Wearable Piezoelectric Sensor Interface Design for Body Signal Monitoring

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XXXVI Cycle

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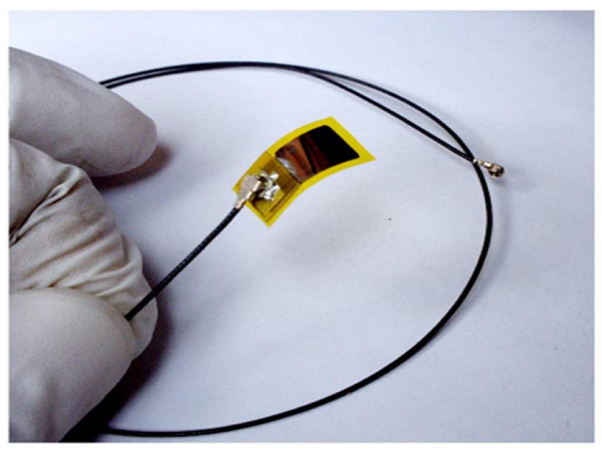
Research context and motivation

- Main motivation of this research is to develop a non-invasive and unobstrusive wearable device that can take advantage of a novel Aluminum Nitrade (AlN) based thin film piezoelectric sensor developed by Istituto Italiano di Tecnologia (IIT) Center for Biomolecular Nanotecnologies (CBN) at Lecce.
- Soft and flexible piezoelectric smart patch is capable of monitoring multiple body signals such as pulse wave, heart sound and speech depending on the sensor position. This AlN-based thin film is as thin as 26 μm and the weight is less than 2 g. In addition, the smart-patch is made of biocompatible and non-toxic materials which is another advantage of avoiding the possibility of any irritations or allergic reactions on subjects' skins.



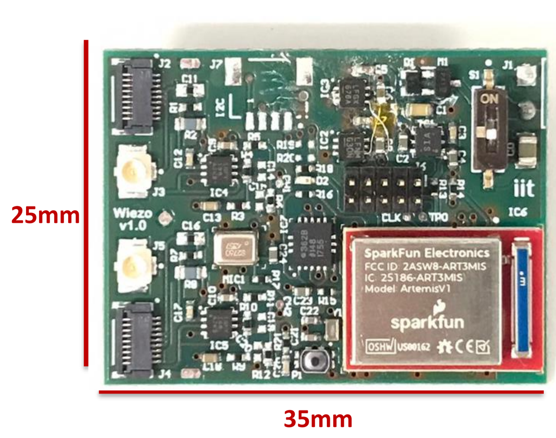
- Taking advantage of all these properties, a wearable device consisting of the thin-film piezoelectric sensor, an optimized interface electronics, and a suitable case is proposed by this work to detect various body signals that create mechanical movements on the skin.
- Interface electronics and the firmware development is the main focus of this study. The interface electronics must be optimized for multiple applications in terms of signal to noise (SNR) ratio and the firmware should be easily adaptable to different configurations since the output frequency of mechanical movement of various body signals alter substantially.
- Aim of this research is eventually having a wearable device for Internet of Medical Things (IoMT) applications that gains a significant attention especially in the time of Covid-19 era.

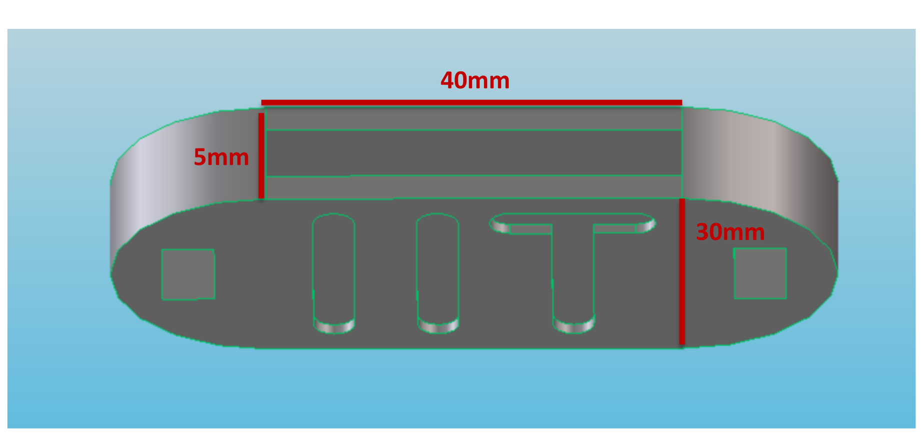
Addressed research questions/problems

- AlN-based piezoelectric smart-patch might detect the mechanical output of multiple body signals simultaneously. Therefore, the interface electronics must be designed and realized in a way that all the possible information could be collected without any loss.
- Size of the interface electronics plays a crucial role for non-invasive and unobstrusive monitoring of vital body signals particularly for daily life utilization.
- Furthermore, collected information must be passed to the client, possibly to the doctor, for the evaluation of the results. Hence, data collection and transfer with minimum energy consumption is the primary goal of this project to increase the battery life of the wearable device for possible IoMT applications.

Adopted methodologies

- A 2-channel interface electronics consisting of a charge amplifier (in order to convert charge output of the piezoelectric smart patch into voltage), and a voltage-gain stage for each channel, a 3-axis accelereometer, a PDM digital microphone and a microcontroller unit (for ADC and BLE communication) has been developed and fabricated.
- Firmware development and case designed have been performed to complete the wearable device prototype.



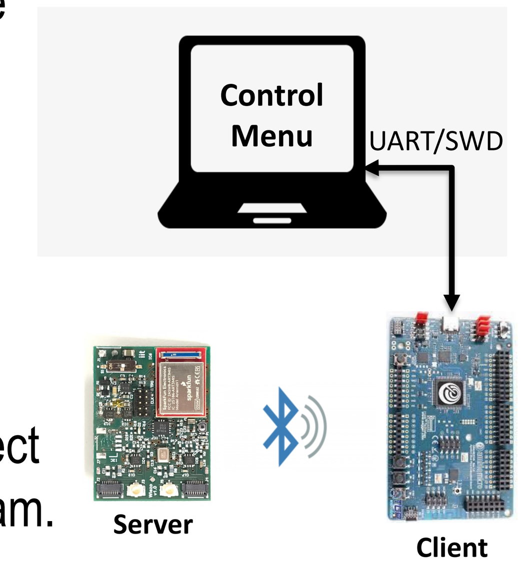


List of attended classes

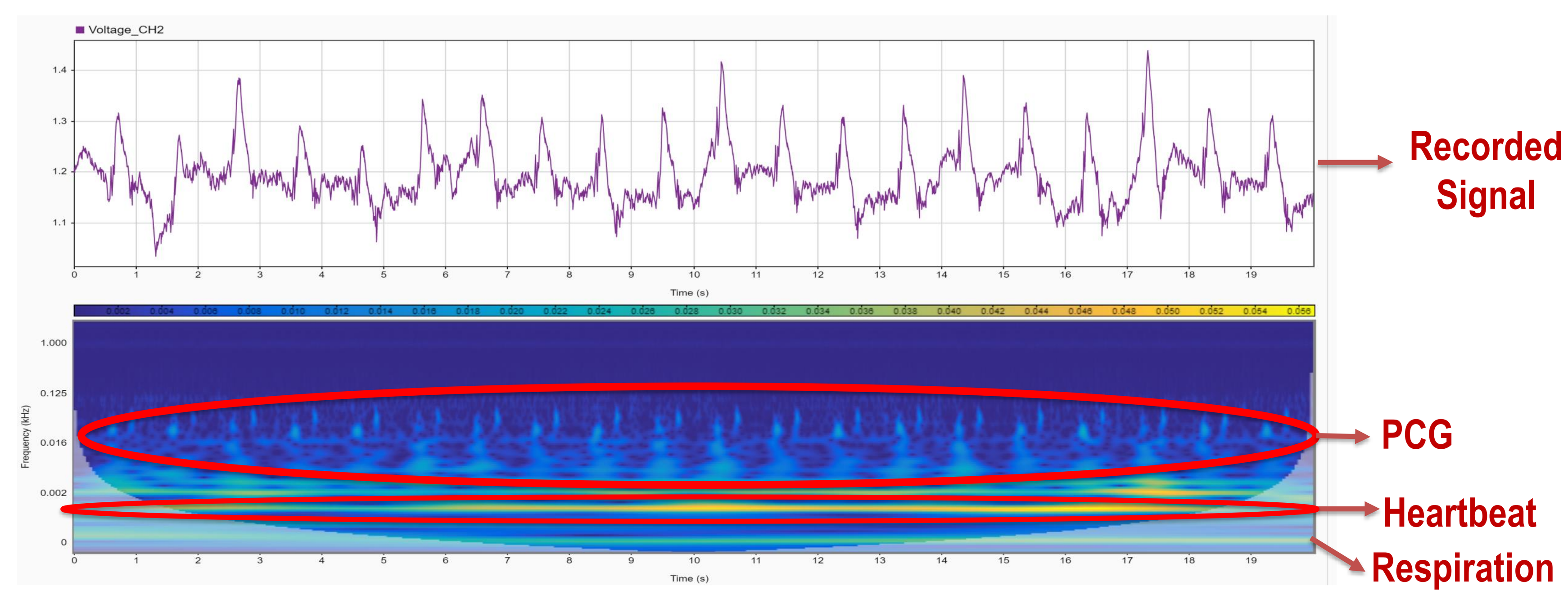
- 01MNFIU – Parallel and distributed computing (26/7/2021, 5 CFU)
- 01QEZRV – Sviluppo e gestione di sistemi di acquisizione dati (13/12/2021, 5 CFU)
- 01SHORV – Nano & Quantum Computing (16/12/2021, 8 CFU)
- 01RGGRV – Telemedicine and Distributed Healthcare (22/3/2022, 4 CFU)
- 02SFURV – Programmazione scientifica avanzata in matlab (21/4/2022, 6 CFU)
- 01UNXRV – Thinking out of the box (2/12/2020, 1 CFU)
- 01SWPRV – Time management (26/1/2021, 1 CFU)
- 01UNVRV – Navigating the hiring process: CV, tests, interview (29/9/2021, 1 CFU)
- 02RHORV – The new Internet Society: entering the black-box of digital innovations (1/10/2021, 1 CFU)
- 01SHMRV – Entrepreneurial Finance (4/10/2021, 1 CFU)
- 08IXTRV – Project management (5/10/2021, 1 CFU)
- 01RISRV – Public speaking (6/10/2021, 1 CFU)
- 02LWHRV – Communication (7/10/2021, 1 CFU)
- 01SWQRV – Responsible research and innovation, the impact on social challenges (11/10/2021, 1 CFU)
- 01SYBRV – Research integrity (13/10/2021, 1 CFU)

Novel contributions

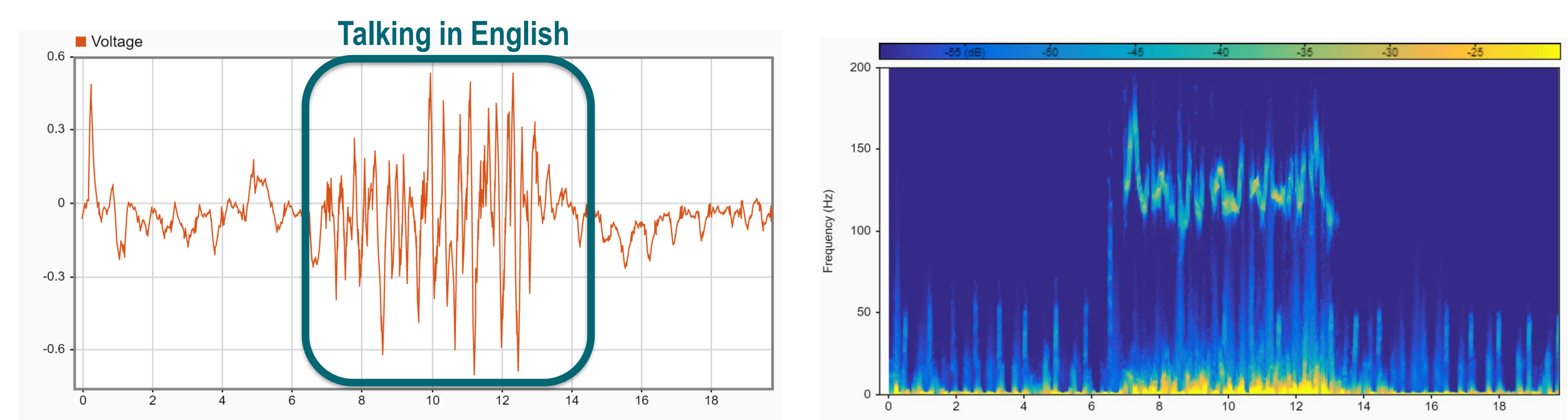
- Ambiq Apollo3 Blue EVB is used as a client to test the wearable device (Wiezo v1.0). BLE connection, data transfer start/stop and direction are controlled by a personal computer.



- Body signal measurements have been performed for heart rate, heart sound (phonocardiogram), respiration and speech.
- At first, the sensor has been placed on the neck of a male subject and the output waveform has been investigated using scaleogram.
- Results show that there are frequency components at ~0.25 Hz and ~1.3 Hz which belong to respiration and heartbeat, respectively. Moreover, the first and the second components of the phonocardiogram (PCG), S1 and S2, could be detected approximately around 30 and 60 Hz, respectively. The results have also been validated using FFT.



- Another test has been performed for speech detection without changing sensor position.



- Output waveform spectrogram and FFT results show that the center frequency of the speech is at 120 Hz, which is perfectly consistent with male speech center frequency whilst talking in English. Also, the sensor could detect higher speech frequencies, approximately up to 5 kHz, depending on the sampling frequency.
- Results are promising since every language has different center frequencies, and the system could be used to detect different languages, dialects and genders by looking at the frequency response of the output waveform.
- In addition, S1 and S2 components of the PCG signal could still easily be observed below the speech center frequency meaning that multiple signals can be acquired simultaneously from the same position.

Future work

- Power consumption measurement and possible hardware/software optimizations will be performed to minimize the consumption and increase the battery life.
- Thanks to having two identical channels on the PCB, pulse wave velocity (PWV) measurement will be executed, and different (possibly very close) positions will be investigated to see if «Wiezo» could be utilized for unobstrusive PWV measurement.
- On board PDM microphone will be used simultaneously to record the speech signal and comparison will be performed between the sensor output and the recorded signal.
- On board 3-axis accelerometer will be integrated to the system to expand the applications.
- The system will be placed inside the previously designed case and the comfort will be evaluated. Then, possible modifications will be performed for the final device.

Submitted and published works

In preparation:

- A conference paper for IEEE International Symposium on Circuits and Systems 2023
- A journal paper for IEEE Transactions on Wireless Communications