipped with strategically embedded temperature and humidity sensors. By analyzing data from these sensors, the pillow can detect patterns of sleep, infer body temperature, and even identify instances of night sweats. This innovative technology enables healthcare professionals to make more informed decisions about diagnosis and treatment, while also empowering individuals to take control of their sleep habits and improve their overall well-being.

Index terms: Sleep, body temperature, sweat patterns, temperature sensors, humidity sensors, clinical diagnosis.

I. INTRODUCTION

Furthermore, the smart pillow's integration with wearable devices, electronic health records, and telehealth platforms enables a holistic approach to sleep medicine, facilitating seamless communication between healthcare providers, patients, and caregivers. By harnessing the power of artificial intelligence, machine learning, and data analytics, the smart pillow provides actionable insights that can inform personalized treatment plans, improve patient outcomes, and enhance the overall quality of life. As the healthcare industry continues to shift towards value-based care, innovative technologies like the smart pillow are poised to play a vital role in transforming the sleep health landscape, enabling more effective disease prevention, diagnosis, and management. By leveraging this cutting-edge technology, healthcare stakeholders can work together to promote better sleep, improved health outcomes, and enhanced patient satisfaction.

II. METHODOLOGY

Research has consistently shown the importance of body temperature in various aspects of human health. Studies have demonstrated that body temperature is closely linked to alertness and performance, with increased body temperature leading to improved alertness and performance, regardless of whether it is synchronized with the internal biological clock. Additionally, research has found that abnormal body temperature rhythms are associated with insomnia in different phases of sleep, and that treatments such as bright light therapy can help adjust the circadian rhythm.

Furthermore, body temperature has been shown to be a critical factor in patient outcomes, particularly in cases of acute stroke. For instance, research has found that patients with mild hypothermia upon admission tend to have better outcomes, while those with hyperthermia tend to have worse outcomes. Given the importance of body temperature, researchers have been working to develop unobtrusive and accurate measurement approaches. One such approach involves the use of the Kalman Filter, which has been extensively adopted in engineering tracking problems. This filter uses a model to estimate the time course of core temperature, employing heart rate measurements as a main indicator.

Another approach involves the use of a new method for monitoring deep body temperature from the skin surface, known as the Zero Heat Flow (ZHF) method. This method creates a zone of zero heat-flow across the body shell, bringing the deep body temperature to the skin surface where it can be measured with a simple electronic thermometer. While this method has been shown to track core temperature well in various ambient conditions, it has an inherent weakness in that it requires the use of a heater to stop surface convection.

A more recent approach involves the use of a dual-heat-flux (DHF) method, which achieves similar outcomes to the ZHF method but with less energy consumption and more sensors. Researchers have suggested enhancements to the DHF method by adjusting the probe size, altering the measurement depth under the skin, and incorporating an aluminum cover to improve measurement accuracy.

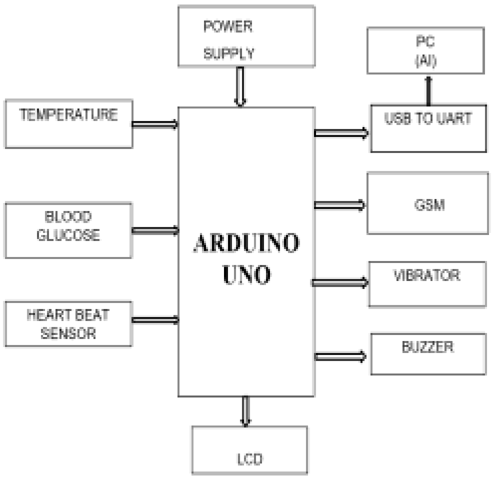
A simpler device, known as the Sensor, has been developed to measure skin temperature and heat flow without the need for a heating element. This advanced device employs just two temperature sensors, delivering accuracy and precision comparable to rectal and distal esophageal measurements. Building on this concept, researchers embedded a Double Heat Flux (DHF) sensor and two Double Sensors into a neck pillow to estimate core body temperature during sleep. Although this approach allows for measurement in three different sleep positions, it has the drawback of requiring the use of a neck pillow, which can be inconvenient.

A more wearable and user-friendly solution has been developed using Temperature Sensing Fabric (TSF), which is manufactured on a knitting machine with fine metal wires integrated into the fabric. This fabric employs the principle that the metal wire's electrical resistance changes with temperature fluctuations. While this garment offers a convenient and wearable solution, its production process can be challenging to scale up for batch manufacturing the rapid advancement of the electronics industry has led to the proliferation of wearable devices, which have become increasingly popular due to their affordability, comfort, and discreetness. For instance, researchers have developed high-sensitivity, low-cost printed wearable temperature sensors using poly (3,4-ethlenedioxythiophene) poly (styrene sulfonate) (PEDOT: PSS) and carbon nanotubes (CNTs). Although these sensors have addressed the issue of size, the next challenge to be addressed is the method of low-power wireless transmission for uploading measurements, with Bluetooth Low Energy (BLE) being a prime candidate.

Several wearable devices have been developed to measure body temperature, including a ring-shaped wrap for the finger that integrates infrared receivers and transmitters for heart rate and temperature sensing. This device transmits data to an Android mobile device in real-time via BLE, triggering an alarm if any abnormal signs are detected. Another example is a forehead-worn thermometer that connects to a mobile device via Bluetooth, utilizing multiple Artificial Neural Networks (ANNs) to estimate body temperature. However, balancing estimation accuracy, computational load, and delay time remains a challenge

A non-invasive, wearable, wireless prototype has been developed for precise body temperature monitoring. This device, which is accurate to 0.02 °C, provides real-time feedback to medical professionals and is based on a Wireless Body Area Network (WBAN). The device features a compact design, measuring 40 mm × 20 mm, and utilizes a Tyndall 10 mm node and Nordic nRF9e5 RF chipset for communication. However, energy consumption issues still need to be addressed to ensure the device's practicality.

A reliable data transmission and storage system is crucial for vital sign measurement. In 2008, Dobrescu et al. presented a WSN-based platform for homecare monitoring, utilizing a Patient Wireless Node (PWN) and Home Wireless Node (HWN) to share resources and increase diagnosis accuracy. ZigBee, a low-data-rate short-range wireless networking technology, is widely used in smart home systems due to its low-cost implementation and low-power consumption. Researchers have proposed various remote health monitoring systems focusing on body temperature, employing temperature sensors, Arduino boards, and WLAN. Recent studies have explored the use of wearable devices, IoT, and Cloud Computing to enhance healthcare systems. For instance, a Long-term Wearable Vital Signs Monitoring System using BSN and ZigBee has been proposed, covering physiological signs such as ECG, SpO2, and systolic blood pressure. Other researchers have presented mobile gateways for ubiquitous healthcare systems using Bluetooth and ZigBee



The integration of 5G technology has also been proposed for smart continuous eHealth monitoring systems, enabling the use of wearable devices, mobile phones, and intelligent databases for big data analysis. However, the availability and affordability of 5G technology remain current challenges. Recently, several smart pillow-based systems have been proposed for sleep quality monitoring and health sensing. For instance, an IoT-based smart pillow integrates sensors for temperature, humidity, luminosity, sound, and vibration, enabling automatic adjustment of environmental parameters for improved sleep quality. Another scheme uses a smart pillow with temperature and humidity sensors to monitor sleep stages with an accuracy of over 60%.

The data flow diagram of the system illustrates the interaction among the sensors, transport agent, and server. The sensors collect data on temperature, humidity, and other parameters, which is then transmitted to the transport agent via BLE/ZigBee. The transport agent uploads the data to the server, which processes and analyzes the data to provide insights on sleep quality and health.

The BLE chip collects and preprocesses sensory data, which is then transmitted to a mobile phone or Wi-Fi agent via Bluetooth and uploaded to a cloud server via the internet. The cloud server analyzes the data and extracts health-related features such as sweat, fever, and insomnia. A daily health report is then generated and presented visually on a webpage or mobile application. Additionally, weekly, monthly, and annual health reports and suggestions are provided based on known medical knowledge. The system also allows for data sharing with professional medical organizations, providing an extra level of patient information to aid in diagnosis and treatment.

The pillow serves as the data source for the system, communicating via Bluetooth with a unique address. The transport agent, featuring Bluetooth and Wi-Fi capabilities, gathers data from the pillows and transmits it to the server. The agent also requests accurate time from the internet to synchronize with the pillow.

The server analyzes the data and provides results in three sections: statistics, inference, and suggestion. Statistics include simple calculations such as sleep duration and room temperature. Inference involves using fuzzy logic to estimate body temperature and sweat levels based on head and environmental temperature. The suggestion section provides health recommendations based on the analysis and general medical knowledge The health recommendation section provides personalized advice based on the analysis of sleep patterns, body temperature, and other factors, as well as general medical knowledge. A mobile phone can serve as a transport agent, leveraging its built-in Bluetooth, Wi-Fi, and 4G capabilities. This approach offers flexibility, local data analysis, and immediate visual results.

In contrast, a customized transport agent provides automated data collection and transmission to the server without analysis or presentation. A key advantage of the agent is its ability to connect with multiple pillows, serving them one-by-one. The differences between using a mobile phone and a customized transport agent are summarized . The temperature data collected from the pillow can be used to infer various aspects of a person's sleep habits. For instance, the duration of sleep can be determined by identifying the points at which the head is placed on and removed from the pillow. This is achieved by analyzing the temperature values from the three sensors, which remain stable and similar before the head is placed on the pillow. The data can also be used to track room temperature and humidity, as well as identify turns in the pillow and sleeping position distribution. These indicators can provide valuable insights into a person's sleep habits. Furthermore, the collected data can be analyzed to extract significant medical indicators, such as body temperature and sweat.

The relationship between head position and body temperature is also explored. The head position is defined as five possibilities, and the temperature values from the sensors are used to infer the body temperature. The results show that the head position affects the temperature readings, and this information can be used to improve the accuracy of body temperature measurements. The core body temperature (CBT) is calculated using the main temperature and a compensatory factor

The head's position is closely linked to the accuracy of body temperature measurement. When the head moves to a new position, the nearby temperature sensor requires a period of time to stabilize. A 15-minute period is used to account for the material of the pillowcase, performance of the temperature sensor, and main temperature. The performance of the developed models is evaluated using metrics such as accuracy, precision, recall, F1-score, and mean squared error. The trained models are then deployed on a cloud-based platform or on-device, enabling real-time health analytics and insights. A user-friendly interface is developed to visualize the collected data, predicted health outcomes, and provide personalized recommendations for improvement.

Continuous learning is also implemented through a feedback loop that collects user feedback, updates the models, and refines the platform to improve its accuracy and effectiveness. Various AI techniques are utilized, including deep learning, natural language processing (NLP), and transfer learning, to analyze complex patterns in the collected data and improve model performance.

The benefits of this platform include providing users with personalized health insights and recommendations to improve their sleep quality and overall well-being. It also enables early detection of potential health risks, such as cardiovascular disease, depression, and anxiety disorders. Additionally, the platform helps users optimize their sleep environment, habits, and routines to improve sleep quality and duration, while offering a user-friendly interface and engaging experience.

III. SIMULATIONS AND EXPERIMENTAL RESULTS

Furthermore, the smart pillow's integration with wearable devices, electronic health records, and telehealth platforms enables a holistic approach to sleep medicine, facilitating seamless communication between healthcare providers, patients, and caregivers. By harnessing the power of artificial intelligence, machine learning, and data analytics, the smart pillow provides actionable insights that can inform personalized treatment plans, improve patient outcomes, and enhance the overall quality of life. As the healthcare industry continues to shift towards value-based care, innovative technologies like the smart pillow are poised to play a vital role in transforming the sleep health landscape, enabling more effective disease prevention, diagnosis, and management. By leveraging this cutting-edge technology, healthcare stakeholders can work together to promote better sleep, improved health outcomes, and enhanced patient satisfaction.

IV. CONCLUSION

In conclusion, the smart pillow represents a paradigm shift in sleep medicine, offering a revolutionary approach to sleep health management. By facilitating collaborative care, bridging disciplinary gaps, and harnessing the power of technology, the smart pillow has the potential to transform the lives of millions of people worldwide. As the healthcare landscape continues to evolve, the smart pillow is poised to play a vital role in shaping the future of sleep medicine, enabling better health outcomes, improved patient satisfaction, and reduced healthcare costs. Ultimately, the smart pillow's innovative technology and collaborative approach will help unlock the full potential of sleep medicine, leading to a brighter, healthier future for all.

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