Universidade do Minho
Escola de Engenharia

Áurea Filipa da Cunha Salgado

Contactless Biometric Sensor for Automotive Applications

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Supervisor
Professor Doutor José Mendes

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Author Declaration

Name: Áurea Filipa da Cunha Salgado
Email: a62017@alunos.uminho.pt Contact: 962052893
Cartão do Cidadão: 14156558
Master Thesis Theme: Contactless biometric sensor for automotive applications

Advisor: Professor Doctor José Mendes

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"Science is about knowing; engineering is about doing."

Henry Petroski

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Contactless biometric sensor for automotive applications

Resumo

Acidentes na estrada são das maiores inesperadas causas de morte no mundo. Devido a este facto, a prevenção destas fatalidades é um importante alvo de estudo e investigação da maioria das empresas de automóveis. Em 2014 existiram cerca de 1.25 milhões de mortes na estrada em todo o mundo, com 20% de acidentes e 12% de possíveis acidentes serem causados por condutores sonolentos.

Esta dissertação visa desenvolver uma solução de monitorização para mundo automóvel através da medição do batimento cardíaco do condutor, para uma futura interpretação do seu estado fisiológico.

A monitorização do batimento cardíaco à distância é uma poderosa ferramenta para cuidados de saúde, quando comparada com as tecnologias alternativas de monitorização média a longo prazo, que requerem um contacto direto com o paciente, tais como: elétrodos, oxímetro e sensores piezoelétricos. Uma vez que a frequência cardíaca se altera ao longo dos diferentes estados de sonolência/fadiga, é possível avaliar o estado de sonolência do condutor usando a variação da frequência cardíaca (Heart Rate Variability - HRV), pela mediação dos valores do batimento cardíaco em todo o espectro.

Após a análise dos métodos de medição de batimento cardíaco sem contato, esta dissertação irá focar-se no uso de uma tecnologia baseada em radar que inclui a versatilidade de monitorizar sem contacto através das roupas do condutor. Este radar será integrado no acento do condutor usando ondas rádio para detetar a aceleração do coração e a respiração do condutor. Estes dados podem ser complementados com outras tecnologias tais como EEG (Electroencephalography) e *eye tracker* (monitorização dos movimentos dos olhos e cabeça), para detetar sonolência com maior fiabilidade.

A partir do momento em que os sinais podem conter ruído, harmónicos e outras interferências provenientes do carro, a filtragem dos dados recolhidos deverá ser tida em consideração.

Esta tese de mestrado será desenvolvida na Universidade do Minho, no projeto "INNOVCAR: The Cockpit of the future", em parceria com a Bosch Car Multimedia.

O conceito deve ser eficiente, confortável ao utilizador, fiável e ter um custo reduzido. A monitorização de sinais vitais do corpo humano pode ser usada para evitar acidentes ou mortes na estrada. Nas estradas através deste conceito, poderá ser possível ativar respostas como avisos, paragem do carro, ou até mesmo uma chamada de emergência.
Palavras-chave: HMI automóvel, sensores biométricos, sonolência, batimento cardíaco

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Contactless biometric sensor for automotive applications

Abstract

Accidents on the road are the biggest unexpected causes of death in the world. Because of this, the prevention of the fatalities is an important target of study and investigation for most of car manufacturers. In 2014 there were 1.25 million deaths on the road worldwide, with 20% of crashes and 12% of near-crashes being caused by drowsy drivers.

This dissertation aims to develop a monitoring solution in the automotive world, to measure the heartbeat of the driver, for a future interpretation of your physiological state.

Heart rate monitoring from a distance is a powerful tool for health care, when compared to alternative techniques for long-term medical monitoring, that require direct contact with the patient such as: electrodes, oximeter and piezoelectric sensors. Since the heart rate changes along the different stages of drowsiness/fatigue, it is possible to evaluate the drowsy state of the driver using Heart Rate Variability (HRV), by measuring values along the frequency spectrum of the heartbeat.

After the analysis of the existing non-contact methods to measure heartbeat, this dissertation will focus on the use of a technology based on radar that includes the versatile ability to function at a distance through the driver´s clothing. The radar that will be integrate on the driver´s seat uses radio waves to detect the heart´s acceleration and the drivers breathing movement. These data can be complemented with other technologies such EEG (Electroencephalography) and eye tracker (monitoring of head and eye movements) to detected the drowsiness state with more reliability [1][2].

Since the signals may contain noise, harmonics and other vehicle induced issues, data filtering will be required [3]. This master thesis will be developed at University of Minho, within the partnership project "INNOVCAR: The Cockpit of the future", with Bosch Car Multimedia.

The concept solution must be efficient, comfortable to the user, reliable and have a low cost. The monitoring of the vital signs of the human body can then be used to ultimately avoid accidents and deaths on the road. Through this concept, it will be possible to trigger responses like activating an alarm, stopping the car, or even calling emergency assistance if needed.

Keywords: : Automotive HMI, biometric sensor, drowsiness, heartbeat

Contents

List of Abbreviations

ADAS	**A**dvanced **D**river **A**ssistance **S**ystems
ADC	**A**nalog-to-**D**igital **C**onverter
BBB	**B**eagle**B**one **B**lack
CMOS	**C**omplementary **M**etal–**O**xide–**S**emiconductor
CW	**C**ontinuous-**W**ave
DAC	**D**igital-to**A**nalog **C**onverter
DSM	**D**river **S**imulator **M**ockup
ECG	**E**lectro**C**ardio**G**raphy
EEG	**E**lectro**E**ncephalo**G**raphy
EMG	**E**lectro**M**yo**G**raphy
EOG	**E**lectro**O**culo**G**raphy
EPIC	**E**lectric **P**otential **I**ntegrated **C**ircuit
FFT	**F**ast **F**ourier **T**ransform
FN	**F**alse **N**egative
FP	**F**alse **P**ositive
GUI	**G**raphical **U**ser **I**nterface
HF	**H**igh **F**requency
HMI	**H**uman **M**achine **I**nterface
HR	**H**eart **R**ate
HRV	**H**eart **R**ate **V**ariability
IP	**I**nternet **P**rotocol
IR	**I**mpulse **R**adio
IBV	**I**nstitute of **B**iomechanic of **V**alencia
KSS	**K**arolinska **S**leepiness **S**cale
LD	**L**aser **D**iode
LF	**L**ow **F**requency
MIT	**M**assachusetts **I**nstitute of **T**echnology
NASA	**N**ational **A**eronautics and **S**pace **A**dministration
NREM	**N**on - **R**apid **E**ye **M**ovement
PD	**P**hoto**D**etector
PVC	**P**remature **V**entricular **c**ontractions
REM	**R**apid **E**ye **M**ovement
RF	**R**adio **F**requency
RR	**R**espiration **R**ate
SOC	**S**ystem-**O**n-a-**C**hip
SPI	**S**erial **P**eripheral **I**nterface
STFT	**S**hort **T**ime **F**ourier **T**ransform
TCP	**T**ransmission **C**ontrol **P**rotocol
TN	**T**rue **N**egative

USB	**U**niversal **S**erial **B**us
UWB	**U**ltra-**W**ide **B**and
VLF	**V**ery **L**ow **F**requency
VST	**V**ehicle **S**afety **T**echnolog

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Chapter 1

Introduction

Accidents on the road are one of the biggest unexpected causes of death in the world. Therefore, the prevention of these fatalities is an important target of study and research for car makers, suppliers and automotive organizations. In 2014, there were 1.25 million deaths on the road worldwide. In the records, 20% of crashes and 12% of near-crashes involving road vehicles were caused by drowsy drivers. For this reason, it is crucial to detect the driver's fatigue in order to prevent further crash events, so this is an important and relevant topic for researchers. Several techniques are used to monitor the vital signs of the drivers. In this specific project, the heart rate signal analysis is used.

Since a person's heartbeat changes along the different stages of drowsiness/fatigue, it is possible to evaluate the drowsy state of a driver using Heart Rate Variability (HRV) [1], by measuring the heartbeat along its frequency spectrum. A monitoring system can then, detect the driver's fatigue and proceed to an alarm, stop the car, or even call emergency assistance. This means that, the monitoring of the human body vital signs can be used to ultimately avoid accidents and deaths on the road.

This dissertation aims to develop a contactless solution to measure the heartbeat of the driver and use the acquired signal to detect the driver's fatigue.

Contactless measurement solutions may offer some advantages compared to other contact solutions, such as electrodes, oxymeter and piezoelectric sensors.

The heart rate monitoring from far distance is a powerful tool for long-term health monitoring without compromising a person's comfort and health [22].

In order to detect the heart's acceleration and breathing movement without any type of contact with the driver, it will be used a radar sensor. This sensor, must be able to make measurements through the driver's clothing. Special attention must be given to the collected signal since errors because of noise, harmonics and other vehicle induced issues must be filtered before the data can be used for monitoring purposes. The main goal is to measure heart rate, frequency and breathing rate using the mentioned radar sensor.

This dissertation will be developed at University of Minho, within the partnership project INNOVCAR: The Cockpit of the future, with Bosch Car Multimedia.

1.1 Motivation

Recent studies have shown that tiredness among drivers accounts for 20% to 35% of the serious road accidents and suggest there are more than 6,000 fatalities a year in Europe.

In the automotive industry, the concept of monitoring the drivers in real time and acting according to their physiological state will be achieved in the near future. The exchange of information is possible using a human machine interface (HMI).

The HMI is not only a communication bridge between the driver and the car itself, but also the main connector between the driver and outside world.

For the development of this dissertation, the key motivation is to avoid accidents caused by driver's fatigue and gain professional experience within the industry. Finally, this project aims to develop a biometric sensor based system capable of detecting driver's fatigue and warn him in useful time.

1.2 Objectives

The main objective of this dissertation is to conceive, develop, implement and test a concept for detecting a driver's fatigue by monitoring their heartbeat using a contactless sensor. The concept solution must be reliable, efficient, and comfortable to the user.

Beyond the main objectives, there are sub-objectives that must be achieved:

- Selection the most appropriate contactless biometric sensor for heartbeat monitoring, taking into consideration criteria like comfortability, size of the sensor and its efficiency;
- Development of a robust algorithms to detect the driver's fatigue using heartbeat;

1.3 Research Questions

The biggest question in this dissertation is: "How to avoid car crashes caused by fatigue/drowsiness?". The purpose of the dissertation is not to give an absolute answer, but to suggest, experiment and prove a concept that leads to a possible answer.

To define a concept, based on the goals, other research questions appear like:

1. "How to detect drowsiness from the driver at distance using heartbeat?"
2. "What is the more reliable sensor to integrate in the car?"
3. "What is the most adequate place for the sensor inside the car to collect data from the driver?"

1.4 Thesis Structure

This thesis consists of 6 chapters and one complementary chapter, the bibliography references.

Chapter 1 gives an overview of the theme of this dissertation, the outlined goals of the project, research questions and the motivation of this research. Here is present a brief justification of why and how this thesis will be executed.

A state of the art with the theoretical concepts related to the monitoring methods for vital signals and a brief state of market is presented in chapter 2. This chapter is divided into 3 sections, where the more extensive is the non contact monitoring methods, the groundwork of this dissertation.

The chapter 3 will be explained the methodology adopted, the important choices and procedures made to lead to the next chapter. This chapter is fundamental to justify some decisions, like hardware and software, and some constraints that conducted to specification of the functional and non-functional requirements.

In the 4 will be detailed the system design, where it will be demonstrated the fundamental flowchart, diagrams and explanation of how the system will be implemented, based on the choices made in the previous chapter.

The chapter 5, called Implementation and Test Results, presents some of the experiences and the resulting from the algorithms implemented.

Lastly the chapter 6, presents the conclusions and the perceptive of the author on future work.

Chapter 2

State of the art

2.1 Introduction

The analysis done about the state of the art is divided into 5 sections: heart; methods to detect heartbeat with and without contact; drowsiness detection methods; the state of the market.

In the first section, it is presented a brief explanation of this vital organ to understand the valuable informations this organ can provide, and also what can influence its activity and the standard values of a healthy adult.

Contact and contactless methods used to monitor are also presented in this chapter, with some of the main advantages and disadvantages being pointed on.

After this analysis, it is presented a study of the methods to detect drowsiness resorting to heartbeat and some are presented around this theme. Lastly a state of the market to explore implementations present in industry.

2.2 Heart

Heart is an important organ in the human cardiovascular system, since it is responsible for the distribution of blood to all organs. The main functionalities of the heart are:

- Create blood pressure: Through contraction of cardiac muscle, the blood pressure is generated, forcing the blood flow between the places of higher to the lower pressure;
- Regulation of the blood supply: through the blood pressure, it possible to supply nutrients needed by each organ;
- Direct blood circulation: to the lung oxygenate the blood the heart shall orientate the blood to them.

- Unidirectional blood flow: the heart has cardiac valves that work like non-return valves, conceiving the blood flow in a single direction.

The below figure demonstrates the anatomy of the heart, with its 4 chambers: 2 atriums and 2 ventricles. The atriums receive the blood with lower pressure and pump it to the ventricles. On the other hand, the ventricles pump the blood with higher pressure to the circulatory system.

The two ventricles are at the bottom and the two atriums on top of the heart chambers.

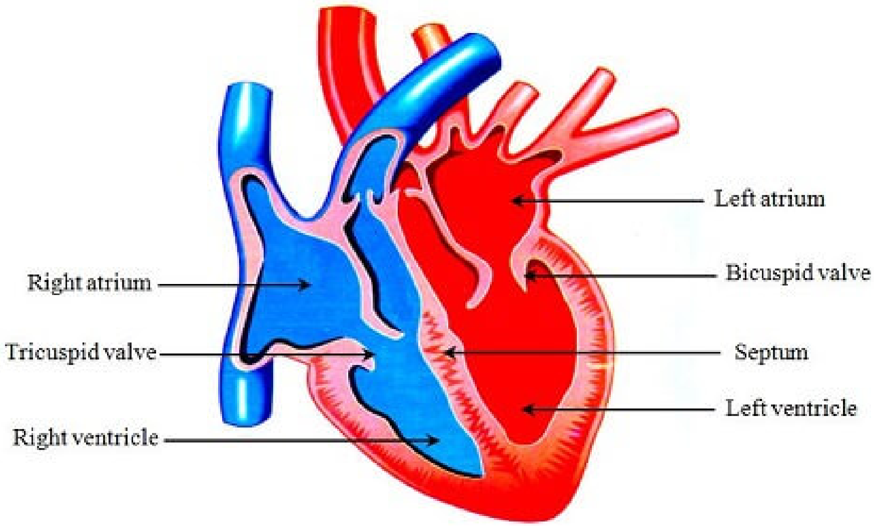

FIGURE 2.1: Heart anatomy [4]

Cardiac cycle corresponds to a number of events that occur since the beginning of one beat until another. This cycle can be divided in two distinct moments: the systole and diastole. That is the relaxation period, where blood goes into the heart. In contrast, the systole corresponds to the contraction period and blood ejection.

Heart operation consist in the atria pumping blood into the ventricles and then the ventricles pumping it out of the heart.

Heart rate is the number of heart beats per unit of time, normally expressed as beats per minute (bpm). The average number is 60-80 bpm for a healthy adult.

Many factors can influence the normal heartbeat of a person, like:

- Activity level;
- Exercise;

- Body Temperature;
- Body position;
- Emotions;
- Medications;
- Cardiovascular Disease;
- etc.

2.3 Contact detection methods

Nowadays the usual way to measure heart rate is manually with devices like electrocardiographs (ECG), that collect the electrical activity of the heart using electrodes placed on the skin. For a standard monitoring, four electrodes are placed on each limb, as well as six electrodes on the chest, Figure 2.3, but a simple clinical placement only requires three limbs: left arm, right arm and left leg.

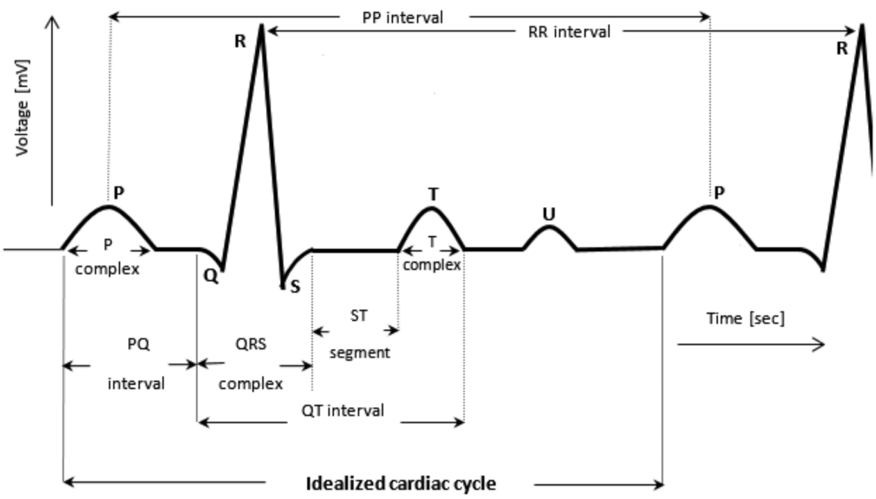

FIGURE 2.2: ECG signal [5]

Figure 2.2 represents one ECG tracing cycle. The QRS complex and the R-peak are the most significant segments in the ECG signal, which provide the information for almost all automated ECG analysis algorithms. R-peaks filtering is necessary for the heart rate detection, where the difference between two successive R peaks can be up to 200 ms.

The time intervals between consecutive heart beats, in QRS complex is used as reference to the calculation of the RR intervals. The measurement, beginning in the R wave until the beginning of the next R wave, provides the number of beats per minute.

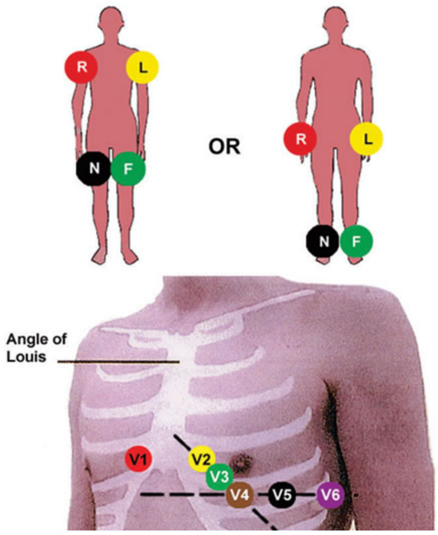

FIGURE 2.3: ECG electrodes placement [6]

The QRS complex corresponds to the depolarization of the right and left ventricles of the human heart, so this complex is associated with ventricular contraction. This behaviour has the name of systole, and occurs when emptying the ventricles.

Besides the ECG, there are other devices like heart rate monitors and pulse oximeters [23]. Since one of the objectives is monitoring the heartbeat of the driver without contact, these technologies are the focus of study and research in this thesis. Despite that, in the health care industry, the systems with skin contact are the most common. One example of the disadvantages of these technologies is in figure 2.4, illustrating a burnt skin due to the use of electrodes. The probable causes can be a sensitive skin, reaction to the electrode adhesive, the electrode gel or an extended exposure to the electrodes.

2.4 Contactless Monitoring Methods

Non-contact methods have some significant advantages compared to the contact ones, since they do not cause discomfort or skin irritation, unlike electrodes and straps do (in extended periods of time).

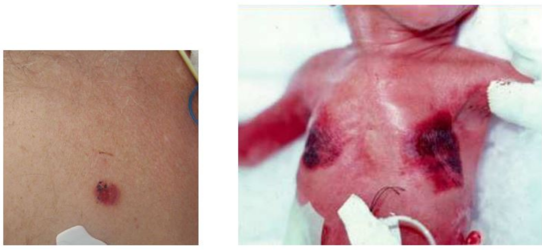

FIGURE 2.4: Skin burn under the electrode [7]

The reliability can increase since the patients do not notice the monitoring and are therefore less probable to alter their respiration and heartbeat. Lastly is the accuracy due to the lack of surface-loading effects [7].

Non-contact detection of cardiac activity is possible through three main techniques:

- Laser-based monitoring systems
- Image-based monitoring systems
- Electromagnetic-based monitoring systems

These three methods provide a monitoring solution without the discomfort of having electrodes attached or devices pressing the finger or ears.

2.4.1 Laser-based Monitoring Systems

Laser-based monitoring systems rely on detecting light reflected by the skin deflection due to the appearance of arterial blood pulses as consequence of the dilatation and contraction of the artery. The heart rate, the artery vessel deformation and the delay in the pressure can be analysed in real time without any contact monitoring system, figure 2.5.

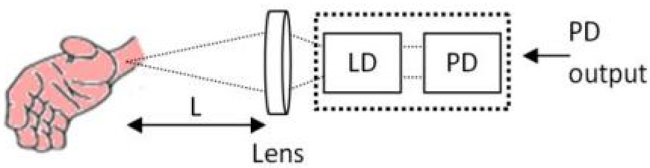

FIGURE 2.5: LD (Laser diode), PD (photodetector)[8]

2.4.2 Image-based Monitoring Systems

These non-contact methods are associated with the use of cameras pointing to a target, with a relaxed and constant posture throughout data or video acquisition [2]. The data collection can be done through the monitoring of the facial video or through another body part by directed a high-powered LED. With the blood flowing, the skin deflects and this movement can be visually observed by a camera to acquire the heartbeat. This method is still the target of investigation to demonstrate more feasibility. The use of image for monitoring heart rates can be useful when used on infants, hospitalized people, etc.

2.4.3 Electromagnetic-based Monitoring Systems

The electromagnetic-based monitoring systems are based in a radar that transmits a radio microwave towards a target. This radio wave is reflected and the strength of the signal is measured. Based on the detection time and frequency of the reflected pulses, information can be derived about the movement of the body with a spatial resolution of up to 1mm.

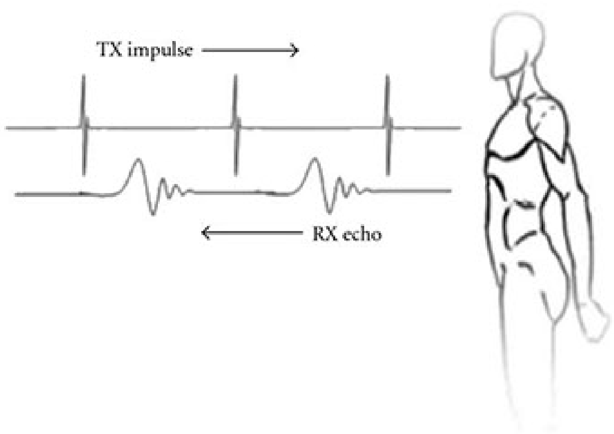

FIGURE 2.6: Vital Radar [9]

The first implementation of a radar technology to measure breathing rate was in the 1970s. The original system was made with heavy and expensive components. Today, the existing radar solutions are compact, lightweight and inexpensive. This cost reduction, associated with mass production of such sensors, is behind the increasing interest in the research and development of contactless solutions to measure heartbeat in humans without special preparation nor placing any device on the human body.

There are two types of radar solutions that are capable of heart rate monitoring: continuous-wave (CW) and wide band pulsed radar (UWB). A continuous stream of electromagnetic radiation, that characterizes the continuous-wave or pulse waveform, are generally more simple than pulsed radars in hardware and signal control. Nonetheless, the CW radars have a disparity between the transmitted and received power levels, which can result in some difficulties on detection [24].

The UWB impulse signals can span a broad frequency range. The wireless systems consist of transmission and reception of sub-nanosecond pulses without carries. This pulsed radar has low power consumption, so it can coexist well with other instruments and is also robust to interference and multipath.

One of the main advantages of the UWB signal is that it can be propagated through objects, and through walls. This feature is especially important in rescue appliances.

Impulse Radio (IR) is a type of UWB that uses short baseband pulses, in the order of a nanosecond. Other example of a UWB radar is the Doppler Radar, that is based on the Doppler effect, which includes a transmitter, receiver, simulated channel and post processor.

The Doppler effect consists in frequency variation of a wave caused by relative motion between the source of the wave and the observer, each means causes a phase shift to the reflected wave proportional to its movement. If the target changes position with respect of the time but without net velocity, the reflected signal has phase proportion to the time-varying position of the target. As depicted in figure 2.7, when an ambulance moves towards the observer, each successive sound wave is emitted from a closer position than that of the previous wave. Because of this change in position, each sound wave takes less time the receiver than the previous one .

The pitch of a sound wave tells us how often the wave encounters the listener. When the sound source moves away, waves are emitted from a more distant source, so the wavelength of wave increases and the frequency decreases.

Over the years, some RF systems used the *Doppler Radar* to detected RR (respiration rate) and HR (heart rate). The radio waves irradiated through the target thorax are reflected back with alterations proportional to its movement. Being reflected from a human body, a signal acquires specific biometrical modulation, which does not appear in the case of reflection from inanimate local objects [25].

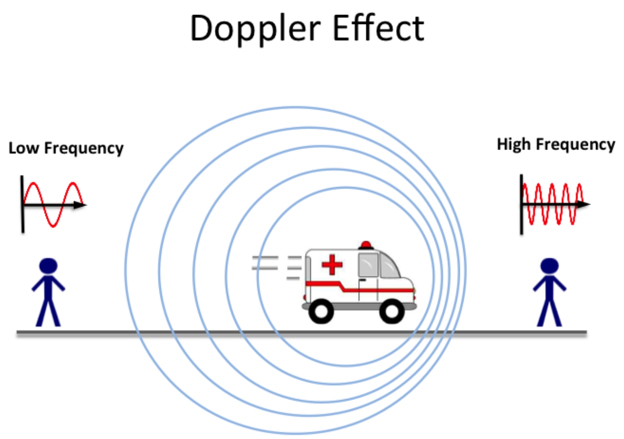

FIGURE 2.7: Example of Doppler effect with passage of an ambulance [10]

2.4.3.1 Radio Frequency Waves

This topic specifies the main features of radio frequency waves, since they are used in electromagnetic-based monitoring systems. The RF waves have a range between 30 kHz to 300 GHz, and have been shown to be a reliable way to a long range communications.

To extract the physiological signal, the waves are in a high frequency range (in GHz order), the waves recreate the thorax changes due to respiratory and cardiac activity. This non-contact monitoring is based on the effect of Doppler shift to sense heartbeat and respiration rate through the contraction and expansion of the chest wall. Looking to the figure 2.8, a person in a stationary position has no net velocity, but the chest has a periodic movement. An RF system pointed to the chest will received a signal $\theta(t)$ with its phase modulated by the time-varying chest position $x(t)$ [26]. If multiplied, the received signal and the original (un-modulated signal)can be used to extract the information about the chest movement during the heartbeat and respiration.

Health Risks

One important subject of study is the behaviour of the biological tissues in presence of RF radiation. When radio waves pass through the human thorax they have contact with different kinds of tissues. Inside of all the RF spectrum the X and Gamma rays are ionizing radiation, so they present more risks of causing cancer and genetic mutation 2.9.

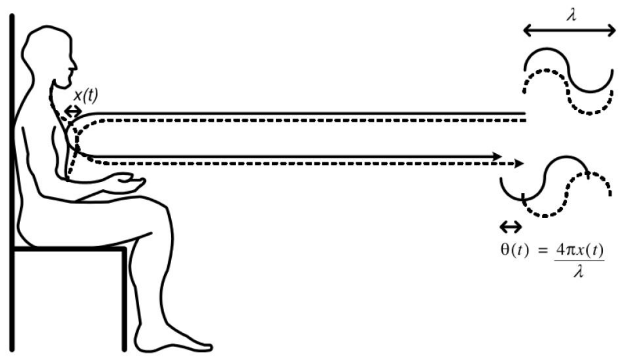

FIGURE 2.8: RF noncontact vital-signs monitoring system [11]

Additionally, the RF communications are very useful nowadays to numerous communication appliances: radio, television and mobile phone communications.

Radio Signal Components

Recent researches describe the ability to detect heart and respiration activities of a subject by utilizing systems with tens of GHz [27].

The figure 2.10 represents a UWB radar signal, where the curves correspond to heart systoles and thorax motion, after the original radar have been filtered to separate the two components.

In some research studies an high-pass filtering is commonly applied to isolate the heart signal. By and applying a low-pass filtering, the out-of-band noise is removed [13].

In specific applications, there are only two main classes of digital filters: finite impulse response (FIR) and infinite impulse response (IIR). Table 2.1 shows both filters, comparing them in terms of phase, stability, order and history [28].

Signal Processing to extract biological signals

Breathing causes a chest displacement between 4 and 12 mm and usually presents a frequency range of 0.1Hz to 0.3 Hz [29]. On the other hand, heartbeat causes a variation of 0.2 and 0.5 mm chest displacement and presents a frequency range between 1 and 3 Hz [30]. The breathing rate is easier to extract

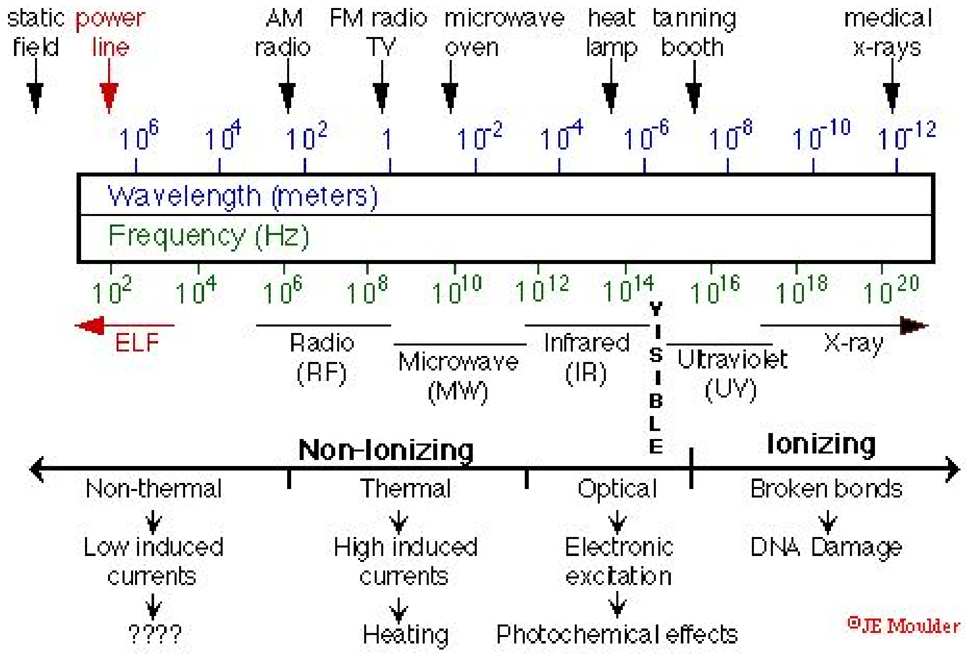

FIGURE 2.9: The Electromagnetic spectrum and the radiation effects [12]

than heartbeat due to the higher displacement of the chest. Therefore, the respiration rate can be detected without any signal processing, while the heart rate must be filtered and isolated from the respiration.

Breathing movement is the dominant variation of the signal, and as such it should correspond to the highest peak in the frequency spectrum. When the person inhales, his chest gets closer to the device and when exhales the opposite happens. Due to this linearity, it is possible to extract the breathing signal. The heart has similar conclusions, but this movement is considerably smaller since the movement is synchronous with ventricular pump activity [31].

Heartbeat and the breathing periodicity are independence of the user's position. If the user is in the back position, the valleys become peaks and vice versa, in the shape signal, but the periodicity continues the same [32][33].

The most common signal processing techniques to obtain the vital signals are Fourier transform, autocorrelation and peak finding. Therefore, to isolate the heart signal from respiration can be dimensioned a high-pass filter with a transition between 0.070 Hz and 0.35 Hz.

Frequency spectrum obtained by the Fourier transform is a conversion of a

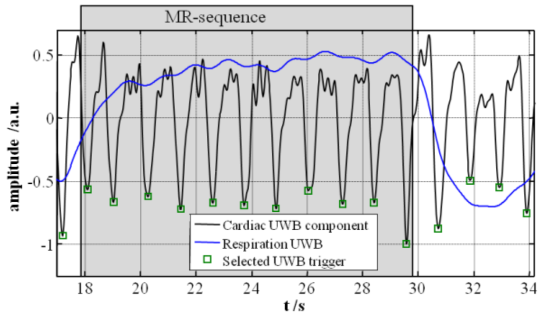

FIGURE 2.10: Cardiac and respiratory UWB signal [13]

	IIR Filters	**FIR Filters**
Phase	difficult to control, no particular techniques available	linear phase always possible
Stability	can be unstable, may have limit cycles	no limit cycles
Order	lower	higher
History	derived from analog filters	no analog history

TABLE 2.1: Digital filters comparison [21]

signal from its original domain (usually time). The importance is the ability to extract the frequencies band with higher spectral power (dominants).

Autocorrelation multiples the signal shifted to emphasize periodicity of the signal, is a tool for finding repeating patterns such as the presence of a periodic signal obscured by noise, or identifying the missing fundamental frequency in a signal implied by its harmonic frequencies. Allows the elimination of noise and static objects, such as the monitoring with a radar. Because the presence accentuation of a moving objects (human body).

Peak-finding is calculate where the peak is found, through an algorithm of peak detection, and with these values calculated the signals rate [21].

2.5 Drowsiness Detection Methods

The drowsy state is defined as a disposition to fall asleep. The sleep stages can be simply divided by: awake, non-rapid eye movement sleep (NREM) and rapid eye movement sleep (REM). The NREM state can also be referred to as somnolence or drowsy sleep. During this state the breathing becomes more regular, the heart rate begins to decrease gradually and consequently, furthermore the reaction time decrease drastically as seen in figure 2.11.

The REM (rapid eye movement) sleep occurs in 70-90 minutes after falling asleep. This stage is where dreams normally occur, breathing quickens and becomes irregular and shallow. The drowsy state is included in the second stage (NREM), which can be subdivided in other three stages :

1. Drowsy: transition from awake to asleep

2. Light sleep: the eyes move very slowly and the muscles relax. In this stage the subject can be awakened easily

3. Deep sleep: the blood pressure drops, breathing slows, the eyes stop moving and the muscles become relaxed.

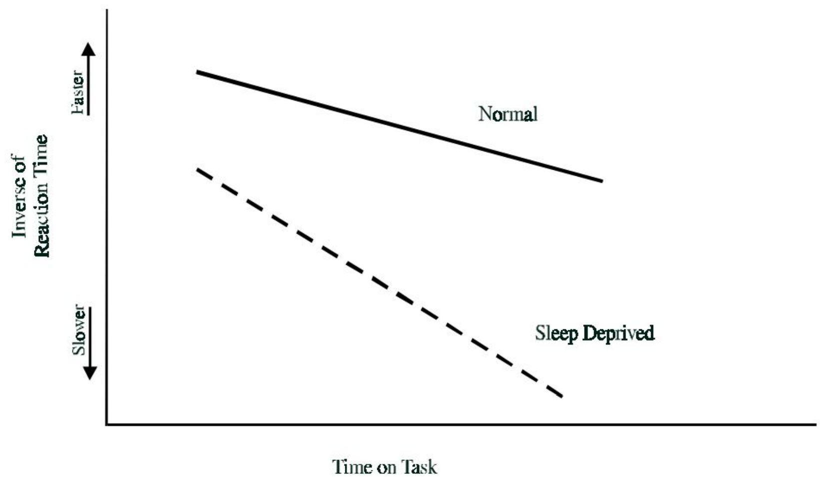

FIGURE 2.11: A summary of data (Kribbs, Dinges, 1994) on reaction to an event marker presented to a subject every 4 seconds. Performance slows with sleep deprivation and normal amounts of sleep [14]

The researchers imply that the stage 1 (drowsy) is the major cause of accidents. Some of the main situations reported, that lead to a drowsy state are described below.

1. Occur late, at night (0:00 am - 7:00 am) or during mid-afternoon (2:00 pm - 4:00 pm);

2. Involve a single vehicle running off the road;

3. Occur on high-speed roadways;

4. Driver is often alone;

5. No skid marks or indication of braking.

Some of the impairments identified in environment laboratory and in a real driving situation, include slower reaction time, a reduction of vigilance and a lack of information processing.

In order to prevent crashes, the drowsiness state of the driver should be monitored. There are several ways to detect and measure the driver's drowsiness level. Usually these methods are divided in four categories: subjective, observation, behavioral, and physiological.

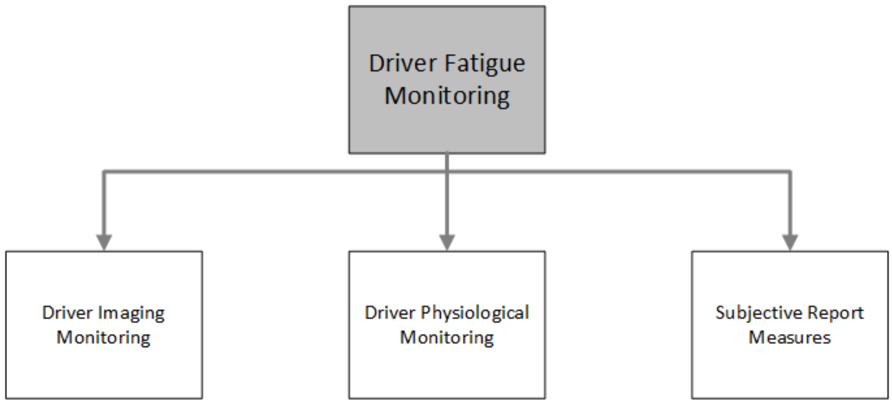

FIGURE 2.12: Driver fatigue monitoring method

Imaging Processing Techniques

In this approach the treatment data is provided by cameras that detect the body movement of the driver like eyelid movement, eye gaze, yaw, and head nodding. One example of the technique is the SmartEye Pro, a software and hardware platform for eye tracking research proposes. It uses infra-red cameras and computer vision proprietary software to obtain eyes and head features.

Physiological Signal Detection Techniques

The bio-signals of the subjects are measured with technologies such as the electroencephalogram (EEG), electrooculograph (EOG), and electrocardiogram (ECG or EKG). The drowsiness/alertness state is correlated with brain and heart activity, so these two physiological signals have been the subject of many researchers to detect driver fatigue.

In the brain a drowsy state is characterized by brainwaves with slow frequencies between 8 and 12 hertz and amplitudes around 50 microvolts, named as Alpha waves [34].

Stage	**Frequency (Hz)**	**Amplitude(μ V)**
awake	15-50	<50
pre-sleep	8-12	50
1	4-8	50-100
2	4-15	50-150
3	2-4	100-150
4	0.5-2	100-200
REM	15-30	<50

TABLE 2.2: Brain sleep stages

Relative to the heart, first irregularity of the RR intervals of the heart was first study in 1600's [35]. Because the heart rate can increase and decrease dramatically in a fraction of seconds it can barely be noted in the RR intervals. So the phenomenon of the heart rate rising and falling on different times scales is the heart rate variability.

There are three classes of HRV:

- Time domain;
- Frequency domain;
- Non-linear methods.

Time domain analysis extracts a few special measures using only the temporal RR interval signals. Frequency domain analysis is based in the spectral analysis of HRV. This spectrum has three components: very low frequency (VLF) between 0.003 Hz and 0.04 Hz, low frequency (LF) between 0.04 Hz and 0.15 Hz and high frequency (HF) between 0.15 Hz and 0.4 Hz. [36]

The HF frequency band is dependent on the parasympathetic branch, which is a autonomic nervous system. This frequency band decreases from a stressful state. The LF is dependent from the other autonomic nervous system's sympathetic branches. This band has the opposite behaviour, which means the heartbeat increases due to circumstances such as stress [16]. The figure 2.13 represents an HRV power spectral analysis.

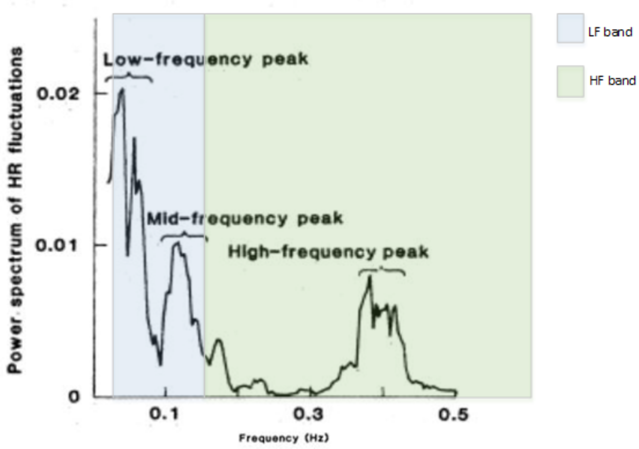

FIGURE 2.13: Heart rate variability [15]

Linear methods have been widely explored and are considered for a initial study of the HRV, but in cases of dynamic changes these methods are not sufficient. Along the years, the non-linear methods were increased due the fluctuation of heart rate [37][38]. The non-linear characterize the structure of the HR time series, each means it is random or self-similar.

In synthesis, the imaging processing techniques can only detect when the driver starts to sleep, being too late to prevent an accident. However, the physiological signals change in earlier stages of drowsiness, so these signals allow for the driver to be alerted in a primary stage. Besides these methods, the vehicle can also give some information about drivers' state, including deviations from lane position, movement of the steering wheel, pressure on the acceleration pedal, etc.

Subjective Detection Techniques

The most subjective tool to measure the fatigue level is the Karolinska Sleepiness Scale (KSS). It is a nine-point scale (see table 2.3), which is used as a base to judge the subjects state in different researches and experiments. Usually, the drivers are questioned every 5 min, so that a historic of its attention may be defined [39].

As an example, a study of Mahachandra et al. [1] was conducted on 16 subjects with at least one year of experience and where the drivers performed for 3,5 hours in a simulator for each cycle of experience. The sensitivity of several parameters of HRV was tested to find sleepiness indicators. Also M.

TABLE 2.3: Karolinska Sleepiness Scale

Rating	Verbal descriptions
1	Extremely alert
2	Very alert
3	Alert
4	Fairly alert
5	Neither alert nor sleepy
6	Some signs of sleepiness
7	Sleepy, but no effort to keep alert
8	Sleepy, some effort to keep alert
9	Very sleepy, great effort to keep alert, fighting sleep

Patel et al. used one algorithm, namely Pan-Tompkins, to conceive an artificial intelligence method to detect fatigue in drivers.

2.5.1 Literature Review

In the previous section, it was presented one algorithm to detect drowsiness with an interpretation of the QRS complex. The accurate detection of this complex is very important because the occurrence of multiple premature complexes indicates changes of the morphology of the ECG signal and the duration of RR interval. This means, the detection of a critical clinical cardiac condition can be affected by the robustness of the QRS detection algorithm.

The Pan-Tompkins is a linear-filtering based algorithm for QRS detection. This is one of the most usual algorithms that detects QRS complex using the ECG signal but there are others algorithms proposed by Benitez et.al., 2001; Burke and Nasor, 2004; Dotsinsky and Stoyanov, 2004.

The Pan-Tompkins algorithm is an improvement to a Hamilton-Tompkins algorithm first-derivative to this detection. Before 1990 this method had been considered to have the higher accuracy for real time analysis of HRV.

More recently, it was proposed by Benitez et.al. [3] a Hilbert transform-based method as an improvement to Tompkins algorithms by using a variable threshold. Unlike the Tompkins algorithms, this threshold does not have to be experimentally determined [40]. The Hilbert transform can distinguish dominant peaks in ECG signal among other peaks, but exhibits some failures in schematic cases and low-amplitude R wave diseases.

To improve the data accuracy, the implementation of variable threshold does not need to be experimentally determined[41][42]. In a ECG data, a QRS complex may vary drastically from one heartbeat to another, thus the use of an adaptive threshold may decrease the number of QRS complexes lost.

Algorithm	Database	Sensitivity	Pos. Predictivity
N. Arzeno *2008* [7]	MIT-BIH	99.68%	99.63%
V. Afonso *1999* [8]	MIT-BIH	99.59%	99.56%
J. Pan *1985* [10]	MIT-BIH	99.3%	-
P. Hamilton *1986* [11]	MIT-BIH	99.69%	99.77%
J. Martinez *2004* [12]	MIT-BIH, QT, ST-T, CSE	99.66%	99.56%
C. Li *1995* [13]	MIT-BIH	99.8%	-
B. Abibullaev *2011* [14]	MIT-BIH	97.2%	98.52%
Q. Xue *1992* [15]	MIT-BIH	99.5%	97.5%
D. Coast *1990* [16]	AHA	97.25%	85.67%
R. Poli *1995* [17]	MIT-BIH	99.6%	99.51%
A. Martinez *2010* [18]	MIT-BIH, QT, ST-T,TWA	99.81%	99.89%

FIGURE 2.14: Performance of some QRS detection algorithms [15]

In the figure 2.14, are the best results of some algorithms to QRS detection. The evaluated parameters are the sensitivity (Se) and positive predictability (P).

The sensitivity is the percentage of beats that were detected by the algorithm as a true beat and the positive predictability is the percentage of correct peak detected.

An experimental study, of two hour driving simulation in two health subjects (male, 24 and female, 24), demonstrates a decrease of the LF/HF ratios. These results differ for different people, there are no conventional values for a person in state of drowsy or not.

The variation of the RR interval can also be an indicator of drowsiness, however it is less reliable as represented in the figure 2.15. Here is evaluated other information given by the heart, it is only regarded the R peaks and the rest of the spectral signal is ignored.

Related to the contactless monitoring also some studies are present in the literature, but with lesser number. The MIT (Massachusetts Institute of Technology) presents a non-contact sensor for use in ambulatory cardiac monitoring. It is a 2.4 GHz prototype sensor that allows wireless communication to send data to a remote PC or mobile phone. The microwave sensor monitors the heart mechanics and abnormalities such as fibrillation and akinesia [43]. The sensor was designed to fit inside a common name badge plastic sleeve and attached over clothing.

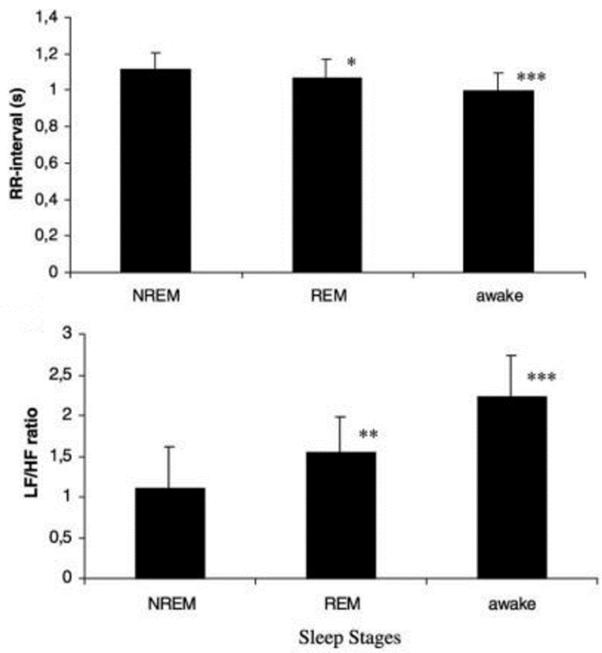

FIGURE 2.15: Variation in the duration of the RR interval, LF and HF frequency across sleep stages [16]

Additionally, it was performed a study about the integration of a radar in a car, and all of the possible interferences caused by it. The radar signal can be contaminated by the motion artefacts, movement of driver and vehicle vibration. This paper proposed a method using multiple signal classification (MUSIC) [44]. This algorithm is based in the autocorrelation method, were the data for the heart and noise are divided in eigenvalues and eigenvectors. The tests encompassed a driving situation of 80 km/h.

2.5.2 Patent

In March of 2007 was published a patent: "Radar-assisted sensing of the position and/or movement of the body or inside the body of living beings" by researchers Hans-Oliver Ruoss, Michael Mahler and Juergen Seidel [17]. The invention relates with the detection of driver body movements through a radar sensing device. Refer also the possibility to detect the breathing, heart rate and the position of the body of a driver in a motor vehicle. The figure 2.16, shows schematically the position of sensor device according to the invention.

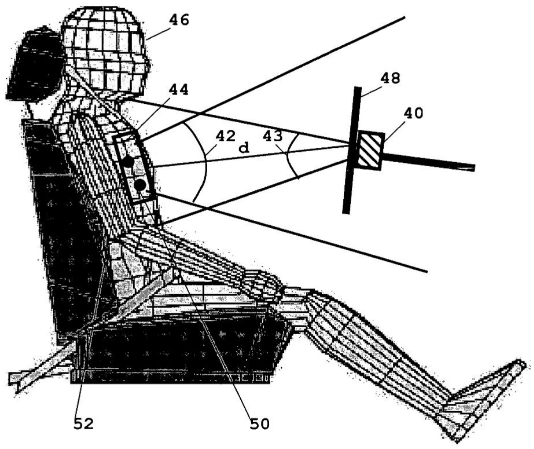

FIGURE 2.16: The sensor device in the sensor region according to the patent in a motor vehicle [17]

2.5.3 State of the Market

In the state of the market, there are several devices that can monitor the heart signal from a subject, and be integrated in cars.

The main places where these devices are integrated are the steering wheel, seat and seat-belt.

Ford developed, in its European Research and Innovation Centre in Aachen, a car that monitors driver's vital signals. The Biometric Seat Research project places 6 sensors on the driver's seat.

Six embedded sensors (capacitive electrodes) are used to monitor the heart rate. Unlike the ECG machine, this technology can detect the heart rate through the driver's clothing. Ford achieved accurate readings during 98% of driving time for 95% of drivers. Data collected intents to be applicable in health care like alerts of imminent cardiovascular issues (heart attack)[45][18]. Fords car seat in some cases can detect anomaly's in heart activity before driver's notice.

This brand did not bound to implement the solution in the seat alone, it also explored monitoring the driver through the steering wheel and seat belt [46].

On the steering wheel, sensors are placed to monitor temperature (both ambient and the drivers), and driver's heart rate (figure 2.17). This sensors are conductive, working through contact with the driver. In the seat belt, the piezoelectric sensors measure respiration rate due the to the chest's movement. Ford intends to mass produce these technologies by 2020.

Another company that produces sensor technology with possible usability in cars is Plessey. The device is a set of sensor electrodes incorporated in the

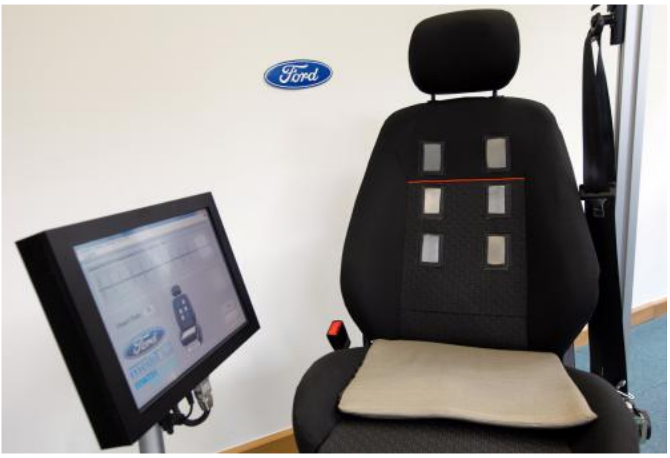

FIGURE 2.17: Ford car seat to monitor heart [18]

seat that can have a number of applications such as alertness detection, occupancy and slow speed collision avoidance. These sensors, EPIC (Electric Potential Integrated Circuit), are integrated circuits with a high impedance amplifier design that allow a contact and a non-contact mode. The contact mode measures bio-electric signals like ECG, EMG, EOG and EEG, and the non-contact measures human body movement: proximity sensing, movement sensing and gesture recognition [47][48].

These sensors have an integration on the seat identical to the electrodes developed by Ford.

The major automotive enterprise like Toyota, Volkswagen, Nissan, Lexus and Mercedes-Benz have invested in driver monitoring technology and as Ford with perspectives to introduce in a few years new models with these technologies.

Mercedes-Benz and Lexus already have some models with biometric sensors, that can measure heart rate, blood pressure, glucose levels and other biometric responses [49][50].

The Lexus RC F an integrated biometric display, that allows the driver to visualize their heart rate, however the sensor is attached to the driver.

The next diagram shows the major types of biological signal recover from the driver, and the companies that are developing the system to monitor these signals.

Looking to the technology, these are specifically built in automotive as RF or ECG technologies. As reported in the figure 2.18, the key developers of these devices that can be integrated in the car to monitoring the driver are: NovelIC,

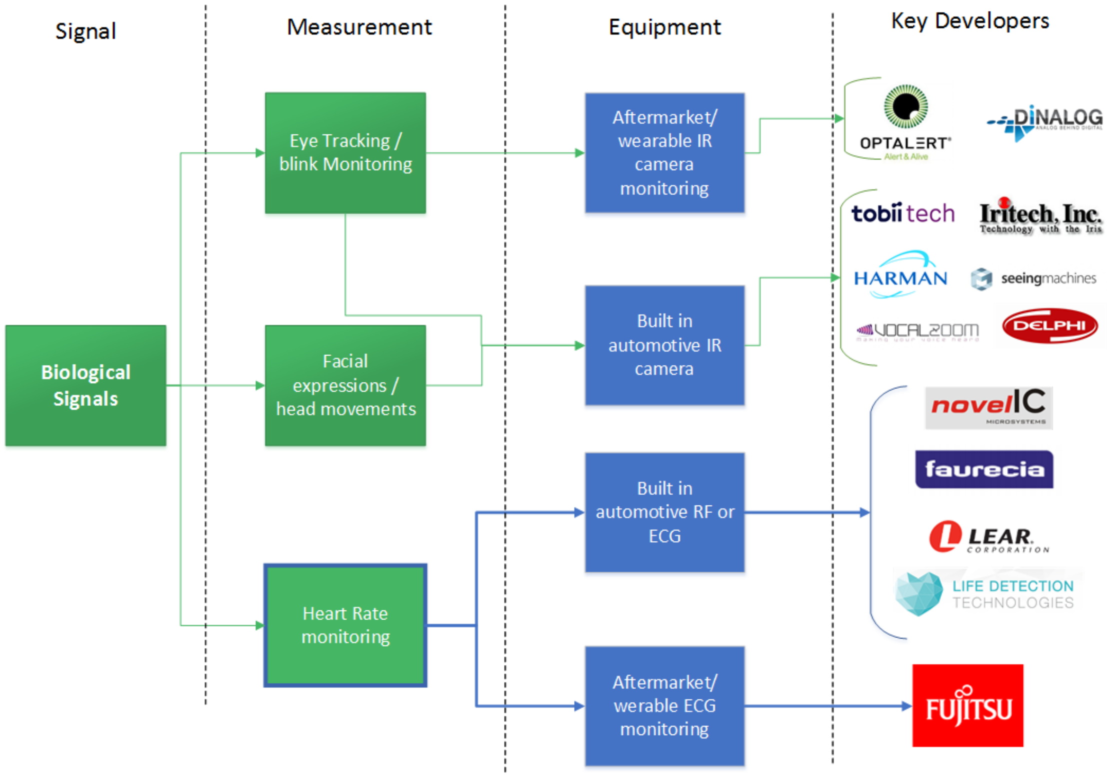

FIGURE 2.18: Driver Monitoring System and correspondent companies

Faurecia, Lear and Life detection.

NovelIC and Life detection develop smart sensors to apply in medical and daily life environments, analysing heartbeat and respiratory dynamics. Example of it is the contactless monitoring of baby vital signs in incubators, beds and cribs, patients in hospital beds, athletes and even monitor animals.

Faurecia has been working for five years to improve the Active Wellness seat, it is intended for the system to work in real time and avoid discomfort to the user. This work results of a partnership with NASA, that already developed an identical system for space suits and aerospace sensors to acquire vital signs [51].

Lear corporation is the only manufacturer of the seat in its entirety in the world. It works with every major automotive enterprises and has been developing advanced solutions to serve the customers.

Mark Boyadjis, technology analyst for IHS Automotive, is skeptical to this approach: *"Car companies shouldn't be worried about biometric devices being embedded in seats. The analogy is to car phones"*.

FIGURE 2.19: DFD-100B [19]

Additionally, another device that is allocated in a different place to those previously referred is the DFD-100B, made by Holux (figure 2.19). It is placed in a seat belt, being an adjustable wireless device that detects drivers heart rate variation to determine the level of fatigue. It also possesses an android app that immediately alerts the driver in a danger situation through an audible sound and sends a SMS to a pre-programmed number or control center. The device has an accuracy of 90% in fatigue detection and less than 1% of false alarm rate. The Bluetooth communication has 8 hours of continuous autonomy.

The Institute of Biomechanic of Valencia(IBV) is developing a non-intrusive sensing system heart and respiration detection integrated into the seat and seat-belt of a car. This project was tested in a driving simulator involving 20 vol-

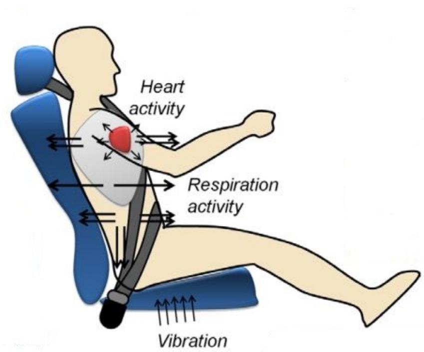

FIGURE 2.20: Harken project [20]

unteers. The validation system was an EEG and eye tracker (PERCLOS), and achieved a 80% success in drowsiness detection. The use of both signals, heart-beat and respiration, in this project shows promising indicators to detect the state of the driver. Figure 2.20 shows the location of the Harken sensors. This project has implemented data fusion to improve the reliability of the results and has also applied adaptive filters to cancel the effect of vibrations caused by the car.

2.6 Conclusion

Since the sleep rhythm is strongly correlated with brain and heart activities, these physiological biosignals can assess drowsiness with high accuracy. However, all the researches up to date need electrode contacts on the drivers head, face, or chest. Wiring is another problem for this approach. The electrode contacts and wires cause discomfort to the drivers and are difficult to implement on vehicles. Therefore the heart rate signals are used to detect drowsiness and aim to overcome the limitation of current methods by developing non-intrusive, easily implementable and accurate heart rate sensors.

The key to the proposed drowsiness detection approach is to have an accurate and non-invasive heart rate signal measurement system. Other biosignals like EEG or EOG require obtrusive instrumentation, which may cause distraction.

Based on the state of the art, it is concluded that the more appropriate non-contact method to detect heart rate is the electromagnetic-based monitoring system. The main reasons are: the existence of more research comparatively to the other non-contact methods, allows the monitoring of cardiac and respiratory activity and it is the closest to future commercialization when compared to other methods.

Chapter 3

Methodology

3.1 Introduction

In this chapter all the design, procedures, risks and algorithmic questions will be answered as well as the methodology followed to achieve the answers for the research questions (1-1.3), considering the objectives(1-1.2).

The development framework used in the dissertation was the waterfall model, which is composed by five distinct phases: analysis, design, implementation, verification and maintenance.

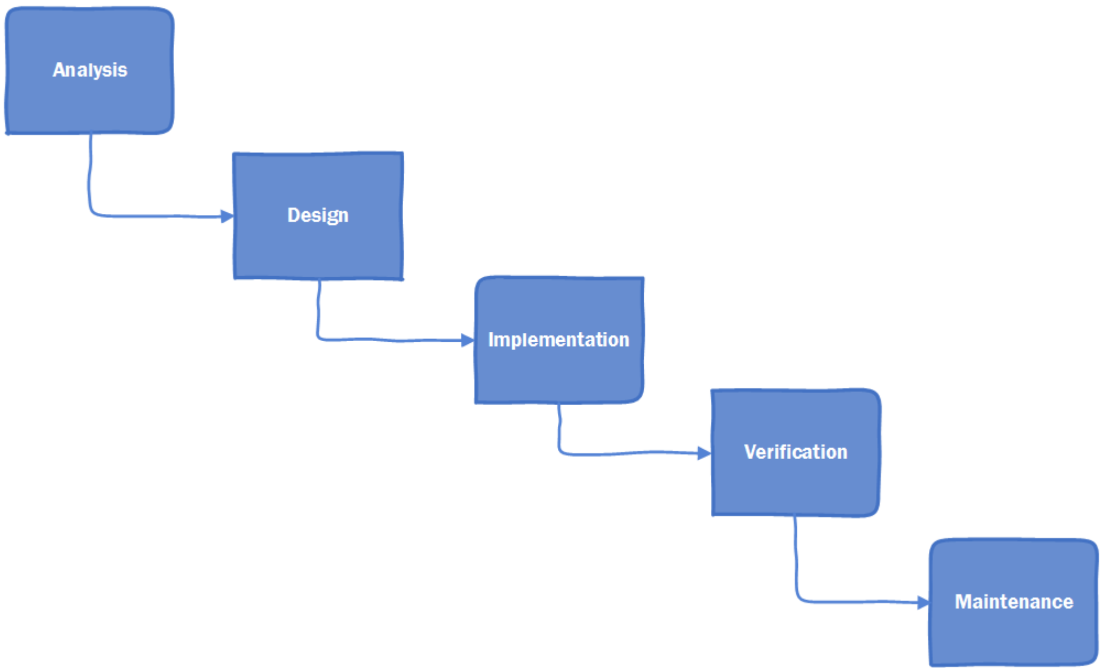

FIGURE 3.1: Waterfall Model

3.2 Analysis

This initial phase will focus on gaining critical knowledge of the contactless heartbeat monitoring technologies, understanding HMI (Human-Machine Interface) concepts within the INNOVCAR project and other important usability considerations from the Human Factors team, in other to gather all relevant functional and non-functional requirements for this thesis.

Preliminary system models, using available sleep related heartbeat datasets, will be developed in order to explore concepts, ideas, algorithms and signal processing techniques.

Vehicle Safety Technology (VST) is a specific technology in the automotive area intended to improve safety and security of all occupants of car. The advanced driver assistance system, or ADAS, is one technology developed from this concept, where the development goal is usually safety improvement. Some examples are adaptive cruise control, driver drowsiness detection, emergency driver assistant, forward collision warning, etc. The improvement and sophistication of these car systems passes by creating more effective concepts to apply in a human machine interface (HMI).

Inside the project INNOVCAR, the automotive HMI concepts introduced by this master thesis are integrated in the biometric sensors area with the specific objective of detect drivers drowsiness. The initial idea resides in monitoring the driver with sensors integrated in the car, allowing a non-contact system with efficient detection. The heartbeat was chosen because it is one of the main vital signals (other signals like brainwaves are also important), to evaluate the state of a person.

To answer the second research question, section 1.3, *"What is the most adequate place for the sensor, inside the car, to collect data from the driver?"*, an analysis of the possible places to collect the data must be performed.

The steering wheel, the seat and the seat-belt, are the more logical and suitable places. As reported in literature, these are the closest locations to the driver with viable integration in automotive.

The main criteria to choose the location to collect data from the driver, by level of priority, are: comfort of the driver, available space for the sensor and main features on the monitoring. Taking these characteristics in consideration a table was elaborated to display this comparison.

As reported in the previous table 3.1 and based on the state of the market, the chosen location was the seat, since it presented more advantages compared to the other locations.

TABLE 3.1: Analysis of the possible locations to collect data

Criteria	**Seat**	**Seatbelt**	**Steering wheel**
Comfort	Maximum, the driver does not feel the device	Medium, the seatbelt requires some modifications that may impact the comfort of the driver	Maximum, the driver does not feel the device
Available Space	Large	Reduced	Reduced
Features	Large range and diverse technologies already implemented (electrodes and radar)	Reduced range and few technologies implemented	Large range and diverse technologies already implemented (electrodes and radar)

Looking to the state of the art, the non-contact monitoring sensor chosen was a radar sensor. This type of sensor has as main advantages a high range of detection, a huge set of potential applications and high flexibility to be adapted to the automotive area.

Due to these facts, the area to explore addresses a set of biological knowledge. The initial steps settled in the study of the heart's behaviour and the aspects that influence its behaviour.

Additionally, a research study regarding the possibility to detect fatigue through this signal was done. All the research led to online databases containing a collection of ECG signals. So the first goal became the implementation of an algorithm to detect drowsiness with heart signals and evaluate its performance using those databases.

After the prove of concept, a non-contact approach was made, using a radar to monitor the heartbeat with a fixed distance to the user.

3.2.1 System Requirements

Non-Functional:

- Robustness of the algorithms (in terms of heartbeat detection and drowsiness detection);
- Safe and secure system;
- Non-contact monitoring sensor;
- Adaptable to the car;

Functional:

- Monitor the driver;
- Detect the driver's drowsiness;
- The input shall be Driver Biometrics;
- The system shall warn the driver.

3.3 Design

3.3.1 System Overview

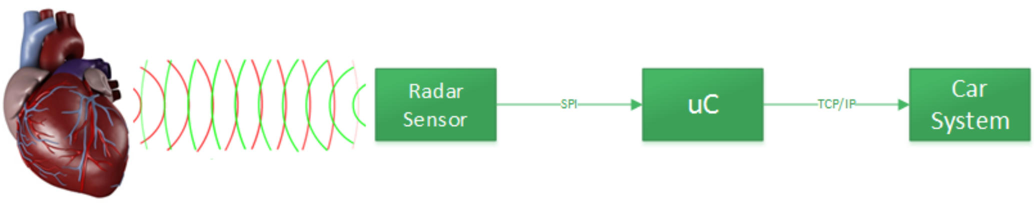

FIGURE 3.2: System Overview

The figure 3.2, illustrates an overview of the biometric system to be implemented in the car.

3.3.2 Hardware Criteria Selection

The hardware selection passed by several phases, the main one was the state of the market of the electromagnetic-based monitoring systems, namely radars with applicability to detect vital signals.

The hardware specification for this selection was:

1. **Contactless sensor:** in the automotive industry the comfort of the driver is the main concern, together with performance, these have been dramatically improved by the industry to fit into customer needs. The choice of this kind of sensor suits those needs.

2. **Size:** due to the space restrictions of the car and to not affect the previous criteria, the size of the sensor was taken in consideration.

3. **Efficiency:** this criteria is only evaluated for customer in a critical situation, and is defined by the ability to achieve a specific task with success in some(s) task(s). In this case, it is the fatigue detection in order to warn the driver.

3.3.3 Software Specification

3.3.3.1 Frameworks

The multi-resolution signal analysis and filtering needs will be fulfilled by the Matlab environment, with the assistance of the library provided by the radar producers.

Matlab also allows the algorithm development, data visualization and data analysis in the programming language developed by MathWorks, furthermore it also has the ability to develop applications with graphical user interfaces (GUIs).

3.3.4 Drowsiness Algorithm

In order to achieve the objectives, the literature review was performed to compile different methods with application in drowsiness detection through heartbeat analysis. After this step, comparing performances and success rates are also important steps.

The chosen algorithm was the Pan-Tompkins, which has several works around it with good performance. Furthermore, many of those works also took advantage of online databases to validate them.

3.4 Implementation Phase

Once the design phase is over, the implementation can start. The main goal is the transformation of the design into a product prototype.

This initial implementation with a ECG databases is important since it allows to study a large collection of recorded ECG signals without noise, which guarantees the reliability of the data.

Hardware wise, the radar needs to be tested in several subjects and distances to conclude the best setup of the system and to adjust the algorithms.

3.5 System Verification & Validation Phase

To assist in the verification and validation of the radar technology, it was considered the use of a ECG monitor.

This validation was performed resorting to the used of the Bosch's DSM (Driver Simulator Mockup) to recreate the driving environment with accuracy, figure 3.3.

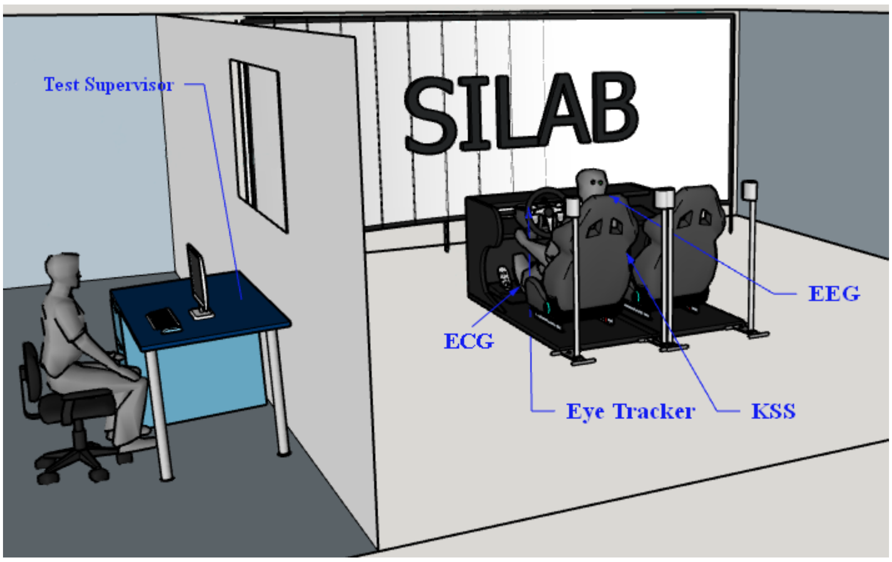

FIGURE 3.3: Test phase Bosch DSM

To perform of these tests, some experimental requirements were defined to guarantee the purpose of the procedures:

- Driver's license;
- Aged between 18-55 years;

- No history of cardiac or respiratory diseases;
- No alcohol and caffeine in the previous 24hours.

The users will be subjected to two tests under different conditions of fatigue: one nocturne session (sleep deprivation) and other diurnal. Each session has a duration of 1 hour and 30 minutes, respectively, with a previous training of 10 min period.

During the test, the person must evaluate its own state throughout the session using the KSS scale every 5 min. With this approach the objective is to detect drowsiness with the implemented algorithm.

The utilization of the ECG monitor is represented in the figure 3.4 and is done to allow the comparison of the data with the one collected by the radar.

In an initial phase, the tests must be accomplished with a constant monitoring of the heartbeat with the ECG monitor and with the radar, to develop the algorithm with more precision.

A disadvantage of ECG and other approaches, like as pulse oximetry, is the impossibility to provide information about the respiratory state (also an important parameter to evaluate the state of a person) , which can be extracted resorting to the radar sensor.

The ECG peaks appear when the electrical potential increases, however radio waves maximums are related to a mechanical motion of the chest due to heart movement. This movement is caused by the contraction phase of the cardiac cycle, also known as systole [52, 53].

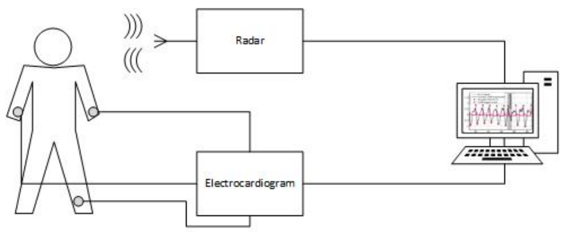

FIGURE 3.4: Overview test phase

Chapter 4

System Design

4.1 Introduction

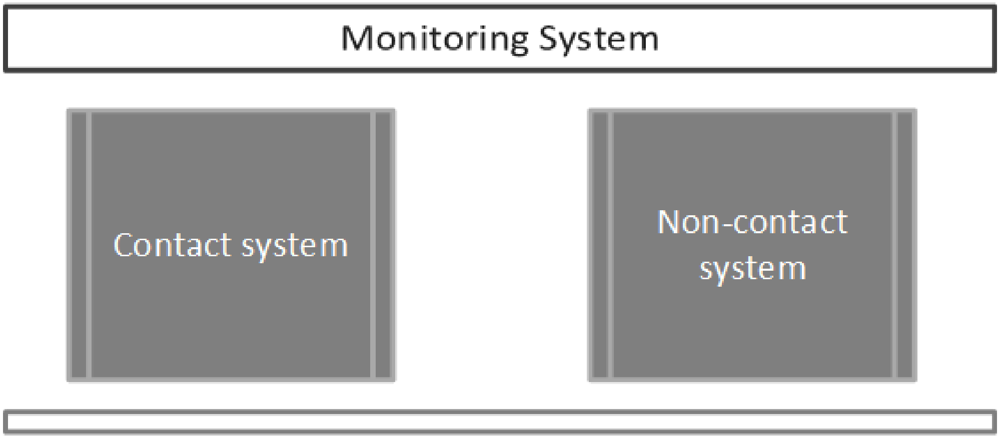

FIGURE 4.1: System and subsystems design

System design consists of transforming the analysis model into a design model that considers the requirements. It also defines the design goals, subsystems decomposition, software architecture, hardware/software mapping, data structures and the chosen algorithm or developed algorithm [54]. The previous schematic represents the system and subsystems decomposition (Figure 4.1).

The first subsystem specifies the methods to achieve the main goal, drowsiness detection through the heartbeat monitoring. It will be explained the algorithm workflow, the implementation approach of the Pan-Tompkins algorithm and comparison to the other researches. All this investigation was achieved in contact with skin of the subject.

The second subsystem is related to the *Non-contact system*, with the following sections explaining the chosen sensor, the specification, other complementary hardware and the programming software.

4.2 Contact-methods

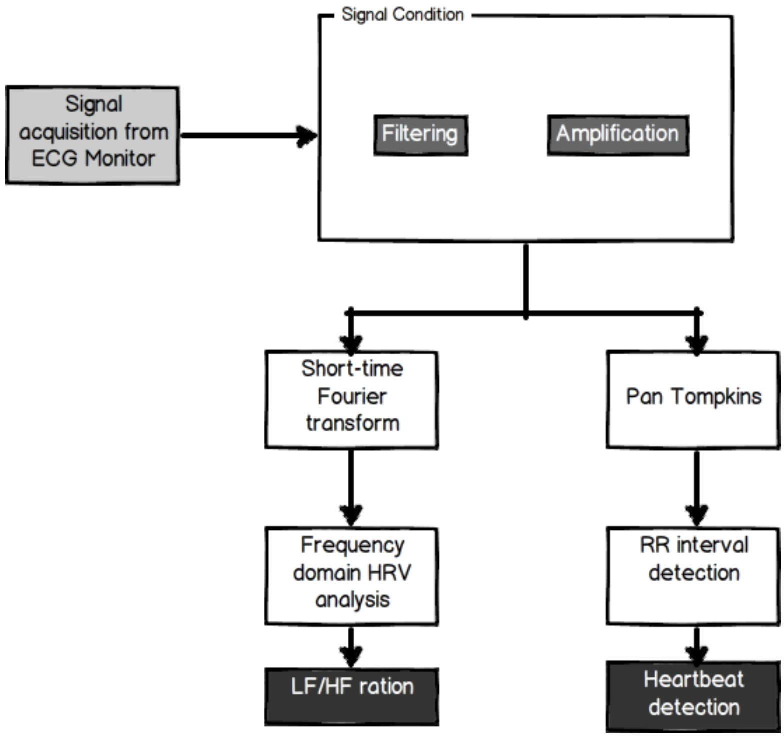

FIGURE 4.2: Algorithm design flowchart

This flowchart explains the algorithm design that leads to conclude if a person is in a drowsy state or not.

As reported, when the ratio between LF and HF decreases and the person has an abnormal heart rate, conclusions towards the state of the driver can be made. This second situation is analysed in parallel to have a strong confirmation of the state of the person, despite the algorithm of LF/HF ration being more reliable (see Chapter 2) [55].

4.2.1 ECG Databases

In the initial implementation, the MIT-BIH database was used to evaluate the performance of the proposed algorithm. It contains a 48 half-hour annotated tape of two-channel ambulatory ECG recordings with sampling rate of 360 Hz and 5 µV/bit resolution. The American Heart Association (AHA) database was also studied, consisting of 80 recordings: 2-leads, 250 Hz sampling rate and 5 µV/bit resolution. This database was already tested with several algorithms, including the algorithm addressed in this master thesis the Pan-Tompkins algorithm which obtained approximately of 99.63% and 99.18% of positive predictability results, respectively [3][56].

4.2.2 Algorithm Design

4.2.2.1 Pan-Tompkins Algorithm

In figure 4.3 the algorithm was divided in two different stages [15]: preprocessing and decision. In this early stage, the pre-processing, the ECG signal is treated to remove the noise, smoothing of the signal and amplification of the QRS slope and width. Next, it is applied a threshold detection scheme to distinguish and identify the R peak from other ECG waves [15]. Each peak that is not considered as a signal peak is classified as a noise. At the start, a peak detection is made, considering the maximum as a peak. Based on it, the next classification will define every peak as noise or signal.

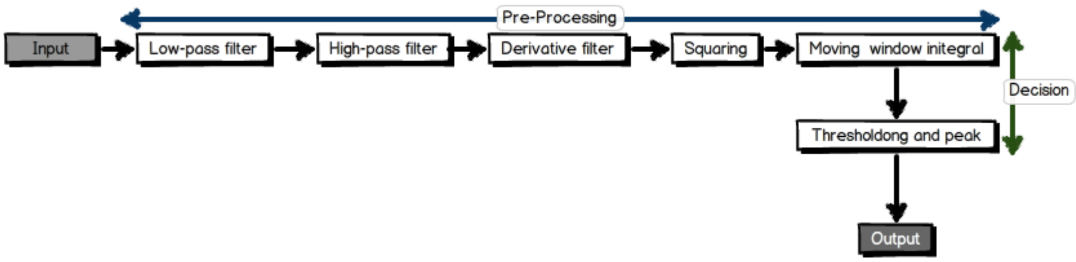

FIGURE 4.3: Schematic of the R-peak detection algorithm

Pre-Processing Stage

This subsection explains in more detail each step of the pre-processing stage. The low-pass filter is used to remove muscle noise while the high-pass filter attenuates P and T waves, baseline drift and also power-line interference. The frequency band desired to maximize the QRS energy is approximately 5-15 Hz [57]. The derivative filter tends to attenuate the signal at the lower frequencies (P and T waves) and provides a large gain to high components. By squaring the entire data, it becomes positive before integration, emphasizing the QRS complexes.

Finally, in the integration stage, the signal is averaged with a moving window to get rid of noise. An import parameter is the length of the integration window because it must contain the QRS complex [15].

Decision Stage

In this stage, two thresholds were applied to the filtered ECG after performing the moving window integration, to achieve better results. The identification of the peaks is accomplished depending on the values of those peaks, compared to the threshold. The peaks are the local maximum of the signal. Once a valid peak is detected, there is an interval of 200 ms where it is not physiologically possible for another peak to occur, however within the next 360ms, the QRS must appear in a normal heart rhythm.

The initial threshold was defined as a mean to detect values between the two first peaks, and the second threshold is half of the initial [58][15]. This second threshold is used if no QRS complex is detected inside the 360 ms period. Each threshold adapts periodically based on the results.

If the peaks are superior to the threshold, they are local maximums with relevance for the signal. If they are below, the threshold they are noise with no interest for interpretation.

In figure 4.4, it is possible to identify this method, where the example has three R peaks found. But in some cases the ECG signal has T or P waves with higher amplitude and that can easily be identified as R peaks, thus leading towards wrong conclusions. So, it is important to correctly implement this and other algorithms of QRS detection.

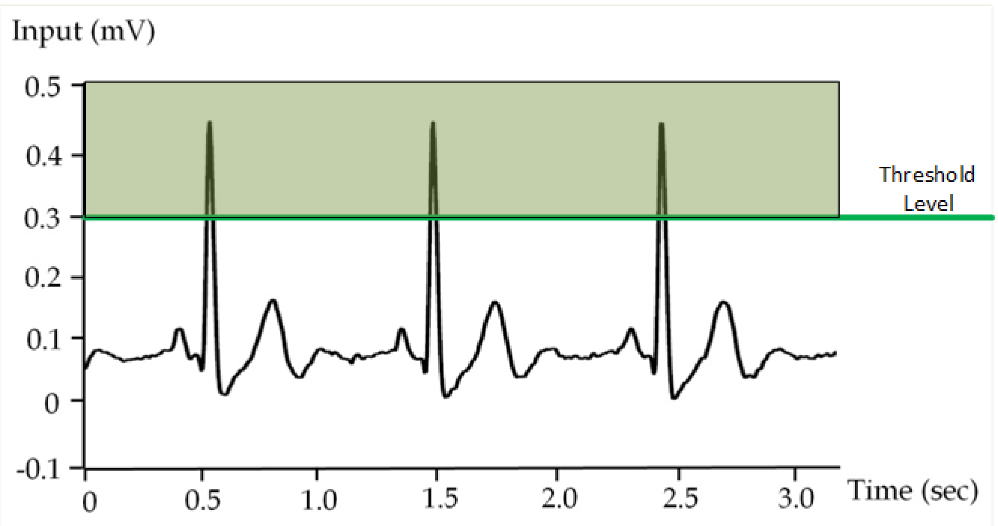

FIGURE 4.4: R peaks identified with threshold level

4.2.2.2 Heartbeat Detection

After the calculation of the R-peaks, it is easily calculated the RR intervals that are the time between beats, i.e. time between QRS complexes. From the RR interval is possible to calculate the heart rate in beats per minute. For example, a RR interval of 1 beat in 1 second can be calculated as:

$$\frac{1beat}{1sec} \times \frac{60sec}{1min} = 60beats/min \tag{4.1}$$

4.2.2.3 Short-time Fourier Transform

One of detection methods that computes the power spectrum is the Short-time Fourier transform (STFT), which is a derivation of the Fourier Transform (FT).

The FT converts a signal from its original domain (usually time) to a representation in the frequency domain.

The STFT measures the model's parameters in a short-time spectrum, performing the FT in such a way that allows to regain temporal resolution of the signal.

4.2.2.4 LF/HF Frequencies Analysis

American Heart Association made a study about *Heart Rate Variability During Specific Sleep Stages* [59], where normal patients (without recent cardiac diseases) were tested in the awake state, non-rapid eye movement and rapid eye movement sleep. The frequency ratio (LF/HF) decreased significantly from the awake to non-REM sleep [60].

The calculation of these two components are done resorting to the following equations:

$$LF = \frac{LF}{Totalpower - VLF} \tag{4.2}$$

$$HF = \frac{HF}{Totalpower - VLF} \tag{4.3}$$

4.2.2.5 Performance of the Algorithm

The sensitivity and positive predictability parameters are calculated by evaluating the number of false positives (FP), true positives (TP) and false negatives (FN) for each data recorded.

$$P = \frac{TP}{TP + FN} \tag{4.4}$$

$$Se = \frac{TP}{TP + FP} \tag{4.5}$$

Also the accuracy of the system is calculated with these values.

$$Accuracy = \frac{TP + TN}{TotalPopulation} \tag{4.6}$$

The algorithms have some error instances in the recording:

- False-negative detection of QRS complexes with decreased slope : wide premature ventricular contractions (PVCs) or low-amplitude QRS complexes
- False-positive detection of other heartbeat signals features: negative QRS complexes or low signal-to-noise ratio [3]

4.2.3 ECG Monitor

FIGURE 4.5: PC-80B

As reported in previous chapters, an ECG monitor device is used in this dissertation, as mean of comparison with the radar and in the DSM driving simulator. The ECG monitor model PC-80B, figure 4.5, was the device used to easily and reliably monitor the heartbeat signal and its frequency through palm, leg or chest measurements. The adopted method, in this case, was the leg measurement since it was the most comfortable for the driver.

The device also includes a support software named ECG Viewer Manager, which is able to transmit the measurements to the PC by wireless (Bluetooth) and USB.

FIGURE 4.6: ECG viewer manager - PC-80B support software

4.3 Non-Contact Methods

4.3.1 Radar Sensor

The selection of the hardware to accomplish the project was based on the HMI concepts that Bosch is trying to implement and the offer available by enterprises that manufacture radar sensors capable of collecting the person's vital signal. Since it is a specific sensor, to a specific purpose, the diversity of devices available was reflected on the options and its costs.

Novelda is a company in Norway specialized in nanoscale wireless low-power technology for ultra-high resolution impulse radars, namely Xethru technology. It recently developed a single chip radar transceiver, the X2 SOC, as seen in the Figure 4.7.

This chip presents important features to the system such as high accuracy, lower power consumption, short start time and highly configurable output frequency band.

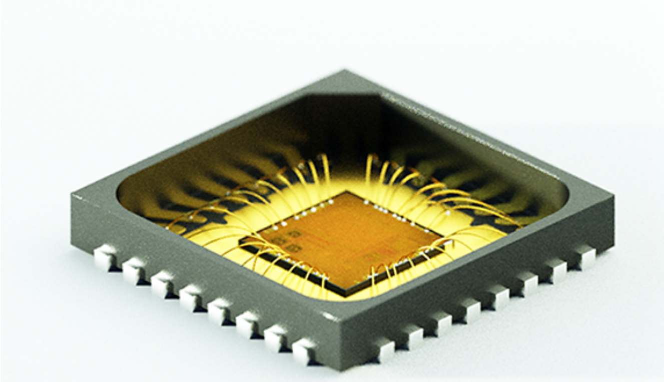

FIGURE 4.7: X2 single-chip UWB

X2 is a UWB radar with a transmitter, a receiver and related control circuits. The controller is the *Sweep Controller*, which coordinates the acquisition of a radar frame.

The X2 SOC has the software integrated in the Beagle Bone Black, the default development platform used by the company that makes the SOC. This microcontroller is a low cost platform that starts under 10 seconds has 4Gb of flash storage , 512Mb DDR3 RAM, connectivity USB and ethernet connectivity.

Radar chip remover, which has a 256 sampler, possesses a default sweep distance of 1 meter. It is based on CMOS (Complementary Metal-Oxide-Semiconductor) technology, where ambient conditions such as the temperature affect the circuit's performance, namely the delay elements.

The information is retrieved from a DAC which calculates the values by voltage assessment, for 10 different configurable pulses with employment of an 11th order Gaussian approximation the chip is able to generate.

System is configurable through a 4-wire Serial Peripheral Interface (SPI). The basic components of the receiver (RX) for the X2 is a Low Noise Amplifier (LNA), a Digital-to-Analog Converter (DAC), 256 Analog-to-Digital Converters (ADC), 256 32-bit digital integrators and an output memory buffer, accessible through the SPI. Software supported languages include Python, MatLab, C and C++.

X2 module that best fits the requirements is the Salsa Ancho radar module, figure 4.9. The Ancho development kit has applications in presence monitoring, health monitoring (such as respiratory and cardio), ranging and proximity sensing. It has two antennas: the LSTA, that has broad bandwidth and high gain creating improved performance, one of them being the transmission antenna and the other one the reception antenna.

Salsa ancho has an online support software in a web browser (*192.168.7.2:8081*)

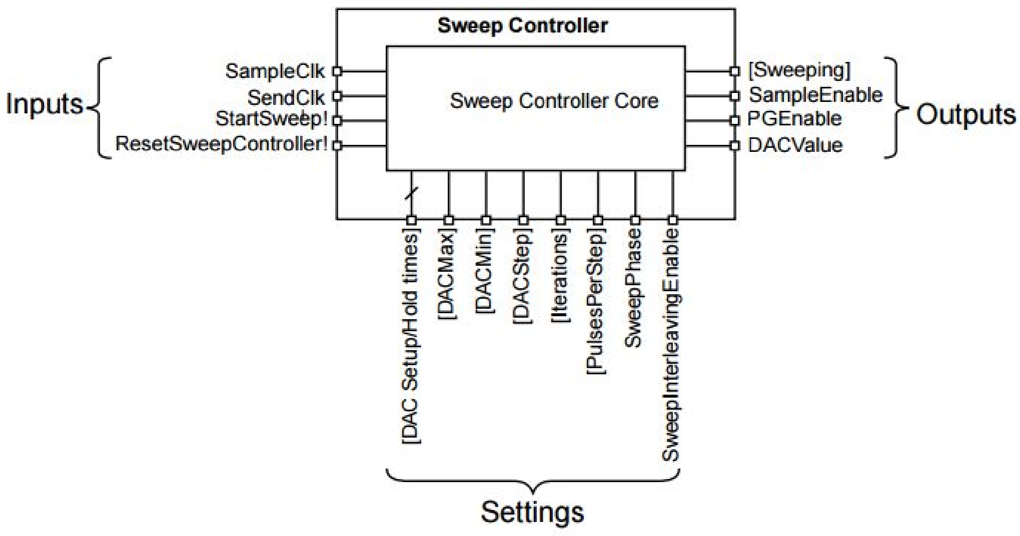

FIGURE 4.8: Sweep Controller

FIGURE 4.9: Salsa Ancho

where some of the main information of the product is available, as well as a scope to view live radar data, figure 4.11.

4.3.2 BeagleBone Black

Beagle bone black (BBB) is a development platform and works as a bridge between the host PC and the processing unit. This microcontroller is a good match for the X2 SOC since it presents features such as:

- Ability to boot under 10 seconds, an important characteristic that indicates that the setup of the system is fast enough to monitor the driver since his arrival to the car;
- Connectivity USB, Ethernet, HDMI and 92 pin headers;

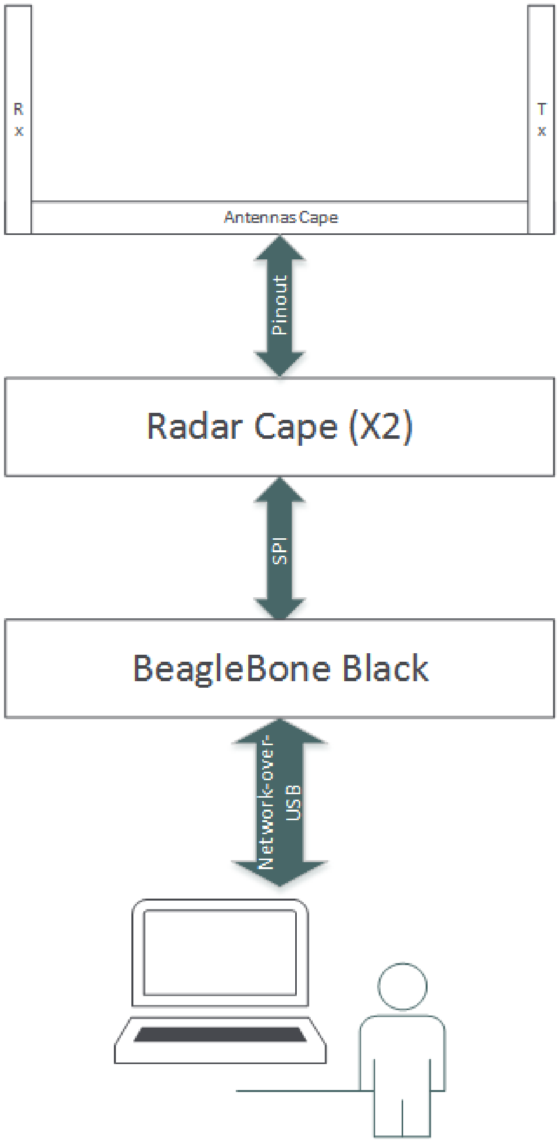

FIGURE 4.10: Radar System Design

- Software compatibility with Debian, Android, Ubuntu and more.

Matlab will be used to program process signal techniques, communicates to the BBB through a exchange of information between the operating system (Linux) and network-over-usb access.

Using the mini USB cable, the BBB and updating the firmware on the board through Matlab, it is possible to build, load, and run applications in the Linux environment on the ARM Cortex-A processor on the BeagleBone Black hardware.

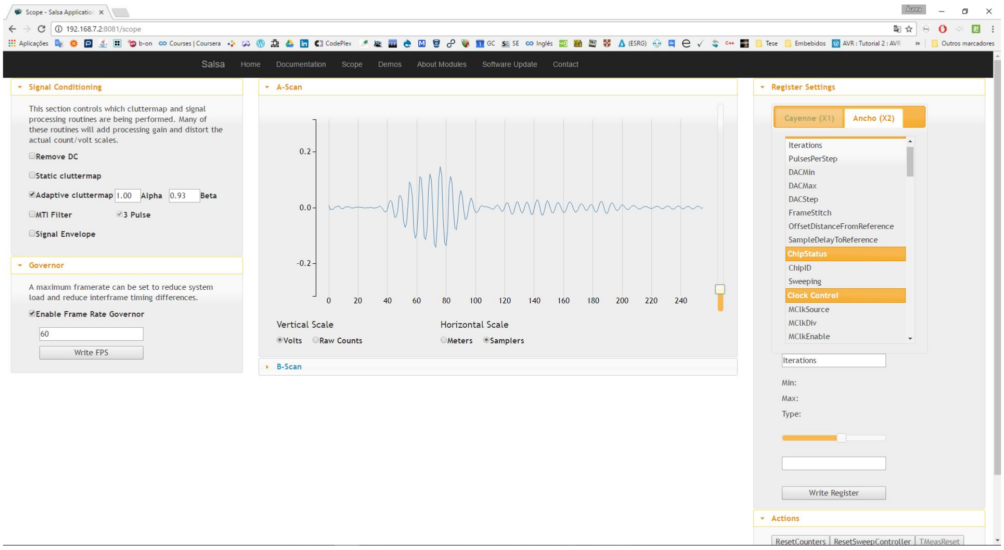

FIGURE 4.11: Radar support interface

4.4 Software Specification

4.4.1 Non-Contact Monitoring

The elaborated algorithm, based on the heart's variation rate of the driver, took a complexity jump since it also takes advantage of the sensor's capabilities to extract other relevant information, such as respiration rate and distance. Although the distance is not a relevant variable for drowsiness assessment, it has other important applications, as assessing if the driver is in range of the sensor in order to evaluate a person's presence in the seat.

The flowchart, Figure 4.12), exhibits the processing sequence applied to the radio wave signal received by the radar sensor. This approach was based on the research and features of the sensor.

First of all, looking at the features of the sensor, the SPI communication protocol between the radar cape and the beagle bone and the size of the each data frame is an array of 256 values. The next flowchart was built looking to the features of the sensor and the objective of your utilization.

4.4.2 Filtering

Since the RF values do not move around the 0 dBm, the signal could appear with a strong component in 0 Hz, so it was crucial to design a high-pass filter to eliminate all values in this frequency. As the heart rate appears in a higher frequencies band (normally between 1Hz and 3Hz), the high-pass filter was dimensioned to eliminate oscillations smaller than 0.1Hz.

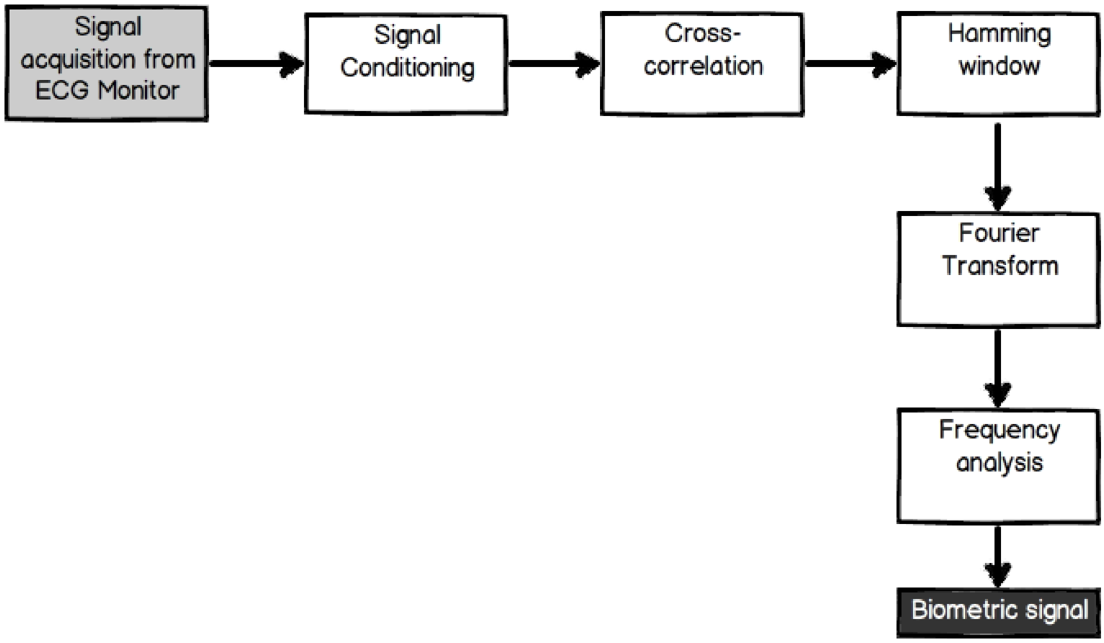

FIGURE 4.12: Description of the biometric signals extraction

Due to IIR filter having characteristics that can introduce distortion in the signal, the FIR filter was the ideal class of digital filters chosen for the project.

There are essentially three well-known methods for FIR filter design namely:

1. The window method;
2. The frequency sampling technique;
3. Optimal filter design methods.

The one that offers more advantages is the window method due to its simplicity (compared to others) and availability to calculate the coefficients.

Inside the windows methods, the Kaiser filters allow a taper effect which gradually decays to zero, overshoot reduction and transition region width spreading (incorporates a ripple control), these characteristics were the deciding factor to choose the filter [61][62].

4.4.3 Cross-correlation

Considering that when a monitored person is surrounded by static objects, a solution to eliminate this component in the signal is implemented by performing the autocorrelation of the signal.

The goal for this step is to compare the phase relationship between the signal and a shifted version of it through time. This way, it is possible to align both signals and ignore the static parts of them.

4.4.4 Hamming Window

A Hamming window was implemented because it minimizes sidelobes (ripple) [21] caused by the respiration signal, these are radiations in undesired directions which can not be entirely eliminated [63] [64].

Furthermore, since the FFT sees the signal as infinitely periodic, if the signal presents discontinuities, some misplaced frequencies will appear in the FFT.

The following code demonstrates the implemented to execute the window.

$$win = hamming(wlen,' periodic');$$
$$xw = signal'_m. * win';$$

4.4.5 Fourier Transform

To do a spectrum analysis of the dominant frequencies in the signal, it was implemented an Fourier transform, namely the Fast Fourier Transform (FFT).

The number of points implemented takes in consideration the system, since it can influence the correct calculation of the heart rate, due to the fact that lower frequencies spectrum are analysed.

The system resolution can be calculated from the following expression:

$$\Delta f = \frac{fs}{N'} \tag{4.7}$$

where the *fs* is the sampling frequency and N' the next power of 2 from N number of samples.

With the processing signal techniques implemented, it is possible to make an analysis of the frequencies from strong components, using an algorithm of peak detection. The heartbeat must be the second strongest component and the first one must correspond to respiration.

Besides the frequency also the amplitude of the spectrum frequency is an important component to analyse, in case of a strong component of noise.

4.4.6 Graphical Interface

For better visualization of the data monitored, it was decided that it was worth to develop a graphical interface where features such as the distance and respiration of the driver were also extracted alongside the heartbeat. Figure 4.13 shows the visual background.

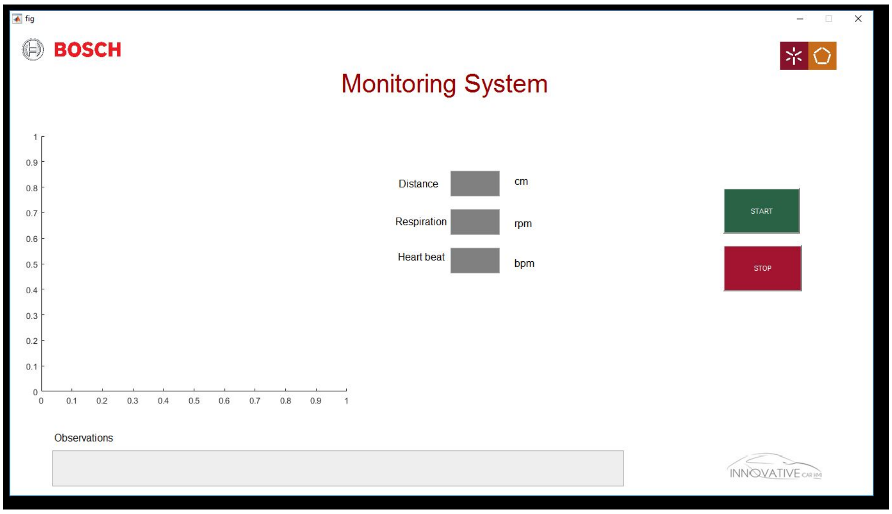

FIGURE 4.13: GUI develop

Chapter 5

Implementation phase and Results

5.1 Introduction

This chapter explains the development work in the implementation of the algorithms, such as hardware programming.

The implementation course had several phases. The initial stage was developed resorting to Physiobank's databases, namely the ECG database. The second was the implementation in a non-contact sensor.

The first phase focused in a contact technology, such strategy was followed to allow a first draft of the heartbeat algorithms applied to an ECG signal, without focusing in a non-contact approach.

The real driving tests were performed by applying the ecg monitor to subjects driving in the DSM to collect the respective signal. The data was then sent to a computer for further interpretation.

This work was valuable since it shows some possible adverse situations and disadvantages of the electrodes' use, such as the noise, the variation or lack of signal due to the driver's movement.

Lastly, the implementation of a non-contact approach to detect a person's heartbeat at distance, as well as the respiration and distance to the subject.

5.2 PhysioBank Archive - ECG databases

The Physiobank platform offers several databases related to bio-signal measurements, between them, ECG databases. The MIT-BIH arrhythmia database was the archive used in this project, due to the amount of literature available around it. It contains data concerning 23 different patients, recorded at a frequency of 360Hz. The files are in a *.dat* format, however it also contains a header file with patient's information (age, gender, etc)

5.2.1 Pan-Tompkins Algorithm

Like it was previously said, this algorithm uses the QRS detection to reduce false detection, calculating properly R peaks, R-R intervals, width of the QRS complex and the interval between R and S peaks [65][66]. The following plots represent some of the tests on the ECG database. The sensitivity and positive predictability calculated using this algorithm achieved values close to 99%.

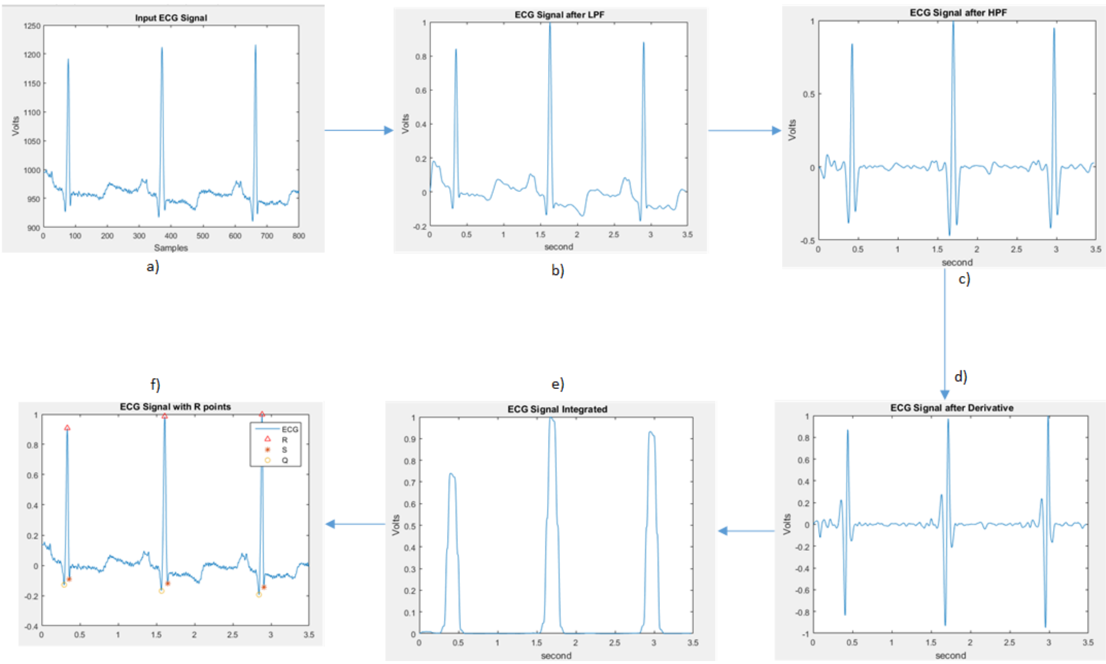

FIGURE 5.1: R peaks detection algorithm

In the figure 5.1 a) is represented a view of the raw ECG signal without any signal processing technique yet applied. All the plots have a window of 800 samples, concerning roughly 3.5 seconds of data, to a better visualization of the results.

To the original signal, a), was applied a 15 Hz low pass filter. The designing of the high-pass filter is done by subtracting the output of a low-pass filter from an all-pass filter. The two filters are applied to remove noise incurred by electromyography interference, power-line interference, baseline drift due to respiration, abrupt baseline shift and any other noise. The combination of these two filters allows the definition of lower thresholds, that would not be possible without this process.

After these steps, the signal is differentiated in order to get the QRS slope information, d), which provides a large gain to high components arising from high slopes of the QRS complexes.

Then, the squaring turns all data positive and the integration reveals the QRS complexes, suppressing the P and T waves e).

Finally, the thresholding is done in order to find the R-peaks. A maximum level is set, which helps to detect R-peaks. It is important to use adaptive threshold rather than fixed threshold because the amplitude of ECG changes for each human.

5.2.2 STFT

The STFT was calculated in a 30-second signal window. It is applied a sliding window of 256 samples and a hop size of 32 in a array with total length of 1024 samples. To calculate the frequencies, it was used a Short-Time Fourier Transform function developed by M.Sc. Eng. Hristo Zhivomirov.

This function returns three variables: the frequency vector (Hz), the time vector (seconds) and the STFT matrix (time across columns, frequencies across rows). Finally, it was calculated the LF and HF spectrum with the equations 4.2 and 4.3, resorting to the matrix calculated.

5.2.3 Algorithm's Performance

The purpose of this implementation was the verification of the correct Pan tompkins algorithm implementation, and verify if the implementation of this algorithm had the objectives of verify the effectiveness of the Pan Tompkins method and its performance to accomplish the objective in question (detection of the R peaks).

The Matlab plot, in the figures 5.2 and 5.3, represents a graphical example of how it was determinated the true positives, false positives and false negatives. Consequently, it was calculated the sensitivity (by equations 4.4), the total number of QRS complexes and the average heart rate.

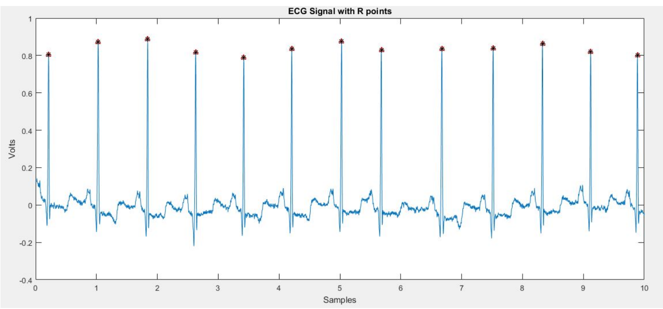

FIGURE 5.2: Example of a ECG Signal

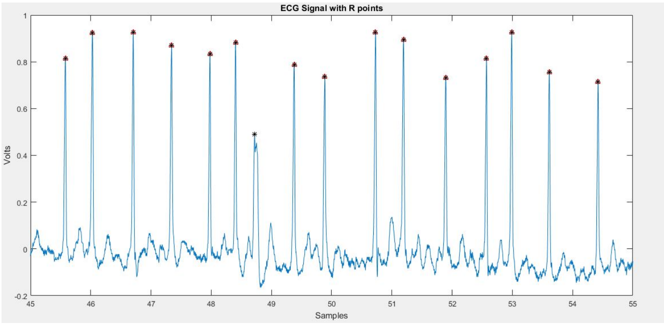

FIGURE 5.3: Example of a ECG Signal

The results concerning some tests done to the ECG database are presented in the table 5.1. These results are very close to the ones reported in the literature, which are satisfactory results.

Files	**Sensitivity**	**Total QRS complex**	**Average of heartbeat**
100.dat	100%	2273	76 bpm
112.dat	99.3%	2601	84 bpm
124.dat	99.8%	1610	55 bpm
201.dat	99.3%	1960	66 bpm

TABLE 5.1: Results for the MIT-BIH ECG databases files

5.3 ECG monitoring in Bosch DSM

The ECG monitor has a sampling frequency of the 223 Hz and makes use of 3 electrodes to perform the measurements.

In the test phase, the main purpose was the creation of a database resorting to the Bosch's DSM. The tests were performed with 3 different monitoring systems: an Eye Tracker (eye monitoring), an EEG device (brain waves monitoring) and a ECG monitor (heart beat monitoring with contact). Figure 5.4 illustrates one of those tests, where each driver makes a 10 min training session to familiarize with the simulator and understand the procedure.

Also is possible observe in figure 5.5 one of the tests and correspondent location of the sensors in the driver. The eye tracking system is behind the steering wheel, the EEG on driver's head and the ECG monitor in the writs the and leg.

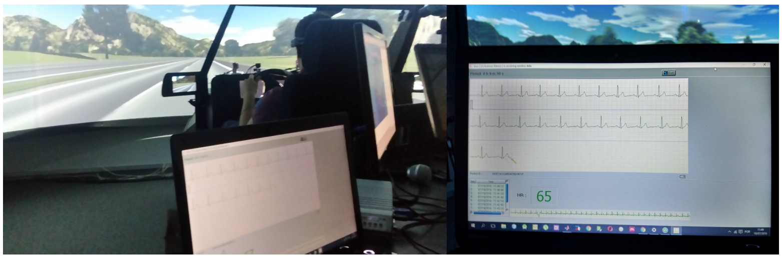

FIGURE 5.4: Real time monitoring

FIGURE 5.5: DSM test

An Android application was developed to simplify the answer of the questionnaire by the drivers, during the DSM tests. This application was developed by a master engineer inside the project. The figure 5.6 shows the android application layout, executed in a tablet placed in the DSM for this purpose.

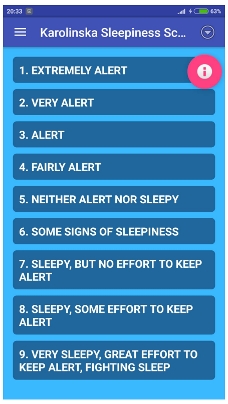

FIGURE 5.6: KSS android app

The electrodes were placed on the wrists (left and right) and left leg, since it was the most comfortable setup for the driver to perform without restrains.

The tests were performed by 11 volunteers of which only 2 auto evaluated its state as sleepy during the sessions, meaning that, at some point they answered the questionnaire with level 7 or above. Some of the disadvantages of these electrodes were highlighted in these tests, since it was recurrent the presence of noise in the signal collected due to poor contact with the skin. Which meant less accuracy on the heart rate variability (HRV) calculation performed further ahead in the PC and consequently the recognition of the driver's state.

In the next graphics are represented the KSS questionnaires answered by the these two drivers during their sessions and the respective physiological state of the heart calculated by the algorithm.

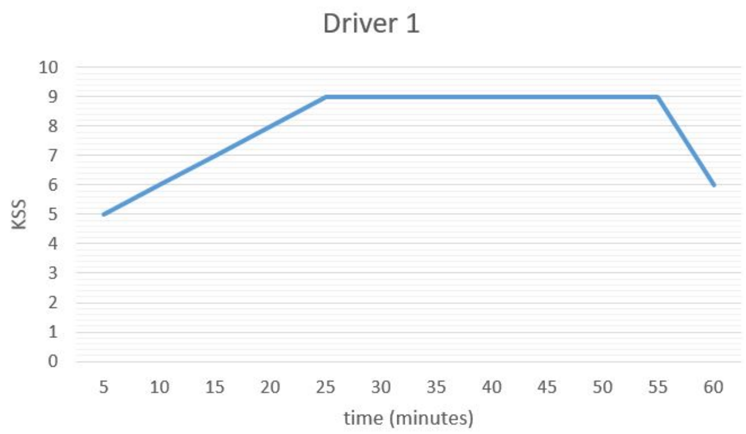

FIGURE 5.7: Driver 1 test: KSS response of the driver

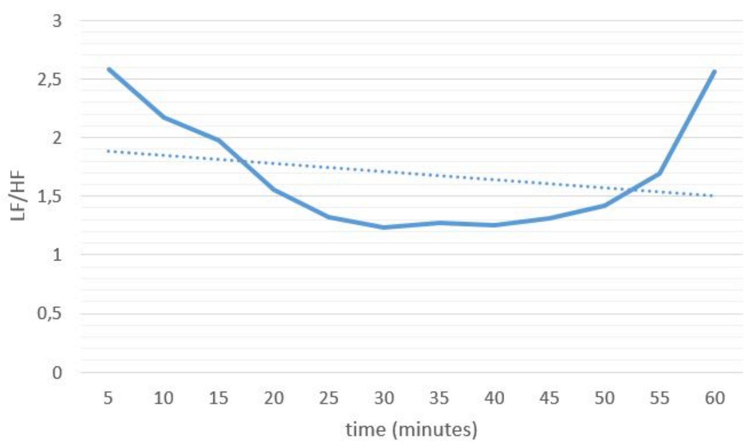

FIGURE 5.8: Driver 1 test: Ratio of LF/HF of the driver

It is was traced a trendline, an average of the data in 2D. Is visible a progress decrease of the ratio LF/HF when a person changes from alert into sleep stage.

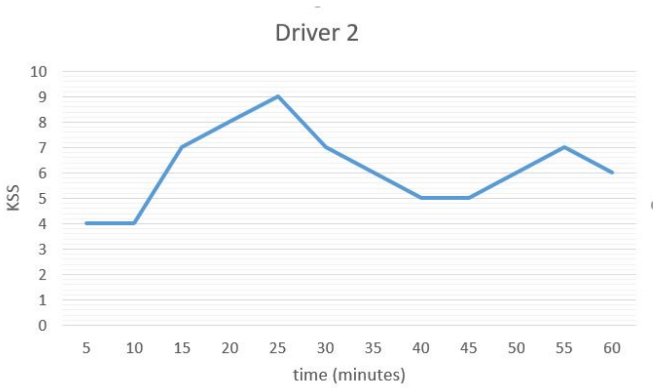

FIGURE 5.9: Driver 2 test: KSS response of the driver

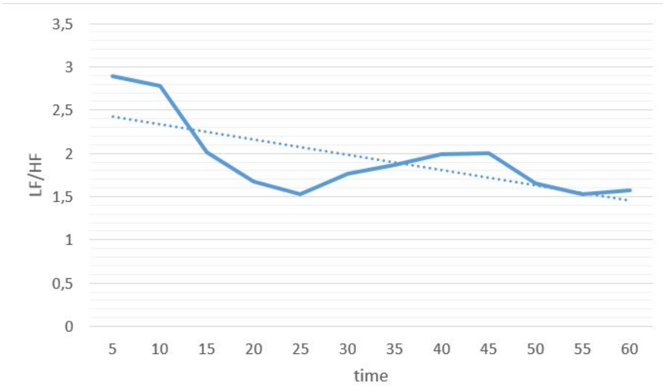

FIGURE 5.10: Driver 2 test:Ratio of LF/HF of the driver

As reported in the graphics 5.7 and 5.10, both drivers presented frequency reduction when they reported themselves as drowsy. The STFT was calculated in time periods of 30 seconds. With energy of bands, the ratio between LF and HF was calculated. The figure 5.11 represent the values obtain in the Matlab environment resulting of the STFT.

	Low Frequency Band			High Frequency Band						
0	0,0439	0,0879	0,1318	0,1758	0,2197	0,2637	0,3076	0,3517	0,4395	...

FIGURE 5.11: ECG frequencies bands calculated from the STFT

To match the KSS scale answered every 5 min, an average value was calculated with the samples corresponding to that segment of time.

The heartbeat analysis revealed not to be correlated enough with the state of the driver, since it presented mostly constant values not related in anyway with the KSS scale. The following graphic plots, 5.12 and 5.13, represent the heartbeat variation of the 2 driver along the driving tests. Once again, the values were averaged every 5 minutes, to make a easier comparison with the KSS response, 5.7a) and 5.10a).

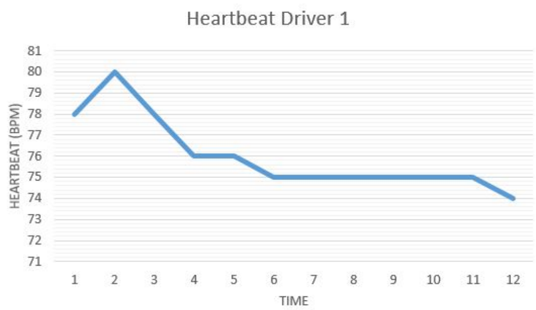

FIGURE 5.12: Heartbeat of the driver 1 during 1 hour of driving test

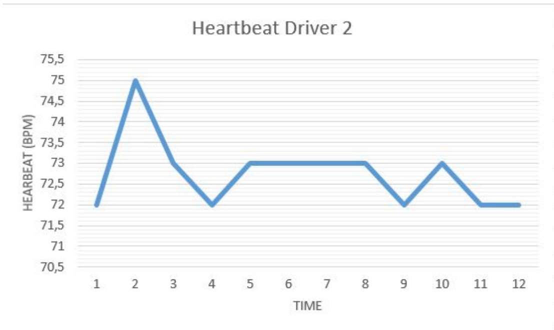

FIGURE 5.13: Heartbeat of the driver 2 during 1 hour of driving test

5.4 Radar Ancho Kit

5.4.1 Transmitter

As stated before, the center frequency output (and hence relative bandwidth) is programmable through the register PGSelect, as well as the offset distance, number of the iterations, values of the DAC's. In all these parameters were made different tests to cover different setups, furthermore it is important to notice that the subject must be be between the minimum and maximum range of the radar in order to collect relevant information. The offset distance of the sensor must have this issue in consideration, otherwise the signal collected is irrelevant.

It is visible in figures 5.14 and 5.15 the different shapes collected by the receiver due to the offset distances programmed in the X2 chip. In the figure 5.14, the offset distance was configured to 10 cm and in the figure 5.15 to 50 cm.

The radar was placed directed to a wall at a distance of 1.15m. This explains the shape difference between graphics, since in figure 5.15 the signal needs less time to travel the distance and being echoed on the wall. This behaviour is achieved by the definition of the offset which ignores the waves reflected previous to that distance.

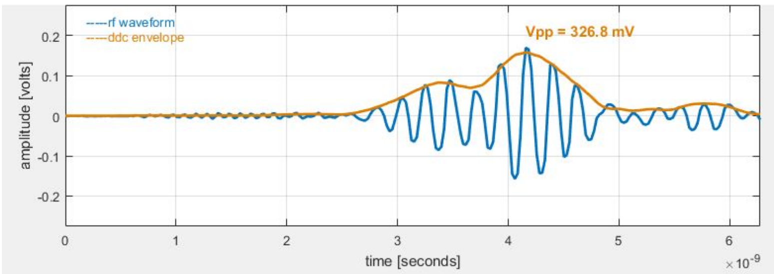

FIGURE 5.14: Offset distance of the 0,100 m

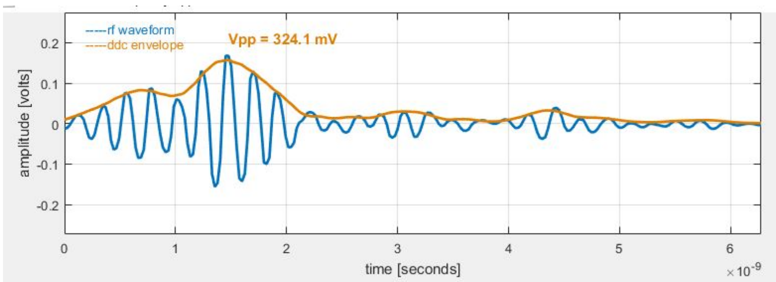

FIGURE 5.15: Offset distance of the 0,500 m

The distance calculation to the obstacle is achieved by the following relationship:

$$d_{frame}[m] = FO[s] \times \frac{c}{VF} \tag{5.1}$$

Where c is the speed of the light (3,0 x10^8 m/s), *VF* is the velocity factor of the transmission and *FO*, the spatial offset between the position of the radar and the start of the observed radar frame (d_{-frame}) [67].

5.4.2 Cross-Correlation

The implementation process demonstrated the occurrence of a drift in the UWB signal, where the transceiver signal has a component in the receiver signal. To eliminate this component and synchronize each frame, the waveforms were cross-correlated [68]. This process eliminates the unwanted components present in the received signal.

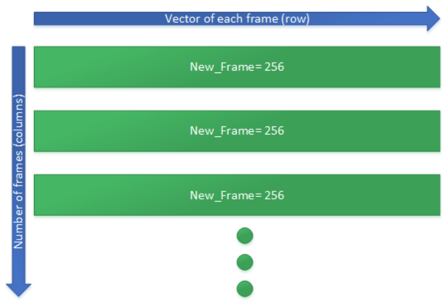

FIGURE 5.16: Matrix that saves the receiver signal

In terms of code, the *xcorr* matlab function assumed the role of synchronizing each frame, obtained in Δt.

The data was stored in a matrix with 256 columns, and N rows (depending of number of frames collected in each period of time), as reported in figure 5.16.

This is a very important step, since it reduces or even removes the influence of static objects on the algorithm developed with the purpose of detecting the heartbeat. Which means that it becomes easier to detect small variations of the body such as the thorax.

The driving environment has a great amount of noise associated due of car movement, so this step helps to filter all this unwanted data in association with the calculation of the variance between frames through time [68][69].

5.4.3 Fourier Transform

The below plots, figures 5.17 and 5.18, demonstrate the Fourier transform obtained when the sensor is in front of a person. To achieve the ideal resolution in this step, a careful analysis was done to reach the ideal value, resorting to the equation 4.7.

As seen in the table 5.2, the greater number of points leads to a better resolution, however it also means the calculation takes longer and it may affect the HR frequency detection. So it takes longer to acquire each sample and the monitoring system loses temporal resolution.

This issue is a huge concern since it means that a longer execution of the code may imply a reduction in the sampling rate. On the other hand, sampling frequency variations are small, and it did not exceed the boundary of the 3Hz.

Number of points	Resolution (Hz)
256	0.156
512	0.078
1024	0.039
2048	0.019

TABLE 5.2: Resolution with different number of points N, for a sampling frequency of the 40 Hz

As the sampling rate is approximately 40 Hz and according to the Nyquist's law, just half of this frequency can be measured (20Hz) in order to minimize the aliasing effect. This frequency is higher than the typical heart rate so it is enough for the proposed objectives.

Based on those conclusions, the chosen number of the points was 1024.

The following tests where performed with people located at a distance higher than the offset distance (which was set to 15 cm).

The next cases are with two different people to illustrate the behaviour of the sensor/algorithms and corresponding breathing and heartbeat extracted.

The results are presented in the next figures:

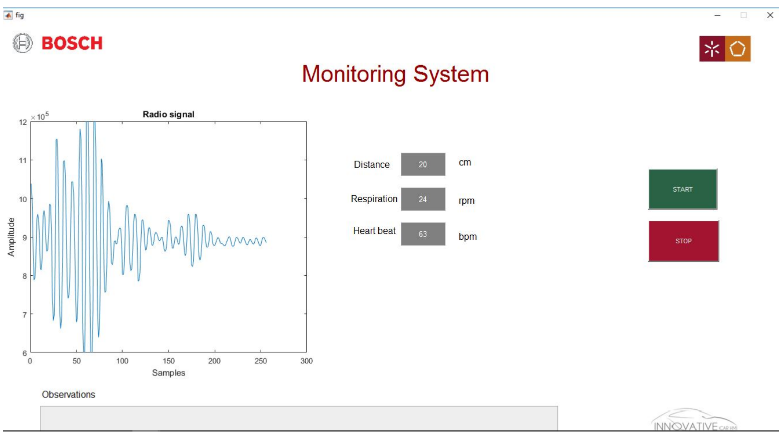

FIGURE 5.17: Subject 1 - view of the GUI

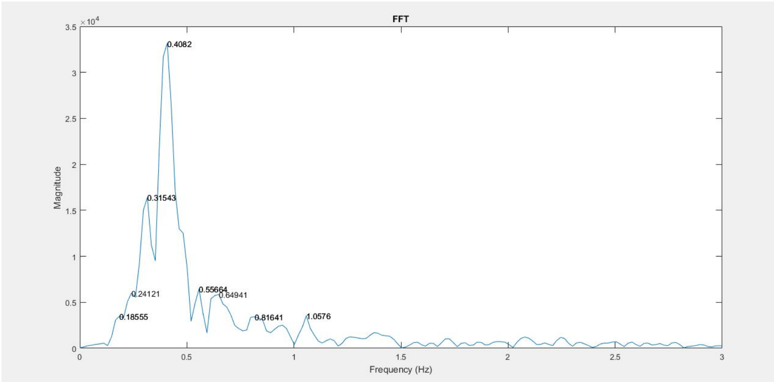

FIGURE 5.18: FFT when a subject 1 standing in front of sensor

In this example, the first highest peak (breathing rate) is at 0.408 Hz, which converting to a time unit, corresponds to 24 breaths per minute (rpm). The heartbeat was extracted from the second highest peak located between frequencies of 0.7 to 3 Hz, since it is the expectable band range for its normal. The peak value was found at 1.058hz and, identically to the respiration, was converted to a time unit presenting a 63 bpm value.

$$\begin{aligned} 0.408Hz \times 60 &= 24rpm \\ 1.058Hz \times 60 &= 63bpm \end{aligned} \tag{5.2}$$

Another test result is visible in the figures 5.20 and 5.19.

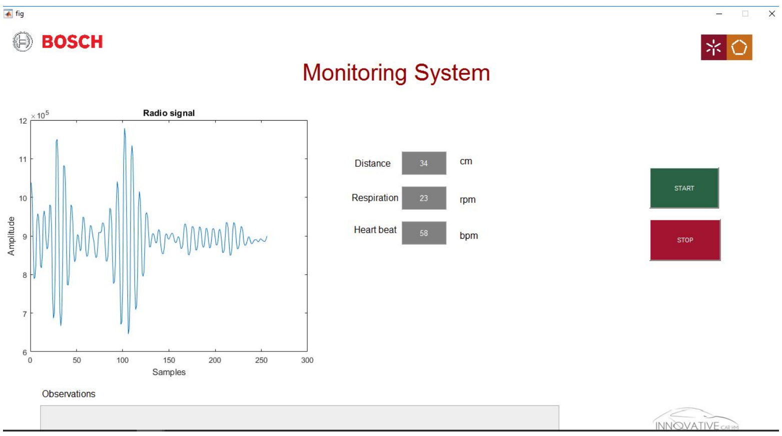

FIGURE 5.19: FFT when a subject 2 standing in front of sensor

It is observable the change in the vital signals calculated according to the FFT extracted from that time segment. It is also important to refer that there

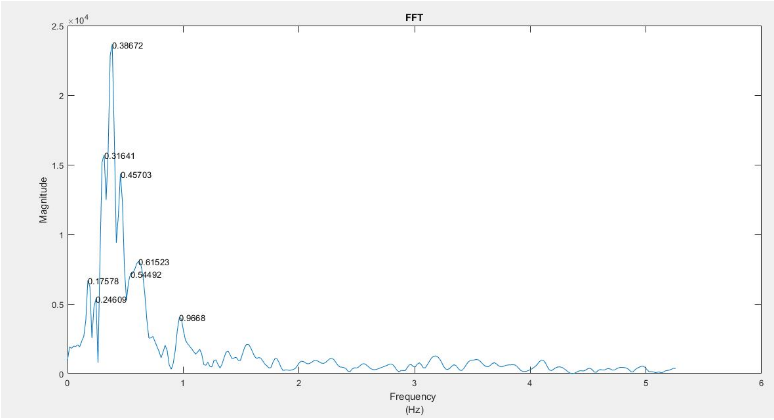

FIGURE 5.20: Subject 2 - view of the GUI

is a shift in the collected waves due to the distance's change of the person in question relatively to the position of the sensor.

$$\begin{aligned} 0.387Hz \times 60 &= 23rpm \\ 0.967Hz \times 60 &= 58bpm \end{aligned} \tag{5.3}$$

The same person was subject to a effort trial running 15 minutes on a treadmill, and repeated the initial test. As demonstrated in figure 5.21, the heartbeat of the person increased to 107 bpm, as expected.

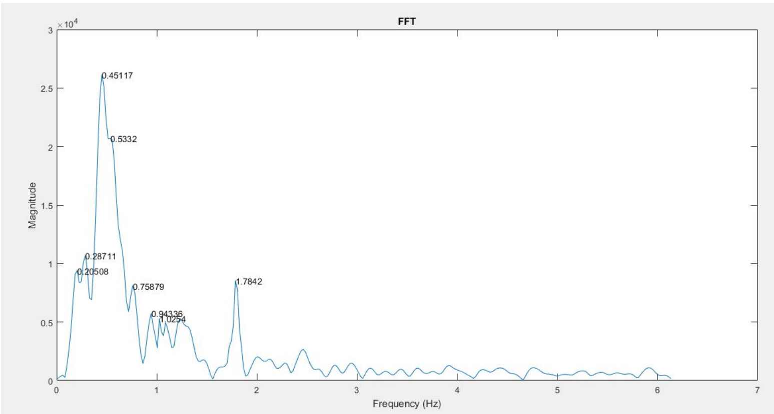

FIGURE 5.21: FFT when a subject 2 standing in front of sensor (after exercise)

In the next plot, figure 5.22, is represented a graphic of the FFT when there is no person in front of the sensor. Some features of the signal were evaluated to achieve this conclusion. First of all, the calculation of each columns' variance, for distances superior to the defined threshold, allows to know if exists a moving target. The next step consists in the calculation of the energy registered between 1 and 3 Hz. Tests, previously performed, allowed to conclude that a person's chest presents values above certain threshold during its movement. If that value is not met, then it is concluded that there is no person in front of the radar. Finally, the last step, that allows the confirmation of a person's presence, is the search of the dominant frequencies. If the 3 highest peaks of the spectrum are outside of the typical vital signal's range, it is concluded that no person was detected.

An example of the GUI's interface behaviour and FFT are in the figure 5.22 and 5.23.

In the third test, the FFT does not present a pattern with such distinctive frequencies as the previous cases. Furthermore, none of those peaks, correspond to expectable values for the heart or lungs.

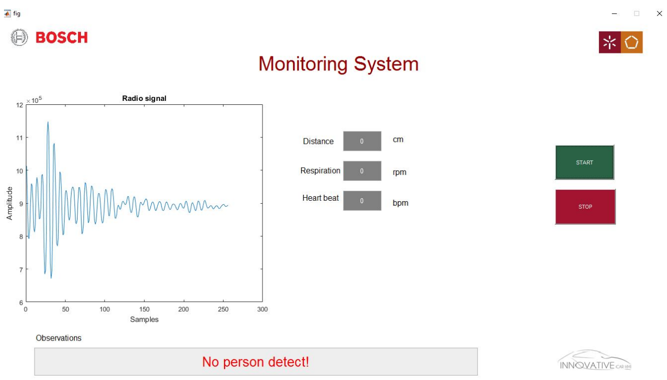

FIGURE 5.22: View of GUI when no one is standing in front of sensor

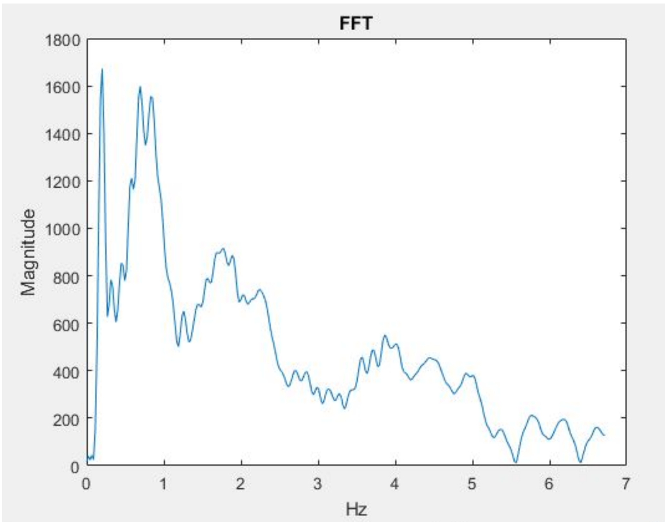

FIGURE 5.23: FFT when no person is standing in front of sensor

It is important so emphasize that all tests were performed together with the ECG monitor to confirm the veracity of the results achieved. On average, it was verified the existence of a difference between both systems of 5 bpm.

The two vitals signals were also compared in their time domain.

Figure 5.24 represents two components: respiration and heartbeat. As expected, the frequency of the respiration was lower than the heart rate. These signals were obtained with the implementation of band-pass filters: 0.1-0.4 Hz to extract the respiration and 0.8-3 Hz for the heartbeat.

The vital signals were achieved resorting to the peaks determination and calculation of the time mean difference between them.

The mean difference of the respiration peaks in all the window was 2.22 s, which means a breath rate of 27 breaths per minute. Realizing the time calculation of the heartbeat, the mean of RR peaks is 0.95 s, or 63 bpm.

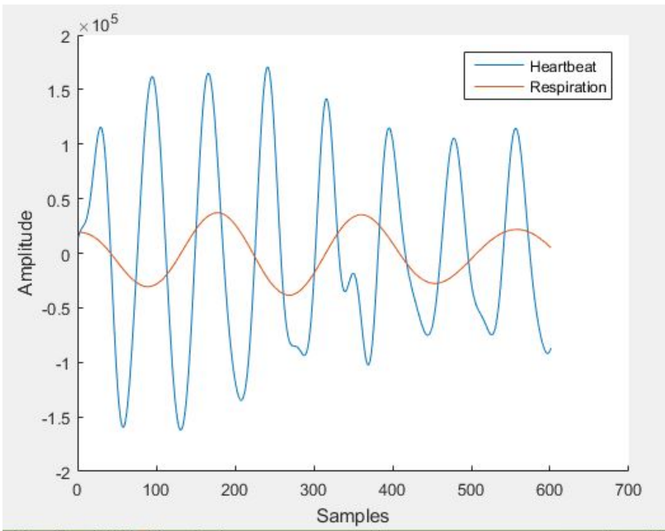

FIGURE 5.24: Time domain heartbeat and respiration

In the frequency domain the results are presented in the plot 5.25. Based on this approach, the heartbeat is 61 bpm and the respiration 24 breaths/min. These results were closer to the ones provided by the ECG monitor and the respiration count.

Ideally the both approaches should present the same results, however since the signal treatment is different (filters applied), it presents small differences between them. The results were closer to the real value when treated in frequency domain, so this was the used method to monitor the vital signals. In the Figure 5.26 is visible both signals collected simultaneously.

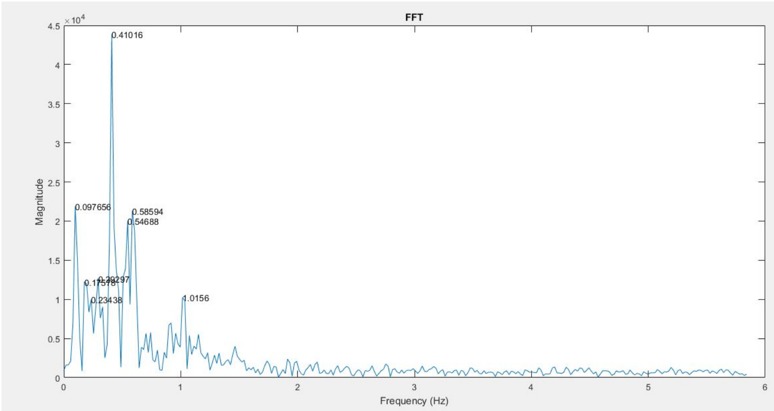

FIGURE 5.25: View of GUI when no person is standing in front of sensor

As shown, the rising edges of the microwave waveform coincides with the R-peaks in the ECG. However, since the sensor directly measures motion and not the electrical activity of the heart, the morphology is not expected to be the same.

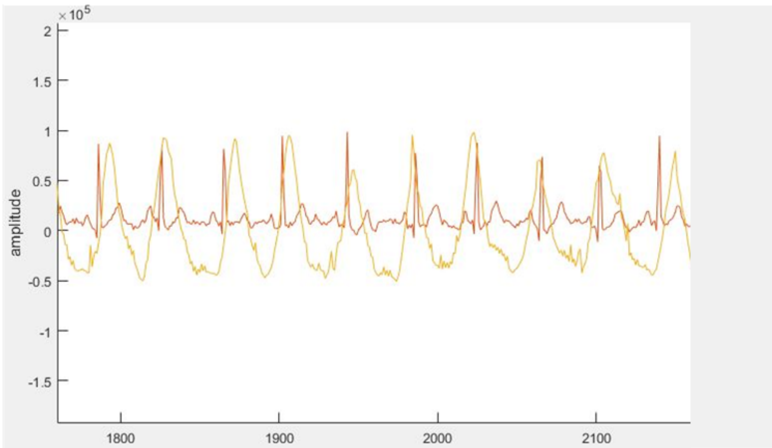

FIGURE 5.26: Radar and ECG signal (simultaneous measure)

Continuous beat-to-beat intervals and instantaneous heart rate measurements are the source information for HRV analysis. As illustrated, the heart signal does not exhibit a peak as sharp as the ECG signal. On the other hand, it was demonstrated that radar has potential to provide a practical tool for heartbeat calculation.

Besides, the time domain technique demonstrate to be not as accuracy as the frequency domain. This conclusion was achieved with the results obtained visually by the ECG monitor, by tested person breaths counting and also by the graphical shape that was demonstrated early.

Chapter 6

Conclusion and Future Work

6.1 Introduction

In this final chapter, a brief reflection of all work elaborated in this dissertation will be presented as well as the exposition of some future work about the addressed subjects and some improvements.

6.2 Conclusion

Most car accidents are caused by drowsiness, distraction or health issues. Driver monitoring systems aim to prevent accidents caused by these issues through a constant evaluation of the driver's state and attention. Over 1,25 million people die each year in the world as a consequence of traffic crashes and 20% of these fatalities are caused by driver's fatigue.

In this dissertation was suggested an HMI concept to monitor the driver. A concept, that identically to the automotive industry, is in a primordial state of investigation.

To make a conclusion, first is necessary to remember the objective defined in Chapter 1, which were:

- Selecting the most appropriate contactless biometric sensor for heartbeat monitoring, taking into consideration criteria like comfortability, size of the sensor and its efficiency;
- Developing robust algorithms to detect the driver's fatigue using heartbeat;

The first objective led to research questions 2 and 3 (in section 1.3), where it was explored possible sensors to detect heartbeat from a person, considering the car integration requirement. The second objective led to the research question 1, and to the motivation to develop this dissertation.

The objectives were achieved, since it was chosen a technology without contact to the subject and implemented an algorithm to monitor a person. This process took in consideration the fact that the solution achieved would be implemented in the automotive world. In parallel, an analysis of a contact method with an implementation of an algorithm to detect drowsiness was made. This algorithm was tested with a database online and also with the aid of a driving simulator. Besides an integration in a seat do not was possible, has been realize some filtering to eliminate possible noise provide by car but remained to be done an extensive analysis and tests in a real driving situation.

In conclusion, this non-contact technology is a possible solution to monitor a person and to reduce the biggest cause of mortality on the road. It can be associated to other technologies and also presents advantages comparatively to these technologies. For instance, some eye tracker systems do not work properly with glasses, other systems need direct contact with the user and other need an initial fixed position (cameras).

6.3 Future Work

In this section is exposed the opinion of the author regarding possible branches to the main themes and also some adjustments to improve the robustness of the system .

- Other algorithm implementations: this project can be incremented with other algorithms of drowsiness detection, specially QRS detection algorithms, such as Hilbert Transform, to further explore possibilities and scenarios in order to answer the objectives of this thesis;

- Comparison with other devices: to develop an accurate and robust system for drowsiness detection, the results should be validated resorting to other technologies such as the EEG or other marketed products like Vigo headset [70];

- Pregnant Driver: This project does not explore cases were the driver may be pregnant, this issue may affect the calculations of the algorithm, due to the presence of two different heartbeats;

- Extensive tests: results for this dissertation were taken from tests in a driving simulator mockup with 11 different people. In the future, there is a need to increase the number of tests, namely the night tests, to further validate the algorithm regarding drowsy cases. Additionally, this validation must be done resorting to the radar device;

- Tests with different materials: experiment the non-contact detection with incorporation of different fabric to simulate the integration in the car seat;
- Health conditions: implement in the device the detection of health conditions with the information provided by the heartbeat and respiration, such as stress, cardiac and respiratory diseases and more;
- Driver identification: since the physical condition and functioning of the heart is different from person to person, and thus unique, there is the potential to identify the driver. Characteristics such as amplitude, shape and frequency of the signal present unique features that allows the identification of a person and are worth exploring;
- Improvement of antennas: the antenna's material and the hardware design can be a problem when incorporating in the car. A solution with flexible antennas and reduced size is one possible path to solve this matter.

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