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(Article begins on next page)

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# Validating photoplethysmography (PPG) data for driver drowsiness detection

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*Abstract*—**Drowsiness is one of the first casualty factors of car accidents. A large number of studies have been conducted to reduce the risk of car accidents and, many of them, are based on the detection of biological signals to determine driver drowsiness. In this way, several prototypes have been proposed but all of them are efficient in specific scenarios only. Photoplethysmography (PPG) is a non-invasive tool that allows monitoring heart activity, it is also used to evaluate driver drowsiness. This paper introduces a prototype based on PPG signals able to improve current systems in terms of evaluation time and results clearness. We performed a measurement campaign to compare experimental data with literature. The goal is to validate the prototype.**

*Index Terms*—**driver drowsiness, Photoplethysmography, validation, PPG shape parameters.**

## I. INTRODUCTION

Human factors are the primary reasons causing car accidents [1] and driver drowsiness plays an important role in this scenario [2]. Drowsiness is defined as the transition period between wakefulness and non-rapid eye movement (non-REM) sleep [3]. It is ruled by Autonomous Nervous System (ANS); therefore, it is strictly related to brain activity. The best technique to analyze brain activity is Electroencephalography (EEG), but it is not suitable for automotive applications, being not embeddable in a commercial car environment.

In recent years, researchers and carmakers have proposed several systems and prototypes to detect driver drowsiness in non-invasive manner. Steering Wheel Movement (SWM) and Standard Deviation respect to Lateral Position (SDLP) systems [4] are already implemented in cars. They analyze brain activity indirectly by studying driving behavior and performance, they do not require a direct contact but they detect sleep state and not drowsiness. This could be a severe issue since an accident might occur in the time the driver falls asleep and the car detects this sleep state. For this reason, novel prototypes exploit biological signal to test brain activity and perform an evaluation of driver psychophysiological state [1].

Several systems employ heart-monitoring techniques, such as Electrocardiogram (ECG) and Photoplethysmography (PPG), to evaluate brain activity [1]. These devices perform a driver analysis based on heartbeat duration parameters. It is a non-invasive method but it requires a direct contact between driver and detector, and it is not completely trustable since there are different opinions in the scientific community [5], [6]. Moreover, ECG or PPG based devices performs frequency domain analysis that need at least 5 minutes measurements, and this is too long for critical safe assessment.

Many systems use cameras to monitor eye blinking and face movement, which are well-known drowsiness indicators [4]. Others systems use IR cameras to monitor face temperature since thermal imaging analysis allow to evaluate brain activity and, in turn, drowsiness [7]. Camera-based prototypes are the most studied since they are contactless, but they have many problems related to different light in-car environments or face movements [8].

From the above-cited literature, existing prototypes and systems cannot perform a trustable driver state evaluation. Described systems do not cover all driving situations and they need improvements to be employed in automotive applications.

In this paper, we introduce a new prototype based on PPG signal analysis for driver drowsiness monitoring. Photoplethysmography is a non-invasive technique used to monitor heart activity in medical application [9] and it allows to infer driver drowsiness [9]–[12]. The system acquires PPG signal from hand palm: a novelty in the field. The prototype analyzes PPG signal and it elaborates not only on heartbeat pulse duration but also on other waveform shape parameters. This analysis brings new and important advantages in the automotive field that result in faster drowsiness state detection and univocal results [13].

The paper starts with a brief introduction about PPG measuring principle. In addition, there is a short presentation about system main blocks and measurements protocols. Section III shows experimental results and discussion. Section IV resumes and concludes the work.

## II. SYSTEM DESCRIPTION

### A. Measuring Principle

The system operating principle is based on Photoplethysmography, also called PPG, an optical measurement technique used to detect blood volume changes in the microvascular bed of tissue [14]. PPG requires a light source

and a photo-detector (PD). The light source illuminates the tissue, and the photodetector senses the small variations in reflected light intensity associated with perfusion changes in the catchment volume.

The PPG technique allows the correlation of physiological and psychological parameters since it measures the cardiac cycle, which is ruled by Autonomous Nervous System (ANS) [15]. Therefore, through the study of PPG signals, it is possible to obtain information on brain activity, such as drowsiness.

From an electrical point of view, the recorded PPG waveform signal has two components, AC and DC, which are related to blood flow governed by the cardiac cycle. In this study, we were interested only in the AC component that reflects cardiac synchronous changes in blood volume at each heartbeat [16].

In the literature, photoplethysmogram second derivative, called Acceleration Plethysmogram or APG, is commonly exploited due to its informative content [17]. Indeed, it defines different characteristic points that allow PPG specific parameters determination. Moreover, APG allows to analyse PPG shape. The signal analysis performed in this study relies mainly on shape parameters.

From both PPG and APG signals it is possible to extract different parameters. In this work, we have considered many indicators displayed in Fig. 1, for both to PPG and to APG. They are:

- *Augmentation Index (Aix)*, it evaluates the relative reflective wave contribution and it is defined as the ratio between Augmentation Pressure (AP) over the Pulse Pressure (PP) [18] (see Fig. 1.a);
- *b/a ratio*, where **a** and **b** are two APG characteristics points (see Fig. 1.b). It reflects the increased arterial stiffness and it increases with age [19];
- *Aging Index,* it is defined as *(b-c-d-e)/a,* where a, b, c, d and e are APG characteristics points (see Fig. 1.b). It reflects aging effect on arteries [19].

Another useful parameter, called *SDNN*, is the standard deviation of every cardiac cycle interval considered in a time interval [20]. All parameters, except SDNN, are related to the PPG signal shape.
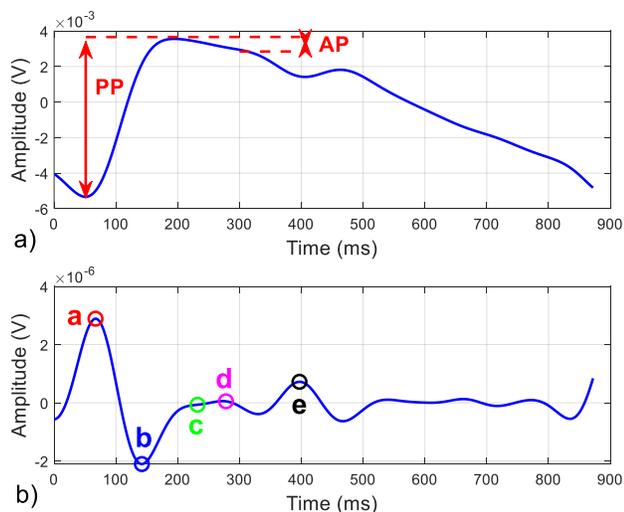


a)



b)

**Fig. 1 a) PPG signal and b) APG signal with characteristic points.**

### B. System Overview

The prototype system is composed of three main blocks: (i) PPG sensor probes, (ii) acquisition system and (iii) PC (Fig. 2).

PPG sensor probes are miniaturized optical systems for PPG acquisition. They are composed by a Silicon Photomultipliers (SiPMs) photodetector coupled with infrared and red LEDs used as optical light sources. The SiPM detector was fabricated by STMicroelectronics and features a total area of 4.0 x 4.5 mm$^2$ and 4871 square microcells with 60 µm of pitch [21]. Probes are encapsulated into a 3D printed support. An optical long-pass filter covers the SiPM to avoid external light interference.

The acquisition system is a specific board providing the biasing for the probes, signal acquisition and management of data transfer between probes and PC.

PC drives board and probes, displays and stores real-time signals. It allows post-processing, too.
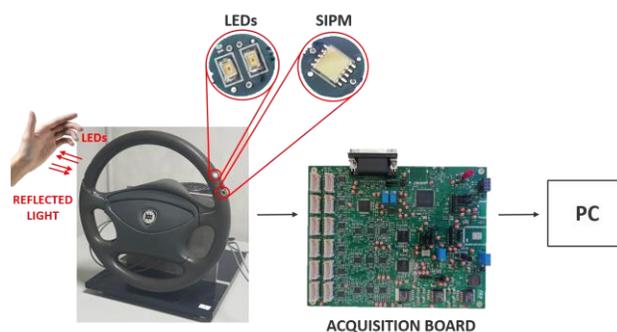


**Fig. 2 System block diagram**

### C. Measurement Setup

This work refers to an early experiment to introduce a new device for automotive application. The measurement setup proposed for this early study is designed to reproduce car environment as much as possible in a laboratory. The protocol is not compliant to medical instrumentation, since the application is different. Nevertheless, measurement setup and protocol have been set to acquire representative measurements of driver signal in a real situation. For this reason, we placed probes on a steering wheel at the theoretical hands' position while driving, Fig. 2.

Measurements are performed in the STMicroelectronics Catania fab in the morning, at the beginning of the workday, to avoid fatigue and stress related to a workaday. Every volunteer driver followed a specific protocol:

· Hand palms on the correct position on the steering wheel, to cover the sensors, both the light source and the photodetector;

· Seated position, to simulate realistic driving conditions.

· Darkroom, to avoid external light interactions.

· Quietness, to reduce emotional effects on PPG signal. To induce this state, before starting the measurement, the driver must wait 2/3 minutes in silence and without anybody in the measurement room.

Measurement population is composed of 50 subjects, 32 males and 18 females, with age between 30 and 70 years old. They were volunteers, thus we had no control over gender and age choice. For this reason, the population is not perfectly

distributed, however, it is enough representative. The measurements were performed in agreement with the ethical standards of the Helsinki Declaration and approved by the Human Board Review and Ethical Committee Catania1 (authorization n. 113/2018/PO).

## III. SYSTEM VALIDATION

PPG is a technique known for a long time in the medical field and there are many studies about PPG parameters. However, hands palm is not a usual measuring site. In this paper we aim to demonstrate the reliability of acquired data, the high sensitivity of the system and the possibility to acquire reliable PPG signals from hands palm. We have performed a comparison between experimental data and the literature and we will draw some conclusions.

Literature data [18], [19], [22] come from experiments that exploit measurement protocols similar to the one used in this work (section II.C). Therefore, this comparison can be considered trustable.

### A. Results

Fig. 3, Fig. 4, Fig. 5, Fig. 6 show the comparison between experimental data (red circles) and literature (black squares); red lines correspond to the experimental data fitting and black lines the literature data fitting.

Experimental data distributions are coherent with literature and trend lines are parallel with a small offset.

### B. Discussion

In general, our results show a clear correspondence between experimental data and literature: fitting lines are almost parallel and have a small offset. This could be due to the measuring site: it is known that PPG signal is different from site to site [23]. For these reasons, we can state that experimental data are coherent with literature and our prototype acquires reliable data.

As explained in section II.A, SDDN is a parameter that gives information about pulse duration [20]. Current prototypes based on heart monitoring techniques (ECG and PPG) analyze heartbeat duration to evaluate driver drowsiness [1], [6], [7], [9]. On that, the most studied parameters refer to beat-to-beat heart rate alterations, as SDNN. In particular, many devices perform Frequency Domain Analysis and extract Low Frequency (LF) and High Frequency (HF) components. The LF/HF ratio denotes a person's drowsiness, but there is not yet a common understanding [6], [7] and further works will be necessary. Fig. 3 shows coherency between data related to SDNN. This means that the prototype acquires trustable data on heartbeat duration from PPG signal and it enables the most popular driver drowsiness analysis.

Fig. 4, Fig. 5, Fig. 6 show coherence for Augmentation Index, b/a ratio, and Aging Index parameters (section II.A). Since they are all parameters related to PPG shape, we state that the proposed system acquires trustable data on PPG shape. This means that the prototype can evaluate at the same time PPG pulse duration and waveform shape parameters: a novelty in automotive application. PPG data fusion can improve current devices for drowsiness monitoring and thus enhances driver
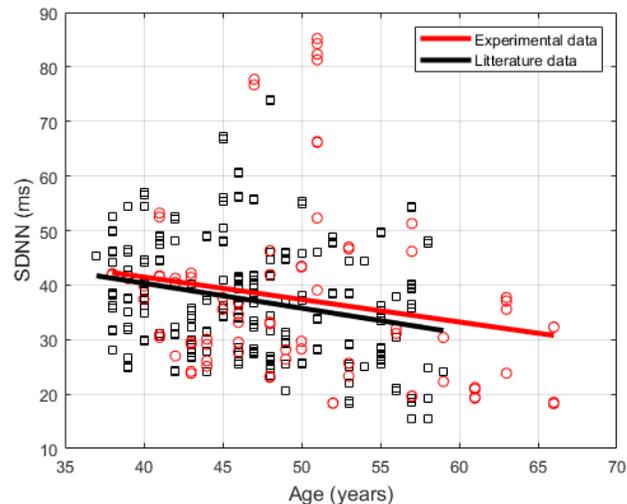
safety.



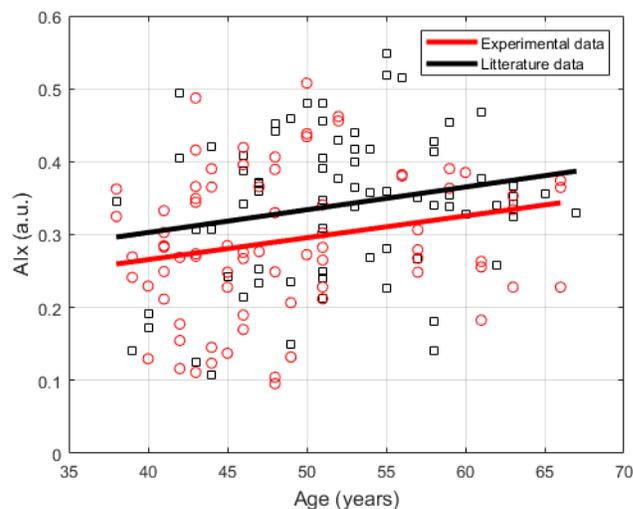**Fig. 3 SDNN comparison between experimental and literature data [22].**



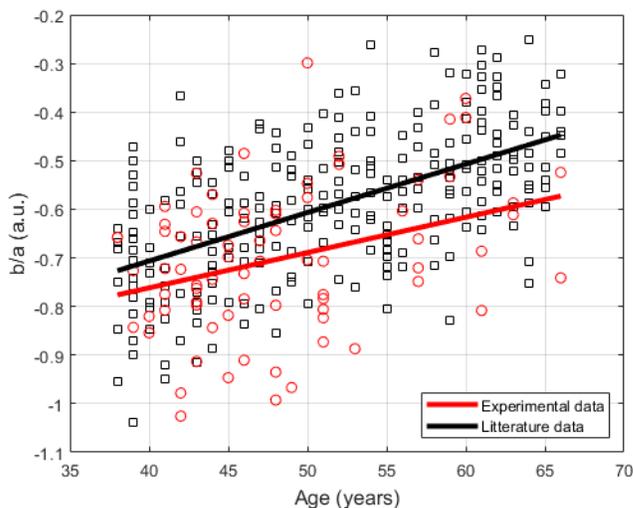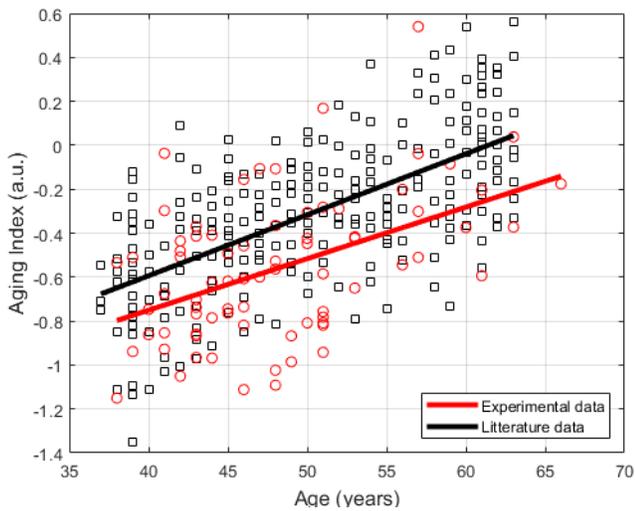**Fig. 4 Augmentation Index comparison between experimental and literature data [18].**



**Fig. 5 b/a ratio comparison between experimental and literature data [19].**

**Fig. 6 Aging Index comparison between experimental and literature data [19].**

## IV. CONCLUSIONS

We have discussed current techniques and prototypes for driver drowsiness monitoring and highlighted advantages and disadvantages. Current prototypes need improvements to achieve a more trustable evaluation of driver drowsiness. We have introduced our new prototype based on the PPG technique. We have performed a measurement campaign to validate the proposed system. We have compared experimental data and literature and we have underlined the coherency between them. Experimental results validate the prototype and demonstrate that we can evaluate at the same time heartbeat duration parameters and PPG shape characteristics: a novelty in automotive application.

Future works will exploit this prototype to evaluate driver fatigue, finding a possible correlation between PPG shape parameters and driver drowsiness [13].

## ACKNOWLEDGMENT

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