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Embedded IoT Data Collection for Snore Analysis

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ABSTRACT

Internet of Things (IoT)-based devices are in demand for capturing different data types to produce essential information for the receiver. Human sleep behavior is one area open for research, particularly on human snoring. The ESP32 microcontroller was used to modify the processes of capturing human snoring during sleep. This embedded IoT-based device monitors and captures the snoring activity of the human being while sleeping. A prototype of the modified device with its new algorithm was developed, and different test experiments were conducted to test its system performance. Experiment results showcased the accuracy of capturing snoring frequencies beyond established norms and measuring decibel levels within specific parameters. Technical challenges were encountered, such as static interferences and data storage errors, but all were systematically addressed, highlighting the system's robustness. Pilot experiments on EXP1 and EXP2 provided insights into the system's adaptability to different environmental conditions. It is recommended to incorporate upgraded machine learning algorithms into a more powerful microcontroller to improve noise differentiation and computational capabilities and to collaborate with sleep experts to enable diagnostic capabilities. The research emphasizes the system's potential for real-world application in advancing healthcare solutions while highlighting the need for continuous evolution.

Key words : Embedded System, ESP32 Microcontroller, Internet of Things (IoT), Snore Monitoring.

1. INTRODUCTION

In recent years, the Internet of Things (IoT) has sparked a transformative revolution across various sectors, reshaping the landscape of healthcare with innovations like real-time health monitoring services [14]. A notable manifestation of this evolution is witnessed in the realm of sleep monitoring, where the fusion of IoT and embedded technologies, particularly utilizing ESP32, enables the precise tracking of vital parameters such as heart rate, body temperature, and various sleep metrics [12].

Quality sleep is recognized as a cornerstone of overall health, with irregular patterns often signaling underlying health issues [9]. The significance of sleep-related concerns, notably issues related to snoring and insufficient sleep quality, has gained substantial recognition in recent times [10]. While snoring may not always conclusively indicate a sleep disorder, it can be a potential marker for conditions like obstructive sleep apnea (OSA), characterized by recurrent pauses in breathing due to a blocked airway during sleep. The technological strides in IoT lay the foundation for creating a reliable and cost-effective system to monitor patients' sleep quality [7]. However, despite the promising benefits, challenges such as high-power consumption, limited real-world testing, user compliance issues, and data security concerns currently impede the full realization of IoT's potential in healthcare [4], [9], [13].

In the medical field, the development of IoT has garnered significant interest, yet there is a notable gap in home monitoring for snoring [16]. Addressing this void, our project aims to create and deploy an Embedded IoT system specifically designed for collecting snoring data. While the proposed system demonstrates the ability to record accurate data, the intricacies of acoustic environments present challenges that may affect the system's complete accuracy in complex scenarios. The overarching goal of this study is to develop a sleep monitoring system utilizing ESP32 for embedded system design. By capturing valuable sleep data, the system aims to raise awareness of potential sleep disorders and encourage timely medical consultation and treatment. The project outlines specific objectives, including identifying and outlining the components of an Embedded IoT Sleep Monitoring System, developing a prototype, designing an algorithm using Arduino IDE, and conducting tests to validate system performance.

The research project's scope is centered on creating an Embedded IoT-based sleep monitoring system tailored for home-based snoring data collection, leveraging the ESP32 microcontroller. It aims to contribute to sleep monitoring technology by providing practical solutions for tracking snoring patterns and enhancing sleep quality. However, the project acknowledges certain limitations, including the potential restriction of advanced techniques like machine learning due to the ESP32's utilization. The system's effectiveness is contingent on ambient noise levels, posing challenges in distinguishing snoring from other sounds in complex acoustic environments. Additionally, the exclusive focus on individual user data limits the generalizability of findings, emphasizing the need for further research in diverse settings. While the system records snoring data, it does not offer a definitive correlation between snoring and the presence of a sleep disorder. Users are encouraged to consult medical professionals for potential diagnoses or treatments based on the collected data, recognizing the system's role as a tool in fostering awareness and facilitating informed healthcare decisions.

2. BACKGROUND

The study unfolds across crucial domains encompassing embedded systems, the Internet of Things (IoT), microcontrollers, and the health implications of snoring. Embedded systems, as a fusion of software and hardware programmed for specific functions, utilize sensors to capture real-time data on physical parameters such as temperature, motion, and proximity [14]. This capability enables these systems to acquire comprehensive information from the environment, facilitating tasks like environmental control, user interaction, and industrial automation [12]. The rise of IoT technology has brought about transformative possibilities in sleep disorder monitoring [7]. IoT lays the foundation for establishing reliable and cost-effective systems to monitor the sleep quality of patients [7]. Previous studies have explored IoT-based sleep monitoring systems using Arduino microcontrollers and sensors for data collection [3], [4]. While these systems offer real-time surveillance benefits, researchers acknowledge the necessity for broader patient data validation, considerations for real-world implementation, and larger sample sizes. Microcontrollers play a pivotal role in IoT applications, with the ESP32 standing out as a versatile and robust hardware platform [9 1]. Developed by Espressif Systems, the ESP32 boasts a dual-core processor, integrated Wi-Fi and Bluetooth connectivity, and numerous GPIO pins supporting various interfaces. Its energy-efficient design makes it particularly suitable for battery-powered or resource-constrained IoT projects. The adaptability and features of the ESP32 position it as a preferred choice for educational purposes and real-world IoT applications [1]. Researchers have proposed unique approaches using microcontrollers in sleep monitoring. For instance, one study utilized an Arduino UNO microcontroller with a nasal cannula pressure transducer for detecting obstructive sleep apnea (OSA) events [15]. Another proposed an E-Health Sensor Platform v2.0, comprising numerous sensors linked with an Arduino Uno to assess various aspects of human biology, including heart rate, breathing, and skin conductance [5]. However, these methods require further validation and comparative studies to establish their efficacy informed healthcare decisions.

Table 1: Snoring Intensity Range

Snoring Intensity	Decibel Range (dB)
No snoring	≤ 40 dB
Mild snoring	40–45 dB
Moderate snoring	45–55 dB
Severe snoring	55–60 dB

Table 1 shows the intensity of snoring categorized based on decibel ranges, providing a quantitative basis for analysis [11]. The health impact of snoring is underscored, with a focus on its potential indication of OSA, a condition characterized by the regular cessation of breathing during sleep, leading to disrupted sleep cycles and insufficient oxygen supply [2]. Additionally, snoring frequencies are defined within the range of 100 – 300Hz [16]. Traditional methodologies for diagnosing sleep disorders, such as overnight sleep studies, are acknowledged as cost-prohibitive and inconvenient. In response, researchers explore innovative and user-friendly alternatives, including smartphone applications that leverage built-in microphones to analyze acoustic data [2], [15], [16], [17]. The emergence of IoT has brought about novel techniques for observing sleep disorders, leveraging Arduino microcontrollers and sensors for real-time data collection [3], [4], [7]. IoT-based systems offer benefits like real-time surveillance capabilities and potential integration with smartphone apps and cloud storage, enhancing accessibility and user experience [6], [8]. The drive to develop accessible and affordable healthcare tools using embedded systems has expanded, offering promising solutions for sleep apnea detection systems [9]. Wearable designs enable continuous tracking of physical activity and essential health data, potentially improving the detection of conditions like OSA [13], [14]. However, concerns about data security, privacy, high power consumption, limited testing in real-world scenarios, and issues related to user compliance and comfort currently pose challenges to the full realization of these systems [9], [13], [14].

3. OPERATIONAL FRAMEWORK

The study progressed through phases of design, implementation, testing, and evaluation. In the design phase, the researchers identified and acquired necessary hardware (e.g., ESP32, microphones) and software tools (e.g., Arduino IDE, Visual Studio Code). Prototyping involved connecting hardware components, illustrated in pin connection tables for ESP-A and ESP-B modules. Table 2 below shows the module pin connections to the ESP32.

Table 2: Module Pin Connections to ESP32

INMP441 Microphone (ESP-A)	I2C Decibel Sound Level Meter Module (ESP-A)	SD Card Module (ESP-A & B)	MAX9814 Microphone (ESP-B)
L/R – GPIO 17	SDA – GPIO 21	CS – GPIO 05	OUT – GPIO 35
WS – GPIO 16	SCL – GPIO 22	SCK – GPIO 18	
SCK – GPIO 18		MOSI – GPIO 23	
SD – GPIO 25		MISO – GPIO 19	

In the implementation phase, open-source code was customized for snoring data recording and analysis, incorporating FFT calculations and decibel meter readings. Accessing the system's web app is simple: users must connect to the same Wi-Fi network as the system and verify its IP address. To ensure security, users must log in with a username and password. Once logged in, the intuitive web interface empowers users to perform tasks such as activating system functions and managing files. Moreover, within the web app, users can easily download or delete recorded data.
The individual modules like ESP32, SD Card, INMP441 Microphone, MAX9814 Microphone, and Decibel Sound Meter Level Module were then tested to ensure functionality and accuracy. The tests phase revealed issues with SD Card initialization, potential static problems with INMP441, and challenges with MAX9814 audio quality and reliability. The researchers conducted stress tests and made adjustments, clearing some modules for experimentation while identifying issues that required resolution. The evaluation phase involved participants of different ages (EXP1, EXP2, MXP1, MXP2, MXP3) in various sleep cycle durations. The study's claim that the Embedded IoT Sleep Monitoring System excels in detecting frequencies beyond established norms and demonstrates a capacity to measure decibel levels accurately was substantiated through the comprehensive testing and evaluation phases

Table 3: Summative Table of Experiments

Id	Age	Data Points	Frequency		Decibel	
			Mean	Std.	Mean	Std.
EXP1	22	278	228.62	28.92	-No Data	-No Data
EXP2	20	2256	1634.75	2143.73	-No Data	-No Data
MXP1	29	1728	333.27	389.32	45.46	4.04
MXP2	20	108	122.98	16.07	48.73	0.80
MXP3	42	281	166.59	25.93	33.48	1.11

Table 3 shows the snoring frequency and decibel levels among participants, discernible patterns were observed. EXP1, aged 22, demonstrated an average snoring frequency of 228.62, while EXP2, aged 20, presented a higher mean frequency of 1634.75. MXP1, aged 29, exhibited a variable snoring pattern (mean 333.27) accompanied by fluctuating decibel levels (mean 45.46). Conversely, MXP2, aged 20, displayed a more consistent snoring pattern (mean 122.98) and stable decibel levels (mean 48.73). MXP3, aged 42, manifested moderate variability in snoring (mean 166.59) and maintained consistent decibel levels (mean 33.48).

4. SUMMARY, CONCLUSION, AND RECOMMENDATION

4.1 Summary

The study aimed to develop a sleep monitoring system utilizing ESP32 for embedded system design, focusing on recording valuable sleep data for expert medical analysis. The objectives included identifying necessary components, designing and developing a prototype, implementing an algorithm using Arduino IDE, and conducting tests to validate the system's performance.
In the design phase, researchers meticulously identified and acquired essential hardware components, such as the ESP32, microphones (INMP441, MAX9814), and employed software tools like Arduino IDE and Visual Studio Code. Prototyping efforts were focused on establishing connectivity between hardware components, illustrated in detailed pin connection tables for ESP-A and ESP-B modules.
Moving on to the implementation phase, the researchers engaged in the customization of code to record and analyze snoring data. This included incorporating Fast Fourier Transform (FFT) calculations and integrating decibel meter readings. Individual modules, including ESP32, SD Card, INMP441 Microphone, MAX9814 Microphone, and the Decibel Sound Meter Level Module, underwent rigorous testing to ensure both functionality and accuracy. The testing process revealed specific issues such as challenges with SD Card initialization, potential accuracy concerns with the INMP441 Microphone, and difficulties related to the audio quality and reliability of the MAX9814 Microphone. Stress tests were conducted, leading to adjustments that allowed for some modules to be cleared for experimentation, while identified issues were prioritized for resolution.
In the evaluation phase, the researchers engaged participants of different ages (EXP1, EXP2, MXP1, MXP2, MXP3) across various sleep cycle durations. The study's assertion that the Embedded IoT Sleep Monitoring System excelled in detecting frequencies beyond established norms and demonstrated accurate decibel level measurements was substantiated through a comprehensive testing and evaluation process. The iterative nature of the testing phase, with its meticulous identification and resolution of challenges, ensured a robust system capable of addressing real-world scenarios. The study

concludes by advocating for ongoing refinement and adaptability to enhance the system's effectiveness and potentially contribute to early detection of sleep-related problems.

4.2 Conclusion

The embedded IoT sleep monitoring system emerged as a compelling alternative in the world of sleep monitoring, challenging the dominance of mobile apps and smartwatches. Its affordability widened access to sleep monitoring, encouraging more people to participate in research studies. The ESP32's open-source nature and hardware flexibility allowed users to customize data acquisition, analysis, and visualization, making it easier to explore different sleep patterns. Privacy concerns were addressed through local data storage, ensuring control over sensitive sleep information. The ESP32 excelled in providing a nuanced understanding of sleep by analyzing snore frequency trends and temporal patterns, even though users had to do some manual data manipulation. The system's text-file output empowered users to analyze data with their preferred tools, making the ESP32 a practical choice for personalized sleep monitoring and research.

The Embedded IoT-based sleep monitoring system, powered by the ESP32 microcontroller, effectively captured and recorded snoring incidents. The carefully selected hardware components, especially the ESP32 microcontroller, established a robust foundation for comprehensive data collection. Despite notable successes, the system had limitations, including susceptibility to static interference and environmental influences.

In conclusion, the research findings underscored the significant promise of the Embedded IoT-based sleep monitoring system in detecting frequencies beyond established norms and accurately measuring decibel levels. Despite these achievements, the study emphasized the ongoing need for refinement and adaptation to address challenges identified during the experiments. The system's success in real-world scenarios depended on its continual evolution, ensuring adaptability across diverse conditions and reinforcing its pivotal role in advancing healthcare solutions.

4.2 Recommendation

• Incorporation of Machine Learning: To overcome noise differentiation limitations, integrating machine learning algorithms could improve the system's ability to distinguish between snoring and ambient sounds in complex environments. However, this would require a more powerful microcontroller to handle the computational demands of machine learning processes.

• Upgrade to a More Powerful Microcontroller: Considering the integration of machine learning algorithms necessitates a more robust processing capability. Upgrading to a more powerful microcontroller capable of handling complex computations is recommended. This enhancement would open avenues for more sophisticated data analysis and pattern recognition.

• Integration of Snoring Analysis with Medical Experts: Collaborating with sleep experts and medical professionals could provide valuable insights into interpreting sleep data. This collaboration can contribute to refining the system's algorithms based on expert knowledge and would allow diagnostic capabilities.

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REFERENCES

1. Hercog, D., Lerher, T., Truntič, M., & Težak, O. (2023). **Design and implementation of ESP32-based IoT devices**. Sensors, 23(15), 6739. https://doi.org/10.3390/s23156739.
2. Le, V. L., Kim, D., Cho, E., Jang, H., Reyes, R. D., Kim, H., Lee, D., Yoon, I.-Y., Hong, J., & Kim, J.-W. (2023). **Real-time detection of sleep apnea based on breathing sounds and prediction reinforcement using home noises: Algorithm development and validation**. Journal of Medical Internet Research, 25, e44818. https://doi.org/10.2196/44818.
3. Dhruba, R., Alam, K. N., Khan, M. S., Bourouis, S., & Khan, M. M. (2021). **Development of an IoT-based sleep apnea monitoring system for healthcare applications**. Computational and Mathematical Methods in Medicine, 2021, 7152576. https://doi.org/10.1155/2021/7152576.
4. Jaworski, D. J., Park, A., & Park, E. J. (2021). **Internet of things for sleep monitoring**. IEEE Instrumentation & Measurement Magazine, 24(2), 30–36. https://doi.org/10.1109/mim.2021.9400950.
5. Rumpa, L. D., Suluh, S., Ramopoly, I. H., & Jefriyanto, W. (2020). **Development of ECG sensor using Arduino Uno and e-health sensor platform: Mood detection from heartbeat**. Journal of Physics: Conference Series, 1528(1), 012043. https://doi.org/10.1088/1742-6596/1528/1/012043.
6. Seelam, K., & Vippu, S. K. (2020). **Design and implementation of IoT based smart health care monitoring system**. International Research Journal of Engineering and Technology (IRJET), 7(2), 1539.
7. Saleem, K., Bajwa, I. S., Sarwar, N., Anwar, W., & Ashraf, A. (2020). **IoT healthcare: Design of smart and cost-effective sleep quality monitoring system**. Journal

of Sensors, 2020, 1–17. https://doi.org/10.1155/2020/8882378.
8. Begum, R. V., & Dharmarajan, K. (2020). **Smart healthcare monitoring system in IoT**. European Journal of Molecular & Clinical Medicine, 7(4), 2647. ISSN 2515-8260.
9. Yüzer, H., Sümbül, H., & Polat, K. (2020). **A novel wearable real-time sleep apnea detection system based on the acceleration sensor**. IRBM, 41(1), 39–47. https://doi.org/10.1016/j.irbm.2019.10.007.
10. Shattuck, N. L., Matsangas, P., Mysliwiec, V., & Creamer, J. L. (2019). **The role of sleep in human performance and well-being**. In Human Performance Optimization (pp. 200–233). Oxford University Press. https://doi.org/10.1093/oso/9780190455132.003.0010.
11. Westreich, R., Gozlan-Talmor, A., Geva-Robinson, S., Schlaeffer-Yosef, T., Slutsky, T., Chen-Hendel, E., Braiman, D., Sherf, Y., Arotsker, N., Abu-Fraiha, Y., Waldman-Radinsky, L., & Maimon, N. (2019). **The presence of snoring as well as its intensity is underreported by women**. Journal of Clinical Sleep Medicine: JCSM: Official Publication of the American Academy of Sleep Medicine, 15(03), 471–476. https://doi.org/10.5664/jcsm.7678.
12. Anandh, R., & Indirani, G. (2018). **Real time health monitoring system using Arduino with cloud technology**. Asian Journal of Computer Science and Technology, 7(S1), 29–32. https://doi.org/10.51983/ajcst-2018.7.s1.1810.
13. Taffoni, F., Rivera, D., La Camera, A., Nicolò, A., Velasco, J. R., & Massaroni, C. (2018). **A wearable system for real-time continuous monitoring of physical activity**. Journal of Healthcare Engineering, 2018, 1878354. https://doi.org/10.1155/2018/1878354.
14. Jayapradha, S., & Vincent, P. M. D. R. (2017). **An IOT based human healthcare system using Arduino uno board**. In 2017 International Conference on Intelligent Computing, Instrumentation and Control Technologies (ICICICT). https://doi.org/10.1109/ICICICT1.2017.8342681.
15. John, K. J. A. (2015). **Arduino Uno based obstructive sleep apnea detection using respiratory signal**. International Journal of Research in Engineering and Technology, 04(03), 599–603. https://doi.org/10.15623/ijret.2015.0403100.
16. Nakano, H., Hirayama, K., Sadamitsu, Y., Toshimitsu, A., Fujita, H., Shin, S., & Tanigawa, T. (2014). **Monitoring sound to quantify snoring and sleep apnea severity using a smartphone: Proof of concept**. Journal of Clinical Sleep Medicine: JCSM: Official Publication of the American Academy of Sleep Medicine, 10(1), 73–78. https://doi.org/10.5664/jcsm.3364.
17. Alqassim, S., Ganesh, M., Khoja, S., Zaidi, M., Aloul, F., & Sagahyroon, A. (2012). **Sleep apnea monitoring using mobile phones**. In 2012 IEEE 14th International Conference on E-Health Networking, Applications and Services (Healthcom). https://doi.org/10.1109/HealthCom.2012.6379457.