Design of a Wearable Bruxism Detection Device

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Abstract—**Bruxism is a common problem which impacts on between 8 –31% of the general population and presents several symptoms including headaches, facial pain and damage to teeth for sufferers. While gold-standard technologies (e.g. polysomnography) exist and can be used in a clinical context for the diagnosis of bruxism, these are cumbersome and are constrained to laboratory-based testing as a result. In recent years, a number of portable wearable technologies have been developed and evaluated which are based on electromyography, electroencephalography, and/or electrocardiography. In this paper, the development of a novel wearable bruxism detection device based on Inertial Measurement Units (IMU) and a microphone is described as an alternative diagnostic tool for bruxism. The overall system architecture is defined and the implemented hardware platforms are described in detail. Finally, a discussion on the future work is also provided.**

Keywords— Accelerometer; Bruxism; IMU; Microphone; Sensors; Wearable

I. Introduction

The use of wearable sensors for monitoring various health-related biometric parameters in everyday activities is attracting more and more interest recently [1-2] in academic, clinical and medical device manufacturing communities.

Continuous monitoring of physiological datasets through the use of wearable sensors will facilitate a number of healthcare services, enabling the early detection of acute/emergency conditions and diseases in at-risk patients, to the management of chronic conditions in people with various degrees of cognitive and physical disabilities [3].

In the domain of ICT for Healthcare, the monitoring of a number of conditions (i.e. physiotherapy and rehabilitation, Parkinson's disease, ageing, etc.) using wearable technology has previously been considered in literature [4-5]. However, despite the fact that the market for the monitoring of oral conditions is projected to reach $ 600 million by 2023 [6], technology meeting this need has not yet reached its full potential. For example, the number of studies published on PubMed with "oral" and "wearable" as keywords were only 35 in 2019 and 15 in 2017. However, in common with technological innovations in other health domains, the development of relevant technologies for oral healthcare will facilitate the move to a sustainable 21st century oral healthcare system. Such technology developments will help engage patients more effectively and deliver timely and personalised behavioural change to support optimal oral health [7].

In particular, bruxism is an oral condition characterised by excessive teeth grinding or jaw clenching, unrelated to normal function such as eating or talking [8]. Bruxism is a common problem which impacts on 8–31% of the general population [8] and includes symptoms such as hypersensitive teeth, aching jaw muscles, headaches, tooth wear, damage to dental restorations (e.g. crowns and fillings), and damage to teeth [9]. Depending on the severity of the condition, diagnosis can be difficult and some sufferers may not be aware that they have the condition, resulting in long-term implications to their health [10]. The current diagnosis of bruxism in dental practice is mostly based on case history, tooth mobility, tooth wear and other clinical findings.

The gold standard in the detection of bruxism is polysomnography (PSG) [8], which involves multi-modal measurements of such parameters as electroencephalography (EEG), electromyography (EMG), electrocardiography (ECG), air flow monitoring and audio–video recording, and it is adopted to detect increased masseter and temporalis muscular activity during sleep typical of bruxism events [11]. This system is quite cumbersome due to the number of electrode channels and sensors required to be worn by the patients and is typically conducted in a laboratory environment as a result.

A number of studies have adopted various technologies for the development of portable solutions. For instance, Maeda et al. [12] developed an ultra-miniature wearable EMG device for monitoring the masseteric muscle. A combination of EMG and 2-axis accelerometers was considered by Yoshimi et al. [13] showing the possibility of distinguishing between tapping, clenching and grinding of the teeth. An EEG-based device was proposed in [14], while the adoption of miniature pressure sensors embedded in splints with biofeedback treatment was investigated in [15-17]. Finally, the use of a single chin-mounted accelerometer was instead proposed in [18].

To date, the combination of sound and Inertial Measurement Units (IMUs) as a diagnostic system for bruxism has not been studied extensively. Hence, the goal of the current paper is to describe the current work-in-progress associated to the design and development of a wearable bruxism detection device based on a combination of accelerometers and microphones, which would allow patients to use the device remotely in a home environment.

The manuscript is organised as follows. An analysis of the devices currently available on the market is carried out in Section II. The system architecture and HW prototyping is described in Section III, while Section IV illustrates the future work. Conclusions are finally drawn in Section V.

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II. State-of-the-Art of Bruxism Systems

The rising prevalence of Obstructive Sleep Apnea (OSA) is likely to propel the demand for sleeping bruxism diagnosis [6]. Indeed, bruxism, temporomandibular joint (TMJ) disorders, and orofacial pain are also very commonly co-morbid with OSA. As a result, there are a number of wearable devices on the market that claim to help monitor and/or prevent bruxism (Figure 1). A recent literature review specifically targeting EMG-based devices for the assessment of bruxism is shown in [19].

One of the most well-known bruxism analysis systems is the Bruxoff device (Bioelettronica, Turin, Italy) [20] which is a portable EMG/ECG device [21]. Additional products combining different sensing technologies include BiteStrip, Bruxane, GrindCare, FLA, SleepScore Labs, Sleep Guard, and STATDDS [22-28]. A comparison of the different solutions is provided in Table I.

Fig. 1. Examples of bruxism devices on the market (from top left to bottom right: Bruxoff [21], Bitestrip [22], Bruxane [23], GrindCare [24], SleepScore Labs [26])

TABLE I. State-of-the-Art Bruxism Systems

Product	Sensing Technology				Biofeedback
	EMG	*ECG*	*IMU*	*Other*	
Bruxoff [21]	X	X			
Bitestrip [22] – discontinued	X				
Bruxane [23]				Pressure sensor in dental splint	Vibration / Audio
GrindCare [24]	X				Pulse
FLA [25]	X				
SleepScore Labs [26]				Audio	
Sleep Guard [27]	X				Audio
STATDDS [28]	X			Physiological sensing	

While the majority of the devices are EMG-based, EMG systems need to overcome crosstalk issues (which is relevant especially on the face because of the small muscles present being measured), they are required to achieve high resolution and specificity in sensed data sets, and avoid the use of gelled electrodes for subject comfort [29]. Thus, to date the possibility to develop a low-cost solution based on IMUs and microphone represents a novelty that has not been extensively studied in the relevant literature and exploited on the market.

III. Prototype Design and Development

A. System Architecture

Described in more detail in the following section, Figure 2 shows a high-level block diagram of the overall system architecture for the envisioned bruxism monitoring system. The system incorporates two 3- axis IMUs to be placed on the chin and the masseter muscle to capture motion parameters of the jaw, as well as a microphone placed on the cheek to capture acoustic signals. The system is also equipped with a high-performance low-power processing unit, a Bluetooth Low-Energy (BLE) transceiver for data communication to a laptop/smartphone, a power management unit with a rechargeable battery (charged via USB), LEDs, and an event button, to allow the tested subject to mark a bruxism event (useful for validation purposes). The bruxism events [30] were classified as:

a) Gnashing/Biting: Tapping of teeth against one another using an up and down movement.

b) Grinding: Rubbing teeth of upper and lower jaw against each other in a sidewise manner.

c) Clenching: The act of pressing teeth of upper and lower jaws shut tightly together.

The sensors connect to the micro-controller over the I^2C bus. The sensed data collected when placed on a patients jaw allows the system to provide an indication on the number of bruxism events detected and their duration. This detection could be obtained by relying either on on-board analytics or on algorithms running on a connected smartphone which could also be used for visualisation purposes.

Two hardware prototypes were built: the first one based on evaluation boards used to prove the principle, and a final one which was an in-house custom-designed Printed Circuit Board (PCB) miniaturised to improve user comfort when in use. In the selection of the sensors, particular attention has been paid to the trade-off between small size, power efficiency and overall performance of the components.

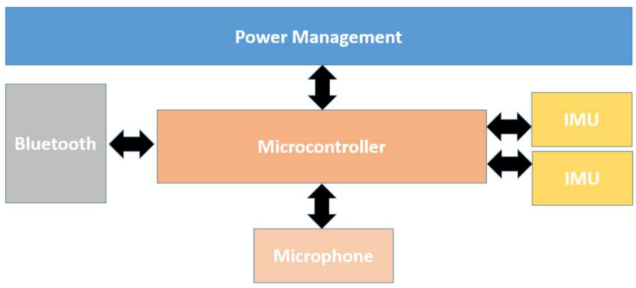

Fig. 2. System architecture for the bruxism diagnostic system

B. First Prototype

The first prototype developed as a proof-of-principle was based on the microcontroller NXP LPC1768 development board [31], two Analog Devices ADXL345 IMU evaluation boards [32], and one Analog Devices ADMP401 [33] MEMS microphone.

The NXP LPC1786 development board was chosen because is a cost-effective, low-power Cortex-M3 device that operates at up to 100 MHz, which features best-in-class peripheral support, it has 512 KB of Flash memory and 64 KB of Static Random-Access Memory (SRAM). The architecture uses a multi-layer Advanced High performance Bus (AHB) bus that allows high-bandwidth peripherals to run simultaneously, without impacting performance.

The ADXL345 accelerometer has a form factor which is extremely small and makes it suitable for such wearable applications.

Finally, the selected microphone data acquisition module is based on the ADMP401 Micro Electro-Mechanical System (MEMS) microphone development kits. The ADMP401 has a high signal-to-noise ratio, flat wideband frequency response, resulting in natural sound with high intelligibility, and low current consumption. Its characteristics are similar to the ones of directional microphones used as gold-standard in literature [34-35]. Figures 3-4 show the developed prototype in a custom-built 3D enclosure and worn by a subject for data collection.

Fig. 3. First prototype developed

Fig. 4. First prototype worn by a subject

To validate the prototype design concept, the prototype bruxism diagnostic system was tested on ten volunteers. Each volunteer wore the Rev 1 prototype and followed a set protocol involving a sequence of bruxism events (biting / grinding / clenching) for 20 seconds followed by a rest period of 20 seconds. This protocol, was repeated for each of the three events considered, thus there was a sequence of biting, followed by one of clenching followed by one of grinding. The participants also simulated three non-bruxism but sleep-related actions (e.g., snoring, talking, and yawning). These activities were repeated three times each. Figure 5 shows an example of the data collected by the board for one data collection sequence. It shows the X, Y, and Z axis values of the accelerometers and gyroscope data of the two IMUs, microphone, and event button outputs. The event button was used to easily identify the event from each participant. Thus, Figure 5 shows that, ideally, the developed system could collect the relevant data required to support in the identification of different bruxism events in a subject.

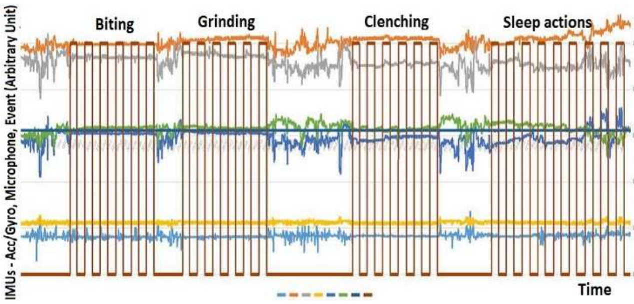

Fig. 5. Example of data collected by the board (3D acceleration for the two IMUs, microphone, and event button)

C. *Second Prototype*

Based on the results obtained with the first proof-of-principle prototype following the initial validation tests described in the previous section, a second, miniaturised prototype was designed, fabricated, and assembled. Figure 6 shows the PCB layout and the finished prototype assembly. This next generation embedded system design presents a more integrated, compact device, and uses flexible connectors to connect the inertial sensors and, hence, is more lightweight and easy to wear by end-users. It is designed around a 6-layer, flexi rigid board which can be used with any type of batteries (including coin cell) or alternatively a Universal Serial Bus (USB) cable as a power supply. This prototype integrates the system building blocks presented by the previous development boards using the same MEMS components and consists of a main board (of dimension 3.5 x 4 x 0.6 cm) worn on the cheek which is connected to two "islands" (both of dimension 0.5 x 0.5 x 0.4 cm) including the motion sensors and located in correspondence of the chin and the masseter muscle to provide accurate measurement of acoustic and inertial parameters associated with the motions associated with bruxism.

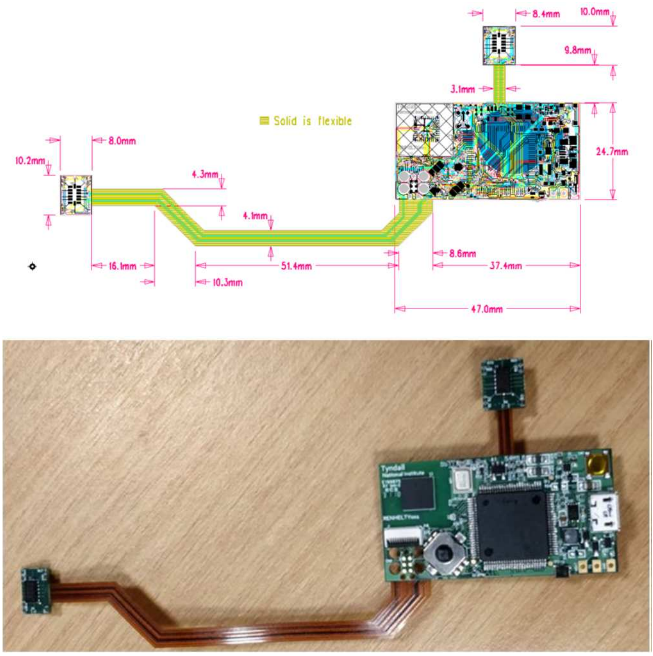

Fig. 6. PCB layout and developed PCB for final prototype

IV. Future Works

This paper describes the early stage research in the development of a prototype wearable bruxism detection device based on a combination of accelerometers and microphone, to detect sensor datasets associated with the diagnosis of bruxism.

There are a number of planned phases for future test and development for the current revision of the prototype. The embedded system should be complemented with a software platform performing relevant data analysis of the sensed signals running on a mobile application with the goal to offer an easy to use interface for researchers and end-users. This will also give the opportunity to develop on-board analytics and Machine Learning (ML) - e.g., decision trees, artificial neural networks - for the automatic detection of bruxism events (especially biting, clenching, and grinding during sleep periods) while being sufficiently robust to non-bruxism-related sleep events. Examples of ML models developed for the detection of bruxism events are shown in [36-37].

The inclusion of industrial design inputs would be also beneficial for better ergonomics and comfort for end users. This is an essential aspect as it is required to guarantee the acceptability of the device by the adopters, as well as ensure a correct placement of the sensors. Indeed, an incorrect placement of the sensors, in terms of position and orientation of the sensor units on the face, would have a significant impact on the data quality, and may decrease the overall accuracy of the system.

Finally, the adoption of the developed system in a clinical population as well as healthy individuals will inform on the usability, acceptability, and performance of the system. The validation trials in a clinical population will be carried out in a real-world scenario adopting gold-standard technologies, such as PSG and/or some of the solutions currently proposed on the market [20-28], to ensure that overall system performance are reliable and accurate.

The inclusion of haptic technology to provide real-time biofeedback is also considered to help prevent continued bruxism activities once one is detected by alerting the user.

Additional applications may include the monitoring of eating events and patterns in populations with diabetes and obesity [38] or undergoing chemotherapy, or stress monitoring and emotional state detection [39].

V. Conclusions

Bruxism is a common oral health problem in the general population which can impact on the quality-of-life of sufferers. While gold-standard diagnosis is limited to lab-based settings, several portable wearable technologies and products have been studied based on EMG, EEG, and/or ECG. In this paper, the authors present the design and development of a novel prototype wearable bruxism detection device based on IMUs and microphone to provide a new set of modalities as part of a diagnostics tool. The device could be also adopted as a low-cost research platform recording bruxism events in free-living settings, while using wireless technology for transferring data to a smartphone or cloud service for further analysis.

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