Wearable Sensing Technologies

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Abstract By bringing the ability to track physiological signals over long periods of time, wearable sensing has the potential to enable new paradigms in disease prevention, treatment and management, in and beyond healthcare. Such paradigms could range from chronic monitoring to observe and detect gradual shifts in relevant parameters to the discovery of rare and asymptomatic biomarkers. The two use cases described in this article are positioned somewhere within this continuum and demonstrate the unique opportunities of this technology, while at the same time demonstrating its challenging requirements and limitations.

Keywords: EEG measurement, wearable.

1. A History of Wearable Sensing at imec

Continuous advances in microelectronics have led to wearable devices that allow for ambulatory recording of physiological signals during daily life. These have been improved drastically in the past years by reduction of weight, size and energy consumption. As they get more power efficient, they permit monitoring over longer periods of time.

At imec, we have contributed to these advances by developing monitoring systems based on integrated circuits (‘chips’) that are developed in-house. These circuits and systems are highly optimized for wearable applications, in which physiological signals need to be acquired under daily life conditions, while operating for as long as possible on a small battery. Imec has also been very actively developing algorithms, for example to ensure a clean and reliable data stream but also for extracting of relevant information under challenging daily-life conditions.

By heavily involving clinical partners and medical experts in the design and evaluation of these devices, we have ensured an evolutionary path towards meaningful components and systems.

As a research institute, imec itself does not make end products. Instead, we develop and validate prototypes as well as key building blocks, which are used by our customers to make final (medical) products. At the same time, our customers and clinical partners need demonstration platforms of high maturity, that can be used for evaluation purposes and in pilot studies.

In the coming sections, we will present two use cases where a selection of these demonstrators is used. It is worth noting that this is just a selection of demonstration devices in imec’s wearable health portfolio, and that other modalities to monitor relevant physiological sensors are also available.

2. Use Case 1: Affective Human-Machine Interaction

Brain-Computer Interfaces (BCI) are systems that measure brain signals (typically by means of EEG), after which these signals are processed and translated to outputs, with the aim to control computers or other devices.

A special case arises when the computer provides feedback to the user based on the recorded and processed outputs. If the aim of this feedback is brainwave modulation based on operant conditioning this is called neurofeedback. There is substantial scientific support for using neurofeedback as therapy for cognitive disorders such as Attention Deficit Hyperactivity Disorder (ADHD).

A relatively new paradigm in BCI is the so-called ‘affective BCI’, in which the aim is not to actively control computers by means of intention detection, but to passively do so by capturing the emotional or cognitive state of the user. An interesting use case arises when the computer is, for example, a humanoid robot that would change its attitude towards the user based on the user’s emotional and cognitive state. A possible aim could be to influence the emotional state or feelings of the user, from negative (such as anger or sadness) to positive.

Capturing emotions from EEG requires capturing the brain waves from the (pre-) frontal cortex, the cortical

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region which plays an important role in emotional processing. One of the working paradigms relates to emotional lateralization, in which the relative differences in alpha power over the frontal cortex are used as input to classify appetitive versus aversive valence. The ‘valence hypothesis’ states that the right hemisphere is dominant for processing negative emotions, while positive emotions are dominantly processed in the left hemisphere. Such hemispherical differences can be utilized to estimate emotional status.

To facilitate research in this fascinating field, imec has developed prototypes for EEG acquisition that can be easily and quickly installed on a user’s head by using a smart design and dry electrodes. The EEG headset consists of the following main parts:

1. Imec’s EEG chipset
2. EEG electronics system
3. Headset platform

2.1 EEG Chipset
By using imec’s read-out circuitry, the EEG headset can make use of high-quality, low-noise amplification and digitization. At the same time, the experimenter continuously receives information about the electrical electrode-to-skin impedance, which is an important indicator for signal quality.

Imec’s EEG chipset is a highly integrated, low-power chipset, optimized for capturing EEG with dry electrodes. The power consumption of the chips is limited to 0.7 mW for capturing 8 channels of EEG. The chipset consists of 2 types of chips: a central chip that is responsible for signal conditioning, final amplification and digitization of signals, and chips at each measurement position, so-called ‘active electrode amplifiers’. Working with active electrodes substantially reduces interference from external sources, which is particularly important when using dry electrodes. These active electrodes are also responsible for the current injection to measure the contact impedance. The noise level, bandwidth and other critical metrics for signal quality conform to the medical standard for EEG equipment.

2.2 EEG Electronics System
The electronics system consists of the EEG chipset, and adds to that other functions, such as Bluetooth wireless transmission, SD card storage, on-board microphone, light sensor and auxiliary input. All signals are forwarded to the microprocessor, which is responsible for further filtering and reduction of the sampling frequency, before sending the signals to the Bluetooth module.

2.3 Headset Platform
A mechanical headset platform was developed that allows for designing dedicated headsets at limited effort and cost. The core idea is the reuse of key elements and ideas such as electrode attachment and core material and shape. The key elements may be improved upon each design iteration.

With these key elements, headset derivations can be designed with unique sensor positions, and varying design requirements such as comfort or disposability.

The design that we would like to highlight here is one derivation of the platform that may be particularly suitable for (affective) BCI research, with electrode positions Fp1, Fp2, C1, C2, O1, O2, T3, T4 and linked-ear referencing, conforming to the international 10/20 system for electrode placement.

Fig. 1  From application to core technology: the range where imec is active.
3. **Use case 2: Assessment and Treatment of Psychological Disorders**

Certain psychological disorders can have a measurable effect on the peripheral nervous system (in particular the autonomic nervous system) or responses of the peripheral nervous system to stimuli. Examples of disorders that received a lot of attention in clinical psychophysiology are anxiety, depression and social disorders, and more recently in cognitive therapy, e.g. for drug addiction and Post Traumatic Stress Disorder (PTSD).

The research to the use of wearable sensors in this context leads to several new requirements:

- The sensors must work outside of controlled environments, and provide high-quality data.
- The sensors must not obstruct the patient in his daily-life activities.
- The patient should not have to worry about the sensors. The sensor should not require regular recharging of batteries, or any other patient interference.
- The sensors should work for long periods of time, preferably a week or longer.

The signals that the sensors should measure are:

- Accurate heart rate and in particular heart rate variations.
- Temperature (core body temperature or skin temperature).
- Electrodermal activity/galvanic skin responses.
- Information about physical activity.

In order to accurately measure heart rate, an ECG patch is provided. The disposable patch is very skin-friendly and can be worn for 3-7 days continuously, depending on the sensitivity of the skin and the amount of physical activity. The electronics module can record for more than 7 days continuously on its internal memory without the need for charging the battery. Acceleration is also measured, which is very indicative for the patient’s level of physical activity, since the patch is worn close to the center of gravity of the body.

For measuring electrodermal responses, a wristband was developed that measures electrodermal responses at the (volar) wrist. A temperature probe touches the skin at the dorsal wrist. Data can be stored for over 7 days continuously on the internal memory of the watch at a single battery charge.

Both devices (ECG patch and wristband) can be controlled from an application software on Android smartphones or tablets. It is worth noting that only the experimenter (or doctor) can start and stop the measurement. Once the patient is sent home, the devices will continuously measure until the battery is empty or until the patient returns and the experimenter stops the recording. Event marking can be done on each of the devices by double tapping on the device. This can be used for self-reporting of, for example, relapses.

The data, which is stored locally on the devices, can be conveniently transferred to the PC by means of a fast USB connection. The USB connector is also used to charge the device, which can be done in one hour, after which the device can be used on the next patient.
4. Conclusion

This article presents two use cases in which wearable sensors can be effectively applied to acquire relevant parameters. In the past, such use cases could only be implemented with the use of large and stationary lab equipment. By using easy-to-use, small and wireless sensors, we allow such experiments to be executed outside of the lab environment into more uncontrolled environments, even into the homes and daily lives of patients!

Acknowledgement

This research is partially supported by the Center of Innovation Program from Japan Science and Technology Agency, JST.

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Bernard Grundleiner received his M.S. degree from the University of Twente in 2002. He joined Holst Centre / IMEC-NL in 2007, where he worked on several topics related to biomedical signal analysis, including ECG analysis, emotion monitoring and bio-acoustics. From 2009 to 2015, he was responsible for the development of the Wearable EEG platform, algorithms for EEG signal improvement and clinical validation of the EEG prototypes. He is currently responsible for the Health Patch program in the role of system architect. He has (co-) authored over 30 papers and conference proceedings in the field of biomedical signal processing and acquisition.