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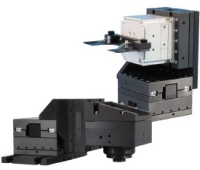
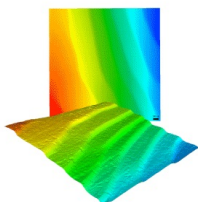
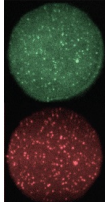
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## ABSTRACT

Nowadays, surveillance systems have evolved significantly; hence, in order to meet the specific needs of the health sector and to monitor the patients' health conditions, intelligent systems have been proposed. These innovations represent a primordial role in road safety, which reduce the risk of traffic accidents. This paper describes an intelligent system design for remote monitoring (tele-monitoring) of a driver's health condition in real time. The measurement using new hardware and software devices is made possible through the contact between the driver contact and an intelligent steering wheel, which is coupled either to an integrated monitor or to a bluetooth link with a local Android smartphone. The driver's heart rate is calculated through the continuous collection of the electrocardiographic signal as well as the blood oxygen saturation SpO<sub>2</sub> by using the photoplethysmographic technique. Consequently, it is necessary to monitor the two vital functions of the driver, cardiac and respiratory activity. This information is transmitted to a remote tele-vigilance center in the case of abnormalities in these functions under the transmission control protocol/internet protocol involving a 4G/3G connection. The application is associated with the system that triggers high and low alarms locally and remotely in the events of tachycardia, bradycardia, or cardiac arrhythmia. Furthermore, another alarm is also triggered in the event of respiratory decompensation.

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## NOMENCLATURE

A <sub>QRS</sub>	QRS complex amplitude
ECG	Electro-Cardio-Gram
GUI	Graphical User Interface
HR	Heart Rate
HRV	Heart Rate Variability
IDE	Integrated Development Environment
PPG	Photo-Plethysmo-Gram
PR interval	The time from the onset of the P wave to the start of the QRS complex
QRS complex	represents the electrical impulse as it spreads through the ventricles and indicates ventricular depolarization
QT interval	The time from the start of the Q wave to the end of the T wave
R–R interval	The time elapsed between two successive R-waves of the QRS signal of the electrocardiogram
SpO <sub>2</sub>	Blood Oxygen Saturation
TCP/IP	Transmission Control Protocol/Internet Protocol
T <sub>QRS</sub>	QRS complex duration

## I. INTRODUCTION

Road accidents cause more than  $1.25 \times 10^6$  deaths per year and cost most countries about 3% of their gross domestic product.<sup>1</sup> The causes and severity of accidents depend on factors related to the driver, vehicle, road, traffic conditions, emergency services, etc. Human factors remain the greatest contributor and cause more than 90% of bodily accidents.<sup>2</sup>

As an indication, these factors are generally due to speeding, fatigue and drowsiness, distracted driving caused by mobile usage, failure to respect safety distances, driving under the influence of alcohol and/or narcotics, and health complications (heart rhythm disorder, respiratory decompensation, hyper-, or hypoglycaemia).<sup>2–4</sup>

Hence, numerous studies and research focused on the development of new monitoring techniques to measure vital physiological parameters of a person at home, vehicle, or in other non-clinical environments in order to reduce accidents and improve public safety have become indispensable and important objectives.

Many companies focus on the development of new health-related technologies for use in non-clinical environments in order

to reduce road accidents. For example, a consortium of companies has developed a prototype connected to the seat belt to measure the driver's heart rate. This connected object can thus detect the sleepiness of the driver and can wake up the driver to take a break. This technological solution was developed by the Biomechanical University of Valencia in Spain and named Harken.<sup>5</sup>

A UK-based company, Plessey, specializing in electronics, defense, telecommunications, and semiconductors, in partnership with researchers at Trent University in Nottingham, England, have developed a brand new prototype: seats with the ability to prevent accidents in the case of drowsiness.<sup>6</sup>

Researchers from the Department of Electronics and Telecommunications, JSPM Narhe Technical Campus, Pune, India, have designed a device that continuously monitors driver vigilance in real time using a computer vision system consisting of the main components such as Raspberry Pi specially designed for the hardware platform, video camera, and alarm system.<sup>7</sup>

Rogado *et al.* proposed a method to detect the first signs of fatigue/sleepiness by measuring the heart rate variability (HRV), steering handle pressure, and the difference in temperature between the inside and the outside of the vehicle while driving. This method will determine if the subject is capable of driving.<sup>8</sup>

A system for monitoring the health status and vigilance of the driver in real time was proposed by Jung, Shin, and Chung. The steering wheel of a car with electrically conductive fabric electrodes is integrated to a electrocardiogram (ECG) sensor to monitor the driver's health status. The ECG signals were measured and transmitted wirelessly to a base station connected to a server's personal computer (PC) in a personal network environment.<sup>9</sup>

Joan Gómez-Clapers and Ramon Casanella proposed a system for non-invasive monitoring of the electrocardiogram signal (ECG) using a wireless steering wheel. A new heart rate detection algorithm based on the continuous wavelet transform has been implemented, specifically designed to resist the most common sources of noise and interference when acquiring the ECG through the hands.<sup>10</sup>

Recently, Japanese researchers have developed a real-time driver monitoring system with a camera that could estimate the heart rate of the driver (HR) and mental stress level (stress index).<sup>11</sup> Another group of researchers from India have developed a portable smart health monitoring system with remote access to the physician for senior citizens and rural healthcare personnel. This can be achieved by using a low-power, accurate, compact, cost-effective, user-friendly system, which is capable of measuring the patient's vital parameters. These data are displayed locally at the patient-end and also regularly sent to the physician-end using the IoT platform. The proposed system uses noninvasive sensors to monitor vital parameters such as the heart rate, SpO<sub>2</sub>, and body temperature accurately.<sup>12</sup>

The aim of this work consists in designing a smart and connected steering wheel to detect the physiological signals such as ECG and photoplethysmographic (PPG) signals and in implementing a device dedicated to the monitoring of the heart rate and its variability in order to detect possible tachycardia, bradycardia, or cardiac arrhythmia, as well as to detect possible respiratory decompensation (hypoxemia). When the driver experiences a complication or cardiac or respiratory failure, an alarm alerts him locally and information

is transmitted instantly and automatically to a remote tele-vigilance station, which directs a medical team to the person behind the wheel.

The proposed study is based on the development of a precise, fast, easy to implement, and non-intrusive system for the detection of cardio-respiratory complications of the driver while driving.

## II. MATERIALS AND METHODS

Monitoring the driver's health depends on continuous measurements of the pathophysiological state of the driver through the detection of the bio-signals, such as the electrocardiogram (ECG) signal, the respiratory signal, and the photoplethysmogram (PPG) signal.<sup>13–15</sup>

Much effort has been devoted to the development of a device to obtain ECG and PPG signals in a convenient, non-intrusive way.

- A wearable and wireless finger base-type pulse oximeter.<sup>16</sup>
- Non-contact measurement of respiration and heart rates by laser.<sup>17–19</sup>
- Non-intrusive and practical ECG signals are obtained by measuring the inductance on a chair.<sup>20,21</sup> Electrodes are placed on the back of the driver's seat. However, the method is very sensitive to the thickness of the driver's clothing and his movements.<sup>20</sup>
- Recently, a portable chest belt with two or three conductive electrodes<sup>15,22,23</sup> has been used to guarantee non-intrusive driving.

The smart steering wheel project to detect physiological signals of a driver can be designed in two ways, as illustrated in Fig. 1:

- a. Monitor integrated to the steering wheel.
- b. Bluetooth link between the steering wheel and a local Android smartphone.

The article describes the design of the monitor integrated to the steering wheel.

Two sensors are used to detect vital physiological signals, namely, cardiac activity and respiratory activity.

**A first electrocardiogram sensor** (DFRobot SEN0213) is used to detect the electrical activity of the heart. This measurement is possible whenever the driver holds the steering wheel attached with conductive fabric electrodes, as shown in Fig. 2. This electrically conductive fabric is used as electrodes and covers each half of the steering wheel. The material of the conductive fabric for the non-intrusive measurement of the ECG signal is flexible and covers the steering wheel in a watertight manner without impeding the driver. This fabric has a thickness of 0.05–0.21 mm<sup>9</sup> and a surface resistance of <0.05 Ω/square. The ECG signal detected by the sensor is filtered and amplified to highlight PR and QT intervals using the AD8232 chip included in the circuit.

**A second photoplethysmographic sensor** (rcwl-0530) attached to the earlobe is used to measure blood oxygen saturation SpO<sub>2</sub> (PPG signal) Fig. 3. It consists of two light-emitting diodes (LEDs) (red and infrared light emitting diodes), a photodetector, and a low-noise analog signal processor to detect pulse oximetry and heart rate signals. To ensure wireless information transmission, the rcwl-0530 photoplethysmographic sensor is coupled to a Arduino Mini board equipped with a Bluetooth module HC-06.

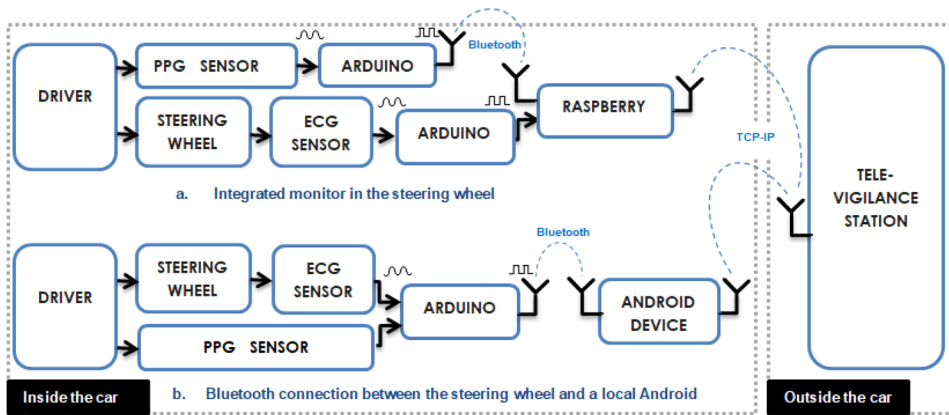


FIG. 1. Smart steering wheel architecture to detect the two physiological signals of a driver.

Each of the two captured analog signals will be transmitted to the successively approximated analog-digital converter, integrated into a corresponding Arduino board. The conversion of signals obtained from the analog devices is done on 10 bits with a sampling frequency of 200 Hz.

After the conversion of analog signals into digital ones, the Arduino board sends in real time and continuously both signals using the universal serial bus (USB) serial link for the ECG signal and the Bluetooth wireless link for the PPG signal, with a communication rate of 250 000 bauds, to a local remote monitoring station in the vehicle interior.

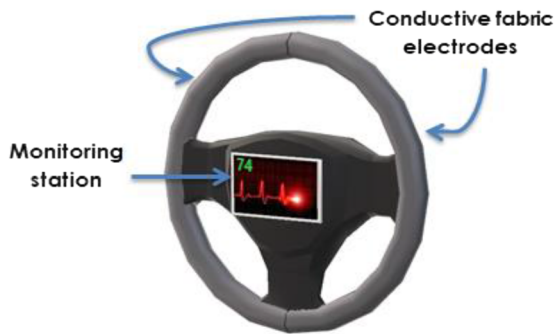


FIG. 2. Location of electrodes and the monitoring station.



FIG. 3. Wireless PPG sensor attached to the earlobe.

Figure 2 the station continuously displays signals, stores data, and will use an algorithm to detect QRS complexes, calculate the heart rate, measure blood oxygen saturation  $SpO_2$ , and detect possible cardiac and/or respiratory dysfunctions. This algorithm

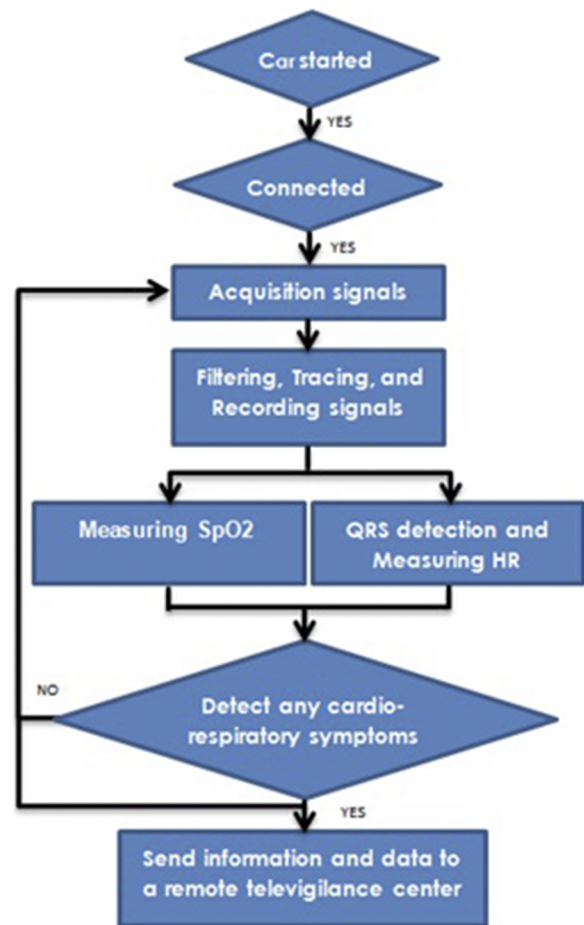


FIG. 4. The flow chart of the application.

implements a graphical user interface (GUI) under the Integrated Development Environment (IDE) Visual Basic to develop an application dedicated to the remote monitoring of a person at the wheel.

The flow chart of this application is shown in Fig. 4.

The Raspberry card is equipped with a memory card and a Wi-Fi module for internet access. The supply voltage of this remote monitoring station is 5 V and can be easily obtained in a car.

### III. RESULTS

#### A. Implementation of electrocardiographic tele-monitoring

Laboratory tests for electrocardiographic signal detection were conclusive. The electrical activity of the driver's heart is obtained through the contact between the driver's hands and electrodes. The driver's steering wheel has a conductive fabric on both halves to serve as electrodes (Fig. 5). Figure 6 illustrates the ECG signal obtained.

Figure 7 shows the automatic detection of Q, R, and S waves in real time.

Figures 8 and 9 show the automatic detection of irregular RR intervals and QRS complexes in red for the ease of reading the signal by doctors.



FIG. 5. Recording of the electrical activity of the heart.

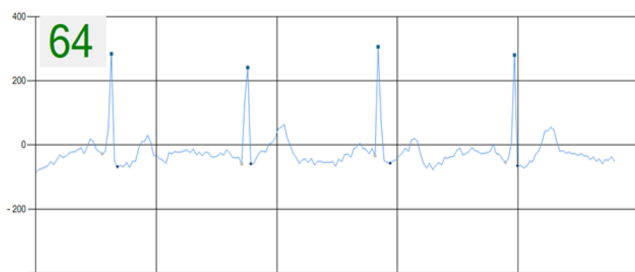


FIG. 6. Electrocardiogram (ECG) signal.

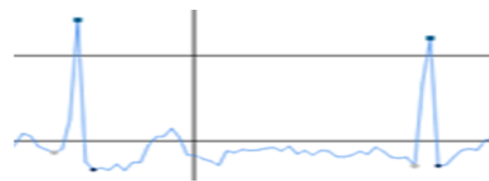


FIG. 7. Detection of Q, R, and S waves.

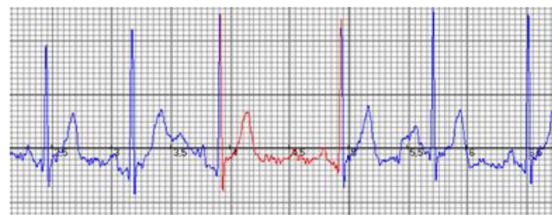


FIG. 8. Detection of the irregular RR interval.

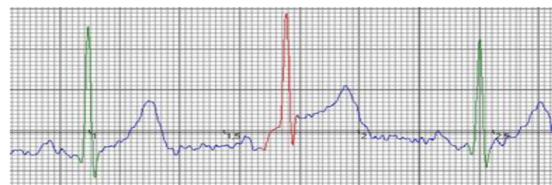


FIG. 9. Detection of the irregular QRS complex.

#### B. Implementation of photoplethysmographic tele-monitoring

To detect the blood oxymetric impulses, a photoplethysmographic sensor is attached to the earlobe to transmit the PPG signal. The laboratory tests were also conclusive. Figure 10 shows the PPG signal obtained.

#### C. The local tele-monitoring station (Raspberry card)

The real-time transmission of signals (ECG and PPG) to the local station and the display and continuous recording of these two signals at this station were also conclusive [Fig. 11]. Figure 12 shows the interface of this station.

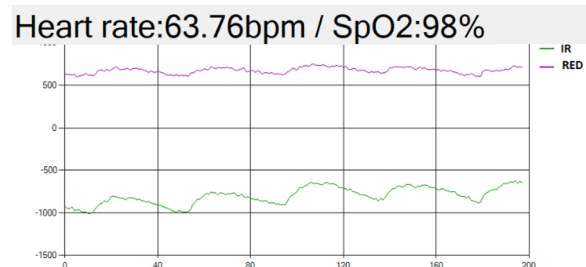


FIG. 10. Photoplethysmogram (PPG) signal.



FIG. 11. The tele-monitoring station and the tele-vigilance station.

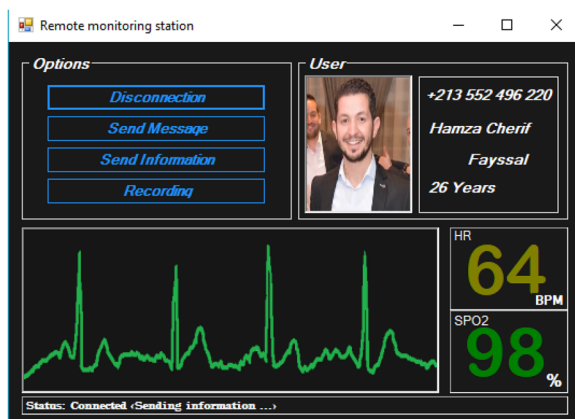


FIG. 12. Tele-monitoring station interface.

#### D. The tele-vigilance station (PC)

Sending the information to the tele-vigilance station in the case of cardiac and/or respiratory complications of the driver was also conclusive. For laboratory tests, a PC was used as a tele-vigilance station (Fig. 11). Figure 13 shows the interface of this remote station.

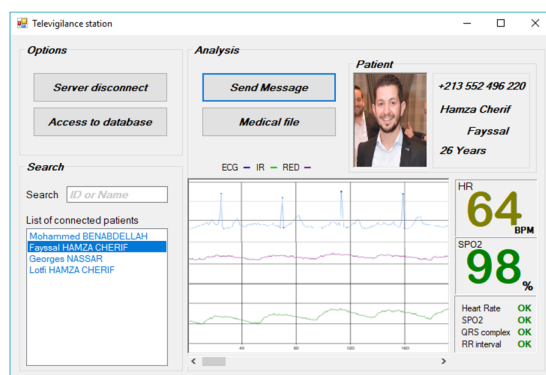


FIG. 13. Tele-vigilance station interface.

## IV. DISCUSSION

As part of this research, two main stations (tele-monitoring and tele-vigilance) have been developed. Each of these two stations contains an application (Figs. 12 and 13), which requires a connection between them for the purpose of transferring medical data including texts and multi-format files as well as multimedia data. The connection principle is based on the client/server architecture.<sup>24,25</sup> This data transfer expands the scope of this study to a tele-medical act dedicated to the tele-surveillance of a person at the wheel (tele-diagnosis and tele-assistance).

### A. Application of the tele-monitoring station

The tele-monitoring station can operate in two modes:

- Online mode: the two stations (tele-monitoring and tele-vigilance) are connected to each other. This option allows us to automatically transfer information about the state of health of the while driving to the tele-vigilance station via 3G/4G connection in the event of a cardiorespiratory complication.
- Offline mode: the remote tele-vigilance station is disconnected from the local tele-monitoring station. The tele-transmission of information concerning the state of health of the driver is then voluntarily interrupted by the driver.

The online mode of operation is enabled when the driver creates an account in order to connect to the remote station. This account hosted on a database contains all personal information about the driver and his medical records.

Pathology detection, such as bradycardia, tachycardia, heart rate variability, and hypoxemia, is based on the availability of the parameters below. Through this system, we will be able to

- collect ECG and PPG signals continuously,
- automatically detect Q, R, and S waves (Fig. 7),
- detect the irregularity of RR intervals (Fig. 8) and QRS complexes (Fig. 9), and
- calculate the heart rate and the SpO<sub>2</sub>.

From these detected parameters, the system allows for the detection of complications through the following procedures:

- Calculates and detects the variation in the heart rate in the last ten seconds. In the event of bradycardia, tachycardia, or detection of a high variability in the heart rate, an alarm will be automatically triggered.
- Bradycardia or tachycardia occurs when the heart rate is outside the normal interval between 60 and 100 BPM.
- Detect intraventricular conduction disorders, knowing that these disorders appear when the duration of the QRS complex exceeds 0.12 seconds. Normally the QRS complex oscillates between 0.06 s and 0.1 s. Beyond this normality, an alarm will be triggered.
- Calculate the blood oxygen saturation SpO<sub>2</sub> and detect any possible respiratory decompensation (hypoxemia). SpO<sub>2</sub> is considered normal when it is greater than 95% and abnormally low when it is less than 92%. An alarm will be triggered in the event of an abnormality.

In the case of the complications mentioned above, the following processes are performed by the system:

Case	Parameter	Value	Clinical significance
Normal	Heart Rate (BPM)	50 < HR < 100	Normal Beats
	QRS amplitude (mV)	0.5 < A <sub>QRS</sub> < 2.6	Normal amplitude
	QRS duration (s)	0.06 < T <sub>QRS</sub> < 0.1	Normal duration
	SpO <sub>2</sub> (%)	Over 95	Normal value
Alarm	Heart Rate (BPM)	Big differences between each successive heartbeat	Heart rate variability (HRV)
		50 < HR < 60	Slow Beats (Confusion, fatigue, dizziness or near-fainting ...)
		Less 50	Bradycardia
		100 < HR < 120	Fast Beats (fear, anxiety or stress ...)
	QRS amplitude (mV)	Over 120	Tachycardia
		Very low-amplitude less 0.5	Pericardial effusion or infiltrative myocardial disease
	QRS duration (s)	Over 2.6	Left ventricular hypertrophy
		0.1 < T <sub>QRS</sub> < 0.12	Prolonged duration indicates
		Over 0.12	Intraventricular conduction disorders (hyperkalemia or bundle branch block)
	SpO <sub>2</sub> (%)	92 < SpO <sub>2</sub> < 95	Low saturation
Less 92		Hypoxemia	

FIG. 14. The overall process of monitoring the driver's condition.

- A first audible and vocal alarm will be triggered instantly and automatically at the local station (tele-monitoring) to warn the driver. A voice message then tells the driver to park.
- At the same time, a second audible alarm will trigger at the remote station (tele-vigilance). The information concerning his health state is also transmitted instantly and automatically to allow the medical team to carry out prompt and appropriate measures to ensure the driver's safety.

Figure 14 shows the overall process of monitoring the driver's condition.

We have considered driving conditions such as the noise problem, regardless of whether removing the hands from the steering wheel will interrupt the ECG signal transmission.

This eventuality is supported, and the system continuously compares the heart rate calculated from the ECG signal and the heart rate calculated from the PPG signal, and in the case where the difference is less than ten beats, both signals will be used for the surveillance of the driver.

In the event where this difference exceeds the ten beats (one or both hands are raised or not placed), the application will automatically neglect the ECG signal and switch only to the PPG signal until the situation is restored again, i.e., when the difference is less than ten beats.

### B. Application of the tele-vigilance station

The tele-vigilance station is a platform where healthcare practitioners can, on the basis of information received from the tele-surveillance station, take quick and appropriate measures to ensure the follow-up and safety of a driver driving a vehicle in real time. This station is hosting the second application. It is linked to a database containing the medical records and information concerning the persons subscribed to this station. This database allows doctors to gather a perfect knowledge about the driver's possible illness and health status in order to enable them to make an optimized decision.

In order to facilitate the task of the station's medical team in the event of a complication, the application will activate an audible alarm and automatically display all the information concerning the failure of the parameters monitored by the station.

### V. CONCLUSIONS AND PERSPECTIVES

In this area, several research studies are based on the detection of fatigue and drowsiness of the driver using the study of visual facts (eye movements, facial expression, etc.) but not pathophysiological facts (ECG, PPG, and breathing pattern), that is, the driver's apparent state but not his health status.

This paper is focused on designing a new practical system for easy monitoring of the person's health status while driving in which two sensors (ECG and PPG) are used to measure the two vital physiological signals of the driver and on an algorithm to detect the heart rate, SpO<sub>2</sub>, and certain cardiac and respiratory dysfunctions (cardiac arrhythmia, bradycardia, tachycardia, and respiratory decompensation). The driver is warned immediately so as to react and consult a doctor. The ultimate goal is to monitor the driver's health status, thus reducing the number of road accidents related to cardiorespiratory system failure that occurs while driving.

This system is open for development through the addition of another biomedical sensor (temperature sensor, pneumotachographic sensor, and capnographic sensor). It will also combine visual and non-visual information with the driving environment. It will be able to analyze the heart rate variability (HRV) in the temporal and frequency domains of ECG signals to detect fatigue and drowsiness during conduction. It can also be coupled with the speed limiter, automatic braking, GPS, and Bluetooth phone. Thus, the vehicle can slow down, brake, park, and finally call the emergency service by indicating the vehicle position.

### ACKNOWLEDGMENTS

The authors declare no competing financial interest.



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