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Comparison between a PPG Wearable Device and an AFE4403-Based Pulse Oximeter

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***Abstract* – The paper shows a comparison between a photoplethysmography wearable device and a bare pulse-oximeter based on an analog front-end for optical bio-sensing applications. In particular, a specific experimental set-up was implemented, simulating an artery, which allows to compare and acquire signals from both proposed devices on a repeatable system. Results both on the artery model and on a healthy volunteer are shown.**

I. INTRODUCTION

National Health System is based on fundamental principles, such as universality, equality and equity; currently, especially after the Covid-19 pandemic, it aims towards the frontiers of Digital Health [1]. The term Digital Health refers to the application of digital technologies to support innovation in the health system, including telemedicine or home automation. In this context, the concept of continuous and remote monitoring is introduced: this type of service allows facilities and doctors to communicate easily both with patients and with other experts, without being physically present, optimizing time and resources [2].

In this way, an invisible connection is established between the doctor and the patient which, through a remote monitoring, allows the acquisition of numerous data relating to his state of health, continuously and in diversified psychophysical conditions. The acquisition of this type of health data takes place mainly through the use of wearable medical devices, i.e. electronic devices that can be easily worn in peripheral areas of the patient's body (such as watches, earphones, glasses) [3].

Some of the wearable medical devices currently on the market base their operating principle on the photoplethysmographic technique. Photoplethysmography (PPG) is a non-invasive method based on optical properties, such as absorption, scattering, and transmission properties of human body composition under a specific light wavelength, that allows the measurement of blood volume changes in a microvascular bed of the skin [4].

The purpose of this paper consists in the comparison of different devices based on the photoplethysmographic technique: first of all, an experimental setup was created, simulating an artery model, from which to acquire detectable and repeatable signals via an analog pulse-oximeter sensor (AFE4403 from Texas Instruments) [5] and the cosinuss° Two headset [6]. Subsequently, the PPG signals from the two different sensors were acquired on the simulated model of an artery. Finally, measurements on a healthy subject were performed.

II. METHODS AND MODELS

A. Artery model

One of the main objectives was to create an experimental setup, which allows to compare and acquire signals from both proposed devices, on a single elementary reference system. The idea was to prepare an apparatus, which was equipped with both a hydraulic system capable of reproducing the pulsating motion of the blood, and an element that simulated peripheral blood perfusion, namely an artery. In this regard, it was decided to modify a model already developed and available within the Microwaves and Electromagnetic Compatibility Laboratory of the Sapienza University of Rome [7, 8]. The Arduino-Controlled Common Artery (ACCA) model features a centrifugal pump (HPR6/8 by Totton Pumps) which draws from a parallelepipedal tank containing water, to bring it into the hydraulic circuit at constant pressure. To simulate the pulsating motion of blood, the following are used: a proportional solenoid valve (PVQ-13-5L-08-M5-A, SMC), three “needle” valves (i.e. flow control) and a T junction valve.

The ACCA system is also equipped with a pressure sensor (Drucksensor RS). The signal sent to the solenoid valve is generated starting from the characteristic points relating to the motion of the blood [9]. All the details of the model are described in [7] and [8].

On the basis of the ACCA model, some additions were made to the set-up in order to make it suitable for PPG device testing. In particular, to simulate the artery perfused from the blood, a transparent tube in flexible rubber and silicone was added, inside which the fluid pumped by the hydraulic system of the ACCA model flows; the dimensions of the tube are respectively 14.5 mm (width) × 4.5 mm (thickness).

The insertion of the transparent tube in the hydraulic circuit took place by connecting both ends of the transparent tube with the drain valve and with the filling valve of the hydraulic system. The connection was made through the use of two pairs of elements for each end, created with the 3D printer (Creality 3D model) present in the EsseDH S.r.l laboratories:

- main connector designed to fit both the transparent tube, with a rectangular section, and the drain and hydraulic fill tube;
- flow reducers, of different sections.
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The 3D-prints, on the other hand, were made in gray PLA, using filaments with a diameter of 1.75 mm, produced by Basicfil Filament. The additional elements listed above were designed in SolidWorks.

The main connector structure consists of:

- a rectangular section parallelepiped, slightly “bulging” on the larger sections, to avoid the collapse of the rectangular section tube when the fluid flows;
- a cylinder with a section of 4 mm;
- a parallelepipedal connection section with a rectangular section.
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The projects were created in STL format (STereo Lithography interface format or acronym for “Standard Triangulation Language” or alternatively “Standard Tassellation Language”), a binary or ASCII file format, created for CAD stereolithography software. The files were then uploaded to the Ultimaker Cura software (a view of the software interface is shown in Fig. 1), for the conversion of project files for 3D printing. A basic elliptical section (in light blue) has also been added through Ultimaker Cura to ensure the absence of displacement of the connector during the printing process (see Fig. 1).

The same procedure took place for the construction of the reducer; in particular, three reducers with different sections were created to experiment which section favored the optimal motion of the fluid inside the transparent rubber tube, which was correctly detectable from the sensors.

The assembly of the main connector and the reducer on each end of the tube was then carried out (see Fig. 2), thus creating a prototype that can be implemented in the ACCA system. As shown in the figure, the designed prototype envisages a flexible rubber and silicone hose, to which a main connector-reducer pair is assembled for each end.

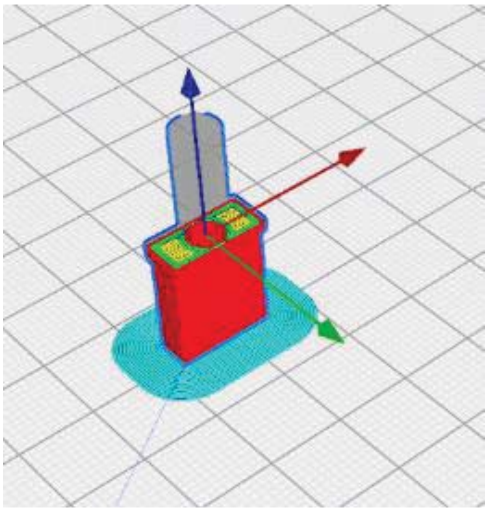

Fig. 1. View of the Ultimaker Cura software interface: representation of the main connector.

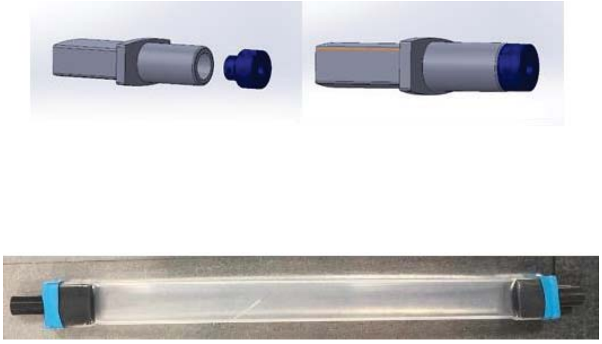

Fig. 2. Main connector and interlocking reducer (top-view); sensor prototype (bottom-view).

B. AFE4403EVM sensor

The AFE4403EVM device is a sensor for monitoring heart rate and oxygen saturation (SpO2). The instrument consists of a low-noise receive channel, the LED transmission section, and diagnostics for sensor and LED fault detection. Its operating principle is based on the use of the photoplethysmographic technique by reflection: the sensor is able to illuminate the area of interest and record, through a specific interface, the reflected signal. Inside the sensor there is a highly configurable timing controller, which allows the user to have complete control of the timing characteristics of the device. The device also has a built-in oscillator that works from two clock sources: an external crystal or the clock from an external host processor to facilitate clock requirements and provide a low jitter clock to the AFE4403. The device communicates with an external host processor using the serial peripheral interface (SPI). The purpose of the AFE4403EVM is to accelerate system evaluation and development activities related to the AFE4403 device [5]. The demonstration kit (Fig. 3) includes:

- an USB cable for connection to the PC;
- an NJRC NJL5310R sensor with green or infrared LED;
- an OSRAM SFH7050 sensor with red or infrared LED;
- a data acquisition and storage board;
- a cable with 8 connection pins for the sensor, to be connected to the acquisition board.

The AFE4403EVM settings and its configurations can be controlled through a Graphical User Interface (GUI) downloadable from the official Texas Instruments website.

Fig. 3. *AFE4403 demonstration kit.*

C. cosinuss° Two

Cosinuss° Two [6] was born from the idea of wanting to introduce remote monitoring of patients in domestic isolation, affected by Covid-19 in a medium-low progress of the infection. The cosinuss° Two wearable sensor (Fig. 4) is designed to detect, analyze and transmit information regarding the physiological signals of the body such as vital signs and environmental data that allow immediate biofeedback to the wearer and/or remote healthcare workers, collecting the following raw data:

- the optical signal, which is the PPG signal;
- internal body temperature;
- 3D acceleration of the head.

From which it is possible to extract the following physiological parameters:

- body temperature;
- heart rate;
- blood oxygen saturation;
- R-R or intra-beat interval;
- blood perfusion index;
- signal quality;
- movements.

The wearable sensor measures vital signs from inside the ear canal and transmits the data via Bluetooth to cosinuss° LabGateway.

Fig. 4. cosinuss° Two wearable sensor

The Gateway forwards the data to a telecommunications network which sends it to cosinuss° LabServer. Through the WebInterface, healthcare professionals are able to view and access the vital information of each patient.

III. RESULTS

A. Measurements on the Artery Model

In the case of the ACCA model, the signals acquired by the two sensors are periodic and morphologically similar.

The dynamics of the signals show the same order of magnitude; however, the intensity of the signal acquired with the AFE4403 sensor is higher than the intensity of the signal acquired with the cosinuss° Two headset. From the graphic superimposition of the two signals (Fig. 5), the following can be deduced:

1. in both traces, approximately 3 peaks can be observed every 10 seconds: this data is physically linked to the frequency with which the device sends the pulses to the artery prototype; corresponding to each impulse, the formation of a belly on the prototype can be observed, due to the perfusion of the water inside the rubber tube, site of the measurement;
2. the dynamics of the signal acquired with the AFE4403 sensor is about 5 times higher than the dynamics of the signal acquired with the cosinuss° Two headset; this is due to the greater sensitivity of the AFE4403 sensor, also in terms of noise, compared to the cosinuss° Two headset.

Fig. 6 shows a normalized graph, in order to better compare the two signals.

It is important to highlight that the ACCA model can be easily reconfigured to produce a pulsating signal that is not exactly periodic, but shows a pre-defined variability. This would allow not only to test the optical response of the devices, but also to assess their functionality in terms of heart rate measurement and possible detection of pathological conditions related to heart activity. The measurement results are repeatable for both devices.

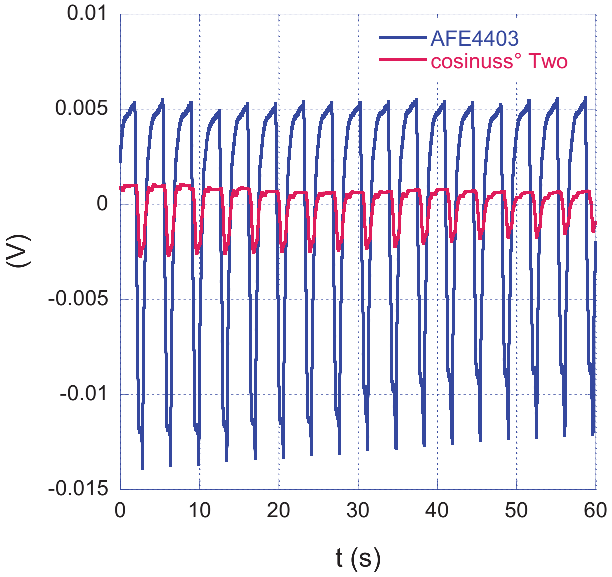

Fig. 5. Comparison between the two sensor signals.

B. Measurements on a healthy subject

In the case of measurement on subjects, the cosinuss° Two was placed on the ear of the volunteer and the AFE4430 on the wrist. The two signals were aligned creating a simultaneous artifact on the two recorded signals. Results on a 20 s time window are shown in Fig. 7.

The obtained results highlight that the two sensors record two very similar signals, also considering the different acquisition location (i.e. ear vs. wrist).

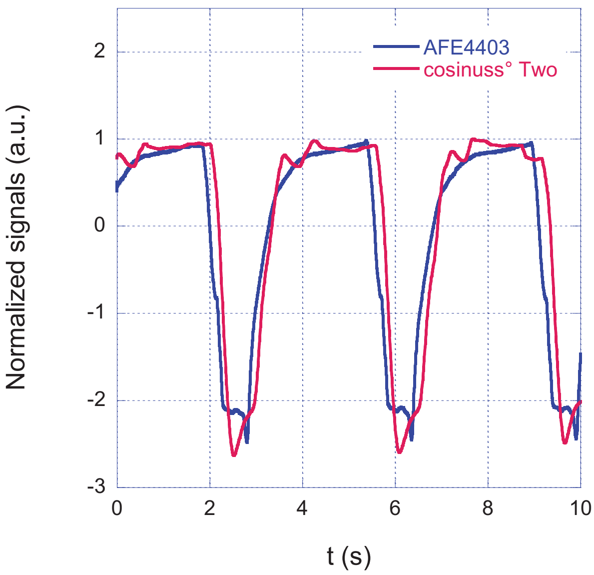

Fig. 6. Comparison between the two normalized sensor signals.

Altogether, the signal acquired with the bare pulse-oximeter exhibits a larger peak-to-peak amplitude (higher sensitivity), even though a higher noise level is present. From the performed tests, the cosinuss° Two represents a reliable and comfortable solution for long term non-obtrusive patient monitoring at home, despite the slightly worse sensitivity as compared to a finger-clamp pulse oximeter.

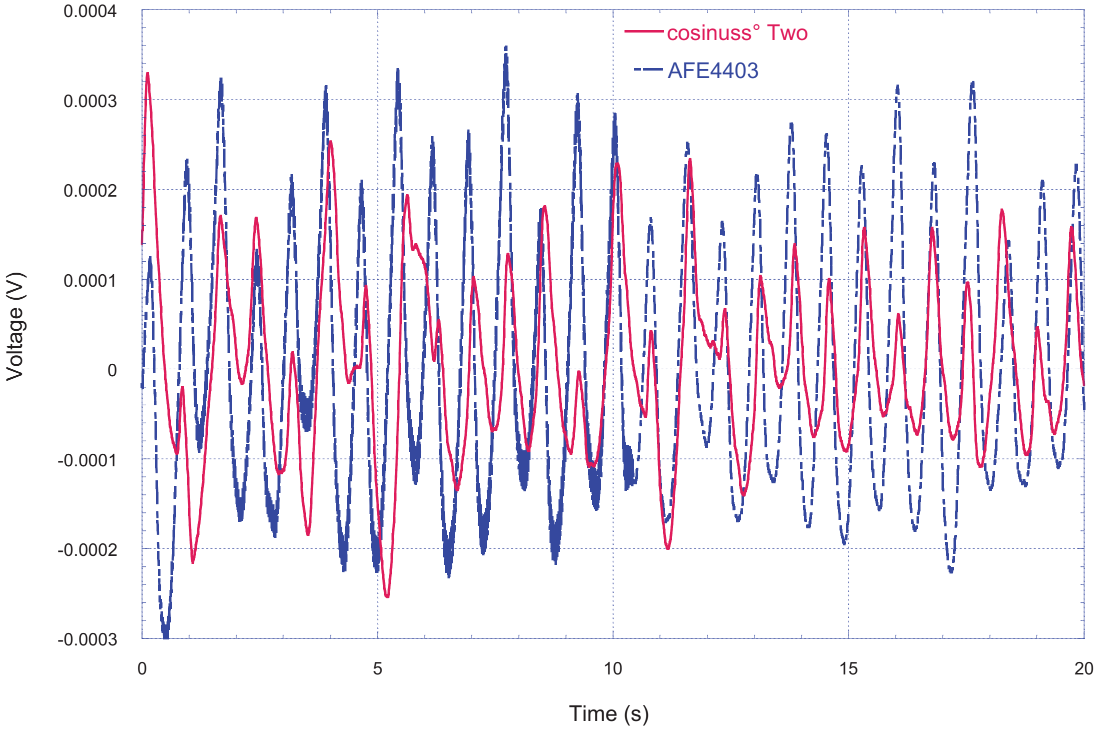

Fig. 7. Comparison between the two sensor signals on a subject.

IV. CONCLUSIONS

The implementation of an experimental setup that uses the prototype of an artery model to compare in a repeatable and controlled way the acquisitions of two different devices opens up the possibility of comparing and analyzing signals from other wearable technologies. Results on volunteers show a good agreement between the two tested devices, proving the feasibility of long-term monitoring with comfortable wearable solutions.

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