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Wearable Piezoelectric Sensor System for Real-Time Detection of Sleep Bruxism

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Abstract

Sleep bruxism is a condition in which people grind their teeth or clench their jaw unconsciously during sleep. It can cause tooth wear, jaw pain, headaches, muscle fatigue, and TMJ issues if left untreated. Polysomnography (PSG), Electromyography (EMG), are dependable and are more expensive, less comfortable, and not suitable for long-term use at home. In order to address these drawbacks, a novel real time sleep bruxism detection system based on a low-cost piezoelectric sensor for a wearable device is proposed. The system to be proposed is based on a piezoelectric vibration sensor which is mounted close to the masseter muscle, to detect the vibrations generated during teeth grinding and jaw clenching. These sensor signals are analysed with an Arduino Uno, after signal conditioning, to detect abnormal jaw movements based on thresholds. If bruxism is detected, the system immediately alerts with an LED and buzzer. Meanwhile, the sensor values are continuously recorded on a microSD card module in CSV format for later analysis. There is also a mobile app for Bluetooth wireless real-time monitoring Results of the experiments demonstrated the applicability of the developed system for the detection of vibrations related to bruxism with a low power consumption, compact dimensions, and user comfort.

Introduction

Sleep bruxism is a sleep-related disorder that involves grinding of teeth and jaw clenching during sleep [(McAuliffe et al., 2015; Thomas et al., 2024)]. One of the most prevalent parafunctional activities among people of various age groups is considered [(Matusz et al., 2022; Thomas et al., 2024a; Wajdowicz et al., 2024)]. People may even be unaware of the condition, as the activity is done in the unconscious state while sleeping [(Wajdowicz et al., 2024; Yanez-Regonesi et al., 2023a)]. While occasional grinding is not necessarily a severe problem, chronic grinding can lead to heavy dental wear and tear, jaw pain, headaches, muscle fatigue and pain, facial discomfort, and TMJ (temporomandibular joint disorder) problems [(Lobbezoo et al., 2018; Maejima et al., 2024; Thomas et al., 2024a; Wajdowicz et al., 2024)]. Dental restorations may also wear down if the teeth continue to grind. This can also have a negative impact on sleep quality [(Li et al., 2024a)]. Early detection and monitoring of sleep bruxism is essential for the prevention of oral and muscular complications from sleep bruxism, as it can be difficult to detect and can progress over time [(McAuliffe et al., 2015; Thomas et al., 2024)].

Conventional diagnostic techniques such as Polysomnography (PSG) and Electromyography (EMG) are widely used for clinical assessment of sleep bruxism [(McAuliffe et al., 2015; Raphael et al., 2012; **"Utility and Validity of a New EMG-Based Bruxism Detection System. | EBSCOhost," n.d.;** Yanez-Regonesi et al., 2023)]. PSG records all physiological signs such as breathing, muscle movement and brain activity, while the EMG is the electrical activity of the jaw muscles during clenching and grinding. These methods are useful for a reliable diagnosis but come with a number of limitations. The systems are costly, need to be used in a specialized clinical setup, and need the patient to wear a number of electrodes and monitoring apparatus, which not only compromises the patient's comfort but also disrupts their natural sleeping rhythm. Consequently, they are not ideal for either long-term or continuous home monitoring [(Maoddi et al., 2022a; Tajitsu et al., 2023)].

The recent advances in wearable healthcare technologies and embedded systems have opened the door to new possibilities for designing lower cost and more simple alternatives to physiological monitoring [(Maoddi et al., 2022a; Wang et al., 2025)]. Piezoelectric sensors have attracted great interest due to their ability to generate an elevated level of electrical signal at a high sensitivity, based on mechanical vibrations [(Baba et al., 2003; Flores-Ramírez et al., 2025; Tajitsu et al., 2023)]. The vibration patterns generated in the jaw during teeth grinding and gnashing can be captured well by using piezoelectric sensors near the masseter muscle [(Baba et al., 2003; Tajitsu et al., 2023; Wang et al., 2025)]. These sensors are small, light, flexible, consume low power, which makes them suitable for wearables and portable healthcare applications.

This paper proposes an embedded sleep bruxism detection system based on a piezoelectric sensing technique that is low in cost. In the developed system, a piezoelectric vibration sensor is combined with an Arduino Uno microcontroller to monitor continuously the movement of the jaws while the user is sleeping. The acquired vibration signals go through real-time processing of filtering and threshold-based analysis techniques to detect abnormal grinding and clenching patterns [(Baba et al., 2003; Tajitsu et al., 2023; Wang et al., 2025)]. The system immediately displays and sounds an alarm when bruxism activity is detected, using an LED and buzzer. Furthermore, the data is continually recorded on a microSD card module in CSV format, which can be utilized for long-term monitoring and analysis in the future. It also includes Bluetooth communication to enable wireless real-time monitoring via a mobile application [(Maoddi et al., 2022a)]. The proposed system would aim to offer an inexpensive, compact, and user-friendly approach to sleep bruxism monitoring in the home to facilitate the accessibility of early diagnosis and preventive measures [(Maoddi et al., 2022a; Tajitsu et al., 2023)].

The use of a piezoelectric intra-splint force detector for detecting bruxism episodes was compared with portable polysomnography in a pilot study, showing the potential effectiveness of piezoelectric sensing to directly measure occlusal force for bruxism detection [(Nahhas et al., 2024, 2024)]. High sensitivity and moderate agreement were reported with EMG recording indicating piezoelectric sensors as potential viable alternatives to long-term home monitoring. Some problems, including false positive detections and lower sensitivity to a prolonged clenching activity were also found. A similar study presented herein was the creation of a splint-based bruxism detection system with embedded pressure sensors which can distinguish bruxism movements from normal oral activities [(Wajdowicz et al., 2024b; Gao et al., 2020)]. The wireless and comfortable system was appropriate for continual monitoring at home.

Some studies have explored the application of EMG with an intelligent algorithm to achieve better accuracy in detection. A complex sensory system that interprets the muscle signals from the temporalis and masseter muscle was used to determine the postures of the sleep positions, with the help of machine learning. The use of machine learning classifiers, such as Random Forest and Support Vector Machines, significantly increased the accuracy of classification and resulted in almost 93% of accuracy in the identification of bruxism events [(Raphael et al., 2012b)]. This study also emphasized the need to consider several sleep postures in monitoring. Similarly, portable instrumental instruments like Bruxoff®

were evaluated against PSG and were found to be suitable for clinical screening purposes, but not a substitute for gold standard tests [**(Yoshida et al., 2017; Kim et al., n.d.)**].

Non-contact and wearable monitoring systems have also become a hot topic since they decrease patient discomfort. A study involving the use of braided piezoelectric poly-l-lactic acid (PLLA) cord sensor embedded in a bed sheet showed an accurate measurement of sleep bruxism without any sensors directly attached to the body to measure it [**(**Pollis et al., 2022)]. The system successfully and accurately retained the high user comfort and maintained a prominent level of accuracy (over 95%). One study developed an acousto-mechanical inertial measurement unit (IMU) based wearable bruxism detection system [**("Utility and Validity of a New EMG-Based Bruxism Detection System. | EBSCOhost," n.d.)**]. The movement and sound analysis enabled the device to distinguish between activities related to bruxism and other normal activities, like talking or yawning.

Due to their compact size, low power consumption, and ability to sense vibration signals, piezoelectric sensing technologies have been extensively researched. An interdental pressure and force intensity measurement system was developed to measure the interdental pressure and the intensity of the forces produced by the teeth during bruxism, with an instrumented dental splint that would not interfere with the patient's bite [(McAuliffe et al., 2015b; Bondareva et al., 2021; Nahhas et al., 2024)]. The experimental results showed reliable detection of bruxism episodes both in lab and real time setting. In another study, a wireless bruxism monitoring device using pressure-sensitive polymers was embedded in a bite guard that was able to transmit data in real time and monitor the activity over the long-term [(Miettinen et al., 2018)].

Physiological characteristics and clinical findings of sleep bruxism are also being studied. When examining the pattern of jaw motor activity during sleep, using video-polysomnography studies, strong correlations were observed between tooth grinding sounds, tooth wear, and rhythmic jaw muscle activity in sleep [**(**Li et al., 2024b; Yanez-Regonesi et al., 2023b**)**]. Other population-based studies also indicated that the most crucial factors associated with sleep bruxism were stress, anxiety, smoking, alcohol consumption, snoring, and obstructive sleep apnea [**(**Nakamura et al., 2019; Lee et al., 2013)].

The literature on wearable and ambulatory monitoring systems showed that portable sensor-based technology provides significant benefits over traditional clinical systems, such as portability, comfort for the user and long-time monitoring. But several of the current systems have problems with false positive detections, lack of standardization, and small-scale validation in the real world. Thus, a low cost, compact, and portable wearable system that can continuously track bruxism activity in the home environment is needed. Based on these observations, the authors present a practical wearable piezoelectric sensor-based sleep bruxism detection system with real-time monitoring and alert in home environment.

Materials and Methodology

The proposed system was designed to be low-cost, wearable, and non-invasive for sleep bruxism detection in real-time. The methodology was based on the continuous monitoring of jaw vibration signals generated in clenching and grinding activities by the adoption of a piezoelectric sensing methodology, combined with embedded processing techniques. The entire system is designed to be portable, energy efficient, comfortable for the user and appropriate for long-term home-based monitoring. The complete architecture comprised sensing module, signal conditioning module, processing module, alert module, data logging module, and wireless communication module.

The primary sensor was a piezoelectric vibration sensor which had small size, flexibility, low cost, and high sensitivity to mechanical vibration. The sensor was placed close to the masseter muscle that is a key muscle in jaw clenching and teeth grinding. When the jaw moves, it is mechanically deformed and produces electrical signals which are proportional to the strength of the vibration. The placement allowed for the acquisition of sleep bruxism vibration patterns without compromising user comfort when monitoring. The light weight of the sensor also allowed it to be used in wearable applications, with minimal disturbance while sleeping.

The analog signals generated by the piezoelectric sensor was collected continuously by the analog input pin of ATmega328P microcontroller namely Arduino Uno. The low power consumption, analog signal acquisition, ease of interfacing with the Arduino and compatibility with the external communication modules made the Arduino Uno the ideal choice. Raw sensor data had noise and other fluctuations due to environmental disturbances and body movements, so a signal conditioning stage was added before processing. For signal stabilization and elimination of unwanted high frequency noise, a filtering circuit was used which relied on RC elements (resistor and capacitor). The resistor was used to provide a fast decay time upon pressure release, and the capacitor was used to reduce the signal variations and enhance the signal stability.

All conditioned signals were treated in real-time by implementing a threshold-based detection algorithm into the microcontroller. During testing, a threshold value was determined experimentally, and the Arduino continuously read the sensor values received and compared them to the threshold value. The vibration amplitude was set as threshold limit and if the amplitude exceeded the threshold limit, the system determined the occurrence as abnormal jaw activity related to the bruxism. The threshold was used as the reference for values below it, indicating normal conditions. Minimisation of false detections due to small fluctuations and external disturbances was also achieved by basic filtering and smoothing operations. The processing methods were lightweight in order to achieve an efficient execution on the embedded platform with its limited computational resources.

The system had both visual and auditory alert features that would give instant feedback during a bruxism event. As the vibration was detected and exceeded the threshold, the Arduino would turn on an LED, as well as a piezo buzzer. The LED gave a visual warning of any abnormality while the buzzer gave an audible warning to raise the behavioural awareness and interrupt any prolonged grinding activity. The

response time of the system was found to be exceptionally low which allows almost real time detection and feedback while operating.

A microSD card module was also integrated into the system for data logging and further analysis over the long term. The DS3231 Real-Time Clock (RTC) module was used to store sensor data and timestamps in CSV format to ensure the data is recorded at the correct time. Data stored allowed for offline analysis of bruxism frequency, duration, and intensity over an extended period. Using CSV format also made it easier to operate with external tools for data analysis and other future machine learning applications.

A HC-05 Bluetooth module was used to interface with the Arduino and enable wireless communication. The Serial Bluetooth Terminal app was used to wirelessly send real-time sensor data and detection results to a mobile device. This was a feature which allowed for easy remote monitoring without the need for a direct computer connection. As far as the Bluetooth interface is concerned, it made the system portable and made it more easily usable by home applications.

The developed prototype was evaluated experimentally in various operating conditions such as normal rest and simulated jaw closure/grinding condition. The sensor output was stable and near zero in idle mode. The simulated bruxism events resulted in clear vibration amplitude increase and the algorithm based on threshold was able to detect these increases successfully. Multiple testing showed that the system responds to test consistently, that the alerts are generated reliably, and that the data logging works well. Some wear and tear were noted, but the filtering techniques used were effective in eliminating noises and increasing the reliability of the detection.

The proposed method suggests a practical and efficient method for real-time monitoring of sleep bruxism with embedded piezoelectric sensing technology. Combining the functions of wearable sensing, real-time signal processing, wireless communication, and long-term data storage yields a compact, cost-effective system that is feasible for home healthcare applications.

Results

The developed wearable piezoelectric sensor system has been evaluated and validated in resting condition and simulated sleep bruxism activities such as jaw clenching and teeth grinding. In experimental tests, under normal jaw conditions, the sensor output was close to the baseline level, whereas simulated bruxism events resulted in significantly higher vibration amplitude. Their resting values were almost zero, while the recorded values during clenching and grinding were between 130 and 417 ADC counts. The clear distinction between normal and abnormal jaw activity clearly illustrates how effective the piezoelectric sensor is in identifying vibration patterns of bruxism.

Table 7.1
Sensor Response Under Different Conditions

Condition	Observed sensor range (ADC counts)
Resting State	0–20
Mild Clenching	130–250
Moderate Grinding	250–350
Strong Grinding	≥350

The threshold-based algorithm was successfully implemented on the Arduino UNO and was able to detect abnormal vibrations of the jaw when the sensor output surpassed the threshold value. Throughout the simulated bruxism events, the system was able to produce detection messages but remained stable during rest. The simple thresholding method allowed the system to be easily implemented in real-time without the need for computationally intensive methods and hence was suitable for a low-cost embedded implementation.

The visual and sound warning devices performed well during the tests. The LED indicator and buzzer were activated as soon as abnormal vibration patterns were detected to immediately give the user feedback. The system was successfully evaluated for stable operation without any perceptible delay between vibration detection and generation of warning, thus proving its suitability for continuous monitoring applications.

A successful wireless communication was achieved using HC-05 Bluetooth module with the Serial Bluetooth Terminal app. The readings obtained from the sensors were in good agreement with those obtained in the Arduino IDE Serial Monitor, showing good wireless data transmission. The microSD card module also stored the values of the sensors along with the RTC module's information regarding the time, allowing the analysis to be performed in the future and storing the events collected from bruxism for prolonged periods of time.

The benefits of the proposed system are demonstrated by comparing to conventional bruxism detection methods. Although polysomnography is still the clinical gold standard for diagnosis, it is very costly and requires special equipment, a special laboratory setting, and trained personnel. Systems based on EMG are accurate, require multiple electrodes, are more complicated, and are less comfortable for the user when used for prolonged periods. Contrary to this, the proposed piezoelectric sensor system requires a single wearable sensor, provides real time monitoring, wireless data transfer, data logging, and immediate alert generation, and is cost-effective and portable.

Table 7.2
Comparison with Existing Bruxism Detection Systems

Parameter	Polysomnography (PSG)	EMG-Based Systems	Proposed Piezoelectric System
Cost	Very High	High	Low
Number of Sensors	Multiple	Multiple Electrodes	Single Sensor
Clinical Setup Required	Yes	Often Required	No
User Comfort	Low	Moderate	High
Wearability	Low	Moderate	High
Portability	Low	Moderate	High
Real-Time Alerts	No	Limited	Yes
Bluetooth Monitoring	Limited	Available in Some Systems	Yes
Data Logging	Yes	Yes	Yes
Home-Based Monitoring	Limited	Moderate	Yes

The proposed system is quite simple in terms of hardware and has almost all the required monitoring functions. The small design with a piezoelectric sensor, Arduino Uno, Bluetooth module, RTC module and microSD module makes it easy to deploy and operate. Overall system cost is significantly less than conventional PSG and EMG systems and is a viable alternative for initial screening and long-term monitoring of sleep bruxism.

Table 7.3
Hardware Complexity Comparison

Parameter	Conventional PSG System	EMG System	Proposed System
Hardware Complexity	High	Moderate	Low
Setup Time	Long	Moderate	Short
Mobility	Low	Moderate	High
Continuous Home Monitoring	Limited	Moderate	High
Ease of Use	Low	Moderate	High

Finally, the experimental results showed that the proposed wearable piezoelectric sensing system can effectively capture the vibrations of the jaws during simulated bruxism activities, with reliable results,

and alert the user in real-time, wirelessly monitor or log the data continuously. The system is low cost, portable and easy-to-use for home-based monitoring of bruxism and provides a solid platform for future incorporation of further sophisticated signal processing and machine learning methods to improve detection accuracy.

Discussion

The outcomes achieved with the proposed bruxism detection system using piezoelectric sensors show that embedded wearable technology is suitable for continuous monitoring of sleep bruxism, which could be performed at home. By real-time analysis of vibration amplitude patterns, the system was able to effectively distinguish normal jaw conditions and abnormal activities such as clenching and grinding. The sharp difference between the baseline signals and vibrations found in bruxism suggests that piezoelectric sensing can be used to capture mechanical jaw movements during sleep bruxism [(McAuliffe et al., 2015b; Nahhas et al., 2024)].

The major advantage of the developed system is the simplicity and low cost of the developed system compared to the conventional clinical diagnostic solutions like polysomnography and electromyography [(Gul et al., 2024)]. Traditional systems are complex and have to be set up in a laboratory, with several electrodes, and personnel trained to use them, making them impractical for routine use. The proposed system, however, offers a compact, light, and low-cost solution that can be continuously used at home without discomfort to the user [(Bondareva et al., 2021; Gao et al., 2020; **"Utility and Validity of a New EMG-Based Bruxism Detection System. | EBSCOhost," n.d.)**]. Real-time alerts, data logging, and Bluetooth connectivity further enhance user-friendliness and enable future monitoring applications.

The threshold-based detection approach achieved good detection results for prototype implementation and allowed efficient real-time processing with a low-power microcontroller. But some limitations were noted while testing. Minor fluctuations in the acquired signals were sometimes introduced by external vibrations or by the body's movements or by changes in the sensor's position. These disturbances were reduced by filtering and smoothing but further improvement in signal processing could improve overall accuracy and robustness. Furthermore, due to the differences between jaw force profile among users and the physiological variation of bruxism, fixed threshold values might not perform in exactly the same manner.

Overall, the developed system offers a solid platform for further study in the field of wearable bruxism monitoring, despite the above-mentioned limitations. Recorded sensor data can be used for advanced feature extraction and machine learning-based classification methods to further enhance detection performance and minimize false detections [(Miettinen et al., 2018; Raphael et al., 2012b; Thomas et al., 2024b)]. In general, the study confirms that the embedded piezoelectric technology is promising for clinical and non-clinical applications, which are low cost, non-invasive, and continuous monitoring of sleep bruxism [(Braz De Oliveira et al., 2021; McAuliffe et al., 2015b)].

Declarations

Ethical Statements:

This study was conducted using publicly available datasets only. No new data was collected directly from human participants or animals. The datasets used were obtained from open-access sources that complied with relevant ethical and institutional guidelines. As the research did not involve direct human or animal involvement, ethical approval and informed consent were not required.

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Declaration of Interest:

The authors declare that there is no conflict of interest in the publication of this article

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Figures

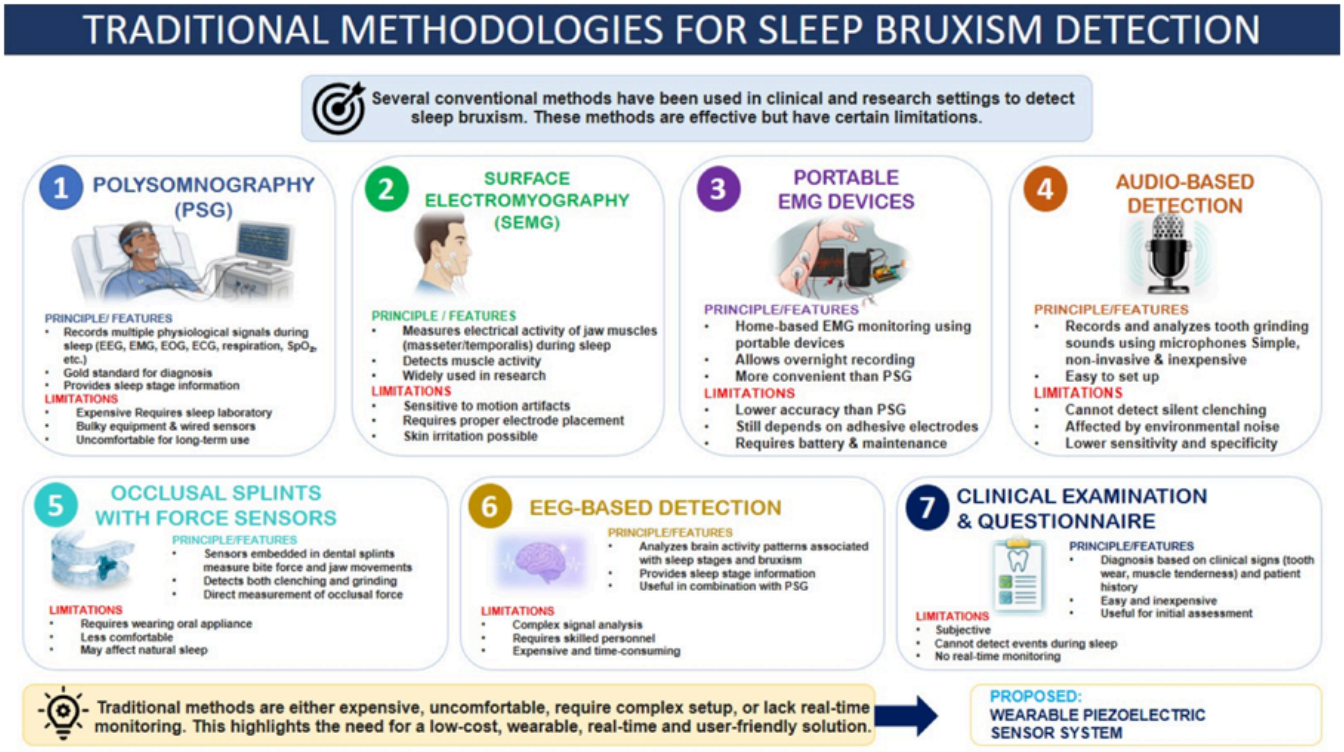


Figure 1

Comparison of Conventional Sleep Bruxism Detection Methods

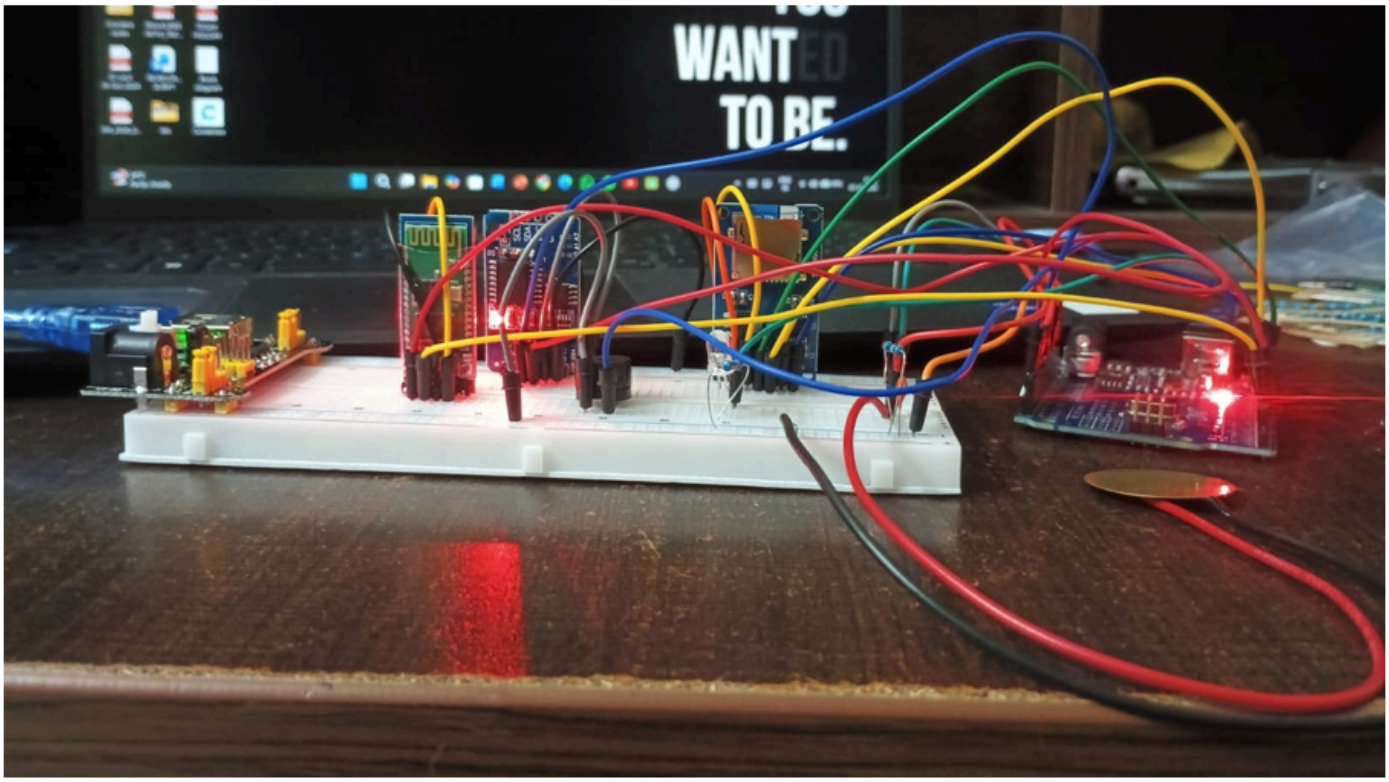


Figure 2

Experimental Setup of the Wearable Piezoelectric Sensor System



Figure 3

Real-Time Testing of the Wearable Piezoelectric Sensor on a Subject

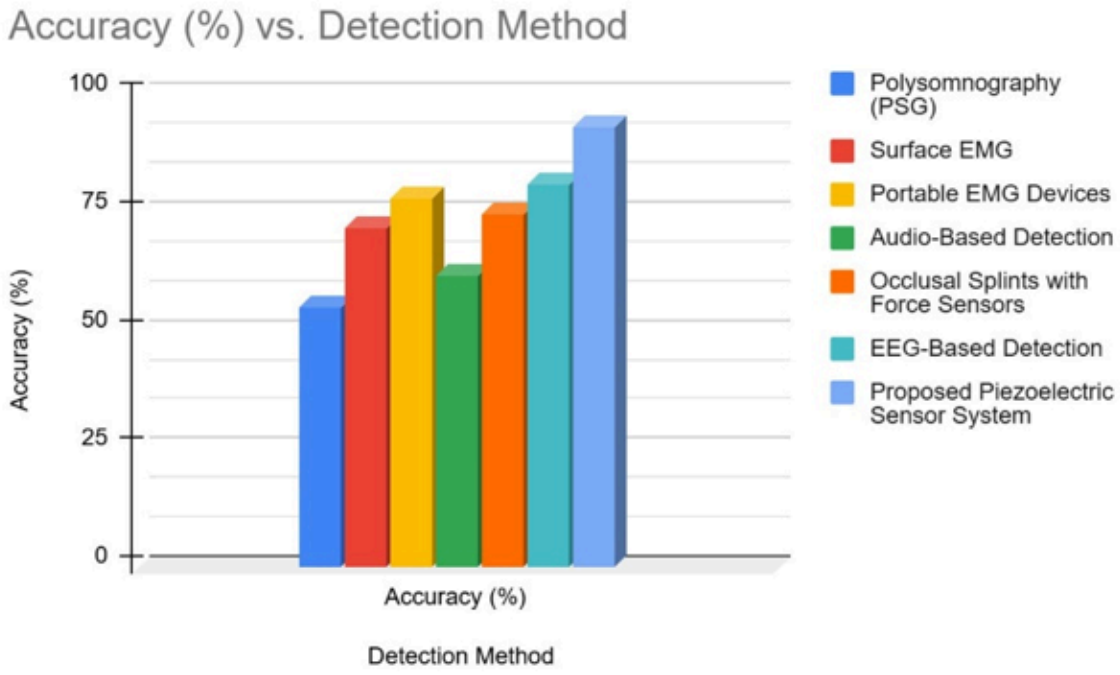


Figure 4

Accuracy Comparison of Different Sleep Bruxism Detection Methods

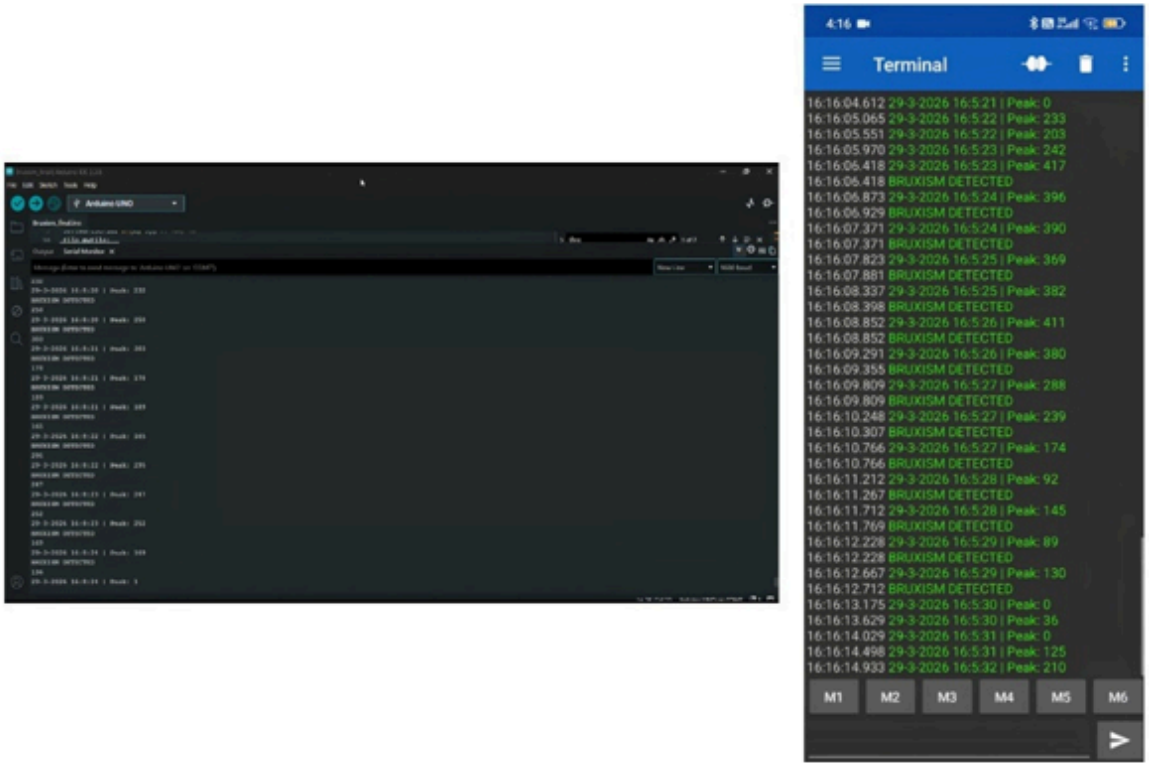


Figure 5

Real-Time Sensor Data Monitoring Using Arduino Serial Monitor and Bluetooth Terminal

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