Novel Wearable System for Surface EMG Using Compact Electronic Board and Printed Matrix of Electrodes

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Abstract. In recent years, the application of IoT for health purposes, including the intense use of wearable devices, has been considerably growing. Among the wearable devices, the systems for measuring EMG (electromyography) signals are highly investigated. The possibility of recording different signals in a multichannel approach can lead to reliable data that can be used to improve diagnostic techniques, analyze performance in sports professionals and perform remote rehabilitation. In this work, we describe the design of a novel wearable system for surface EMG using a compact electronic board and a printed matrix of electrodes. The whole system has an estimated maximum current absorption of 55 mA at 3.3 V. We focused on the subsystem integration and on the real-time data transmission through Bluetooth Low Energy (BLE) with a throughput of 28 kB/s with a success rate of 99%. Some preliminary data are collected on a healthy man's arm to validate the design. The acquired data are then analyzed and processed to improve information quality and extract contraction patterns.

Keywords: Multielectrode EMG · Wearable device · Printed electrodes

1 Introduction

In the last decades, the measurement of physiological signals from the human body has raised great interest to the scientific community, as it allows monitoring subjects' health [1], diagnosing diseases, and providing suitable therapies [2] also for rehabilitation. among the measured signals, biopotential is detected by well-known medical techniques, such as electrocardiography (ECG), electroencephalography (EEG), electromyography (EMG), and electrooculography (EOG) to track the activity of heart, brain, muscles, and eyes, respectively [3, 4]. For instance, EMG signal is exploited to obtain information about muscular activity for diagnosis or rehabilitation purposes, as well as an input to trigger active devices, such as human-machine interfaces and prostheses [5]. State of art EMG devices are usually bulky and require different cables that could be uncomfortable for the final user. To overcome those problems wearable devices are lately arising. These

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devices have small dimensions and they can be worn and carried by the users without interfering with their everyday life improving both the user experience and the quality of collected data. Wearables EMG devices were lately explored for example to remotely monitor patients [6], evaluate neck fatigue [7] and discriminate wrist gestures [8]. In this work we propose a novel wearable device to perform EMG acquisition using a compact electronic board and a matrix of electrodes fabricated by aerosol jet printing (AJP) that can be used in remote rehabilitation or training applications. This device is able to provide a real-time, reliable, wireless data transmission to provide data to a custom application running on a remote unit that can be both a pc or a mobile phone that can send feedback to a clinician to remotely monitor a patient's improvement during remote rehabilitation. In Sect. 2, we discuss the design process and the system's architecture that is later tested and validated in Sect. 3.

2 Materials and Methods

2.1 Device Design

The overall system's architecture (Fig. 1) consists of two main parts: a wearable unit and a remote one. The former acquires signals from the human body through the electrodes, converts them to digital ones and sends them through Bluetooth Low Energy (BLE) to the remote unit that is devoted to store the data, perform pre-processing steps and provide the results to custom applications.

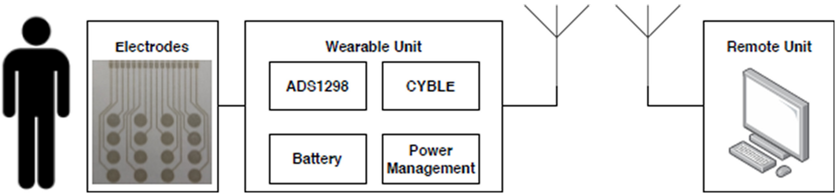

Fig. 1. The architecture of the system.

2.2 Electrode Fabrication

A matrix of 16 electrodes to achieve an 8 channel EMG was designed and fabricated by aerosol jet printing (AJP). This matrix configuration allows monitoring different parts of a muscle to analyze its functionality and the signal transmission, or to interface EMG signals realizing a human-machine interface. AJP is a fully additive printing method that atomizes an ink and deposes it with a sheath gas through a nozzle. With this technique, it is possible to depose a wide set of inks in a low-temperature environment on substrates that are not conventional for electronics, like plastic sheets and paper. The matrix of 16 electrodes was printed (Fig. 2) using the Novacentrix Metalon HPS-108AE1, silver nanoflakes based ink on a photographic paper. This combination allows to achieve flexibility, low-cost, biocompatibility and sustainability (it can be burned after use) and thus simplifies the adhesion between the electrodes and non-planar surface of the body.

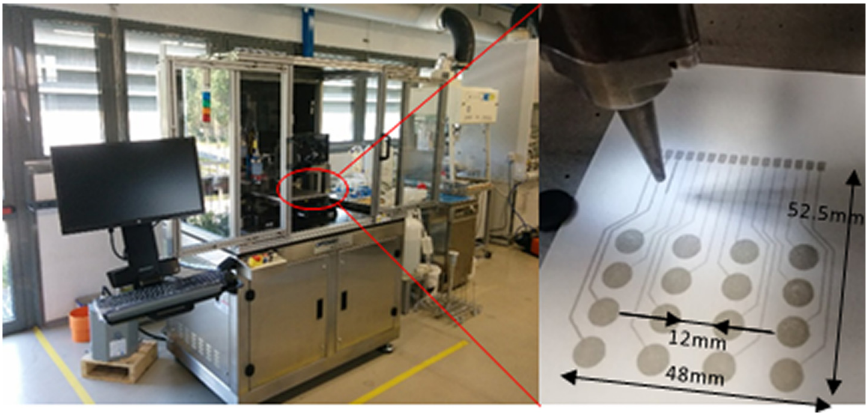

Fig. 2. Matrix electrode during the fabrication

2.3 Wearable Unit

The 52.5 mm × 48.0 mm electrode matrix is connected with the wearable unit that implements analog signal conditioning, signal sampling, data organization and transmission. In Fig. 3 the device block scheme is depicted. In order to optimize device dimensions, its power requirements and its efficiency, the design mostly uses off-the-shelf integrated circuits (IC) and minimizes the number of required components. ADS1298 by Texas Instruments was selected to provide a dedicated analog front-end (AFE) and a 24-bit delta-sigma $\Delta\Sigma$ analog-to-digital converter (ADC) to each of its 8 differential channels. This device is controlled by Serial Peripheral Interface (SPI) commands and allows different gains (the possible are: 1, 2, 3, 4, 6, 8, or 12) and sampling frequencies. To define this last parameter, we considered that most of EMG signal's information is situated below 500 Hz and thus we decided to use a minimum sampling frequency fs = 1 kHz. As regards the gain, in the experimental setup, we finally defined as reliable a value of 12. All the 8 differential channels are sampled synchronously and when the data is ready they are collected through SPI as a 27-Byte array called sample (it also includes a 3 Byte status word that provides information about the ADS1298 status e.g. the values of its GPIOs) by CYBLE-222014–01 Cypress Semiconductor microcontroller. This component controls the device behavior and integrates also a BLE module to transmit towards the remote unit the EMG data. The BLE module was set using the microcontroller API to be a GATT server and to produce a notification event when a packet is ready. The fabricated printed circuit board (PCB) has a dimension of 4.5 cm × 4.5 cm printed circuit board (PCB). This includes the already described components, several required passive components and a TPS709 Texas Instruments voltage regulator that provides a stable 3.3 V supply voltage. The maximum current absorption of 55 mA was estimated for the device during the elaboration and BLE communication. With these specifications (using fs = 1 kHz, 18 ms are required to collect the data), we estimated an average transmission time of 9.5 ms, thus ensuring a possible real-time communication; the maximum transmission time is 65 ms and thus, to avoid overwriting packets, a circular output buffer was introduced.

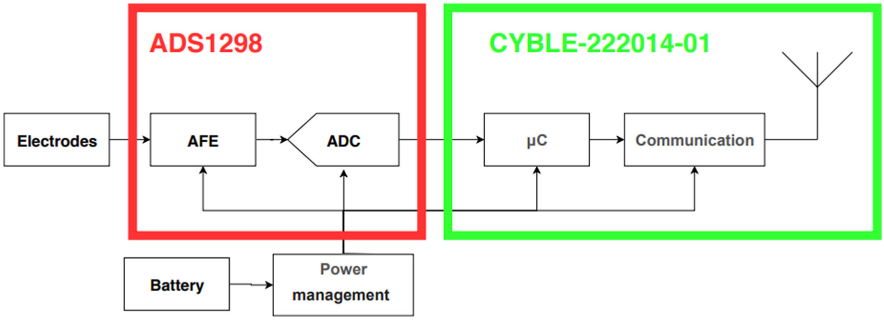

Fig. 3. Block scheme of the wearable unit where the main used components are underlined.

2.4 Remote Unit

The remote unit performs specific communication tasks with the wearable unit in order to configure it and to retrieve data from it. Moreover, the remote unit elaborates, stores and displays the incoming data. CY5677 - CySmart Bluetooth Low Energy 4.2 USB Dongle by Cypress Semiconductors was selected to interface via BLE the wearable unit and a PC to collect and save data in real-time. A dedicated program to elaborate, visualize and save as.csv files the data. Those files could be used to feed some application programs for example to track signal propagation on muscles, evaluate muscles damages, deduce activation patterns and upload on an online database the collected information.

2.5 Testing and Validation

To validate the proposed approach, at first, a signal generator was connected to one of the input channels of the wearable device to verify the correct implementation of the data retrieval and transmission towards the remote unit. In order to optimize the communication with the wearable unit, different packet lengths were tested, and the average and maximum transmission time were measured. Each BLE packet provides different additional information including the incremental number that allowed to track how many packets were received correctly, how long it takes to receive a defined packet and the average throughput. Thanks to this information it is possible to evaluate the overall efficacy of the communication measuring from the remote unit these key parameters. As experimental setup, the wearable device and the remote unit were positioned less than 2 m afar and then we started collecting data for different periods of time from 41.67 s up to 486 s. According to the preliminary experimental results we chose to put in each packet 500 B to store 18 samples and a successive packet identifier.

Furthermore, to validate the proposed wearable device in an application-like fashion, we performed a measure on a healthy volunteer. The printed matrix of 16 electrodes was attached to the brachial biceps using an electroconductive gel to improve the electrodes performances. The electrodes were wired and connected to the PCB. It was required to the subject to follow a pattern mixing maximal isometric contractions with rough duration of 30 s with relaxation periods. The retrieved signals were conditioned and analyzed in both time- and frequency-domain on the remote unit by using MATLAB and including digital notch filters to remove all the 50 Hz harmonics. A proper comparison between commercial and printed electrodes was reported in [9] where is stated that printed electrodes have slightly worse performances than the commercial ones but on the other hand, they present a reduced encumbrance and thickness that are better on the wearability and conformability on the body.

3 Results

From the measurements performed during the transmission test, an average throughput of (27 763 ± 19) B/s was calculated considering that more than 99.7% of the packets were delivered correctly. As regards the transmission time, a mean value of (18.01 ± 0.01) ms was measured for the average transmission time and (63.4 ± 7.0) ms for the maximum transmission time that confirms the values that we used to design the device.

During the system validation on a healthy subject, we were able to correctly retrieve EMG signal on each channel (Fig. 4), where it is possible to clearly distinguish between contraction and relaxation of the muscles. We also observed different spikes on the signals probably due to wiring movements during the acquisition.

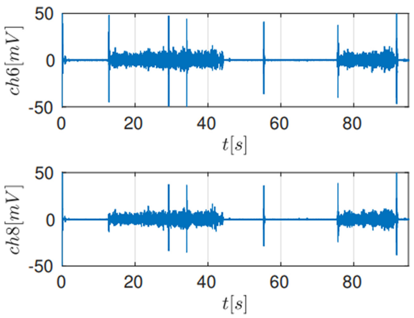

Fig. 4. Resulting signals after digital filtering

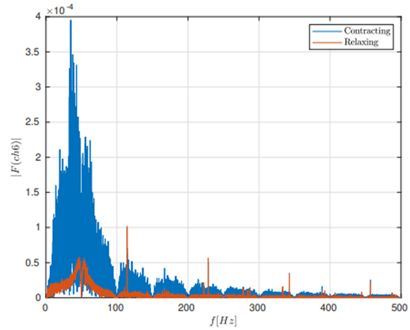

Fig. 5. FFT of the signal on one of the channels. In blue we present the contraction periods and in red the relaxation ones (Color figure online)

Then a fast Fourier transform (FFT) of the signals was performed dividing them between contraction and relaxation of the muscle. Figure 5 shows that most of the energy of the signals during contraction was before 150 Hz as expected. Moreover, we were able to observe both the influence of the filters and noise components introduced by the analog front-end, that are well visible analyzing the relaxed signal. It was also observed the energy difference between the two sets of data. Signal to noise ratio (SNR) was calculated using the RMS value of the contraction (that we used as signal) and the relaxation period (that we used as noise sample). We obtained an SNR of the whole circuit higher than 28 dB. This result can be improved by modifying the electrode geometry such as increasing the area of the electrodes and their adhesion on the muscles.

4 Conclusions

In this work, a novel wearable device to perform a multichannel EMG using an AJP printed matrix of electrodes is shown. The proposed solution allows for flexibility, low-cost, biocompatibility, sustainability and less invasiveness. This device provides a real-time stream of data from wearable to remote unit using BLE achieving an average throughput of 27 763 B/s with a success rate sending packets above 99.7%. The device samples eight channels at $fs = 1$ kHz and this limits the useful signal the bandwidth to 500 Hz. On the remote unit, a set of digital filters were developed to attenuate spurious components and thus improve the SNR to 28 dB. This device exploiting the potentiality of IoT can be used to provide data to a remote unit to perform different tasks as detect activation patterns, monitor muscles fatigue and integrity.

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