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Heart Rate Detection Using Doppler Radar

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***Abstract*—The proposal of this work is to detect the heart rate of a person at rest, using a method that implements the use of Radar Doppler. The results of the tests carried out are presented and it is determined if the method meets the objective.**

***Keywords*— Non-contact monitoring, heart rate, Doppler Radar, band pass filter.**

I. INTRODUCTION

Heart rate monitoring in a person is a commonly used practice in medical care. It is necessary to be able to obtain an adequate signal from this vital sign in order to determine the patient's condition, make an adequate diagnosis and identify possible pathologies such as arrhythmia, arterial obstruction, heart damage or heart failure.[1].

The American Heart Association (AHA) in its studies from 2015 to 2018, determined that in the United States, the prevalence of cardiovascular diseases in the population of adults older than 20 years is 49.2% in total. It also determined that this percentage increases with age, both in men and women.[2]

Currently the most commonly used systems for heart rate detection are ECGs incorporated into vital signs monitors. These use electrodes connected to the patient, they detect changes in voltage generated by cardiac activity, pro-cessing them into electrical signals that are more suitable for interpretation.[1] The use of these systems does not entail a risk for the patient, however, considerations must be taken to obtain the most optimal signal possible in order to give an adequate diagnosis. The greatest number of problems for obtaining the signal are related to the incorrect placement of the electrodes or to patient conditions that modify the signal obtained (sweating, hair in the placement area or feeling of discomfort).[1] Given these problems, the presence of trained personnel is necessary to periodically check the status of the system's electrodes

in order to guarantee that the signal received by the system is correct.[3]

To avoid the problems and inconveniences of the use of electrodes or con-tact sensors, research has been carried out that proposes the implementation of systems that do not require direct or excessively intrusive placement for the patient.[4, 5] The use of radar devices, mainly Doppler radar, has even been suggested as part of a system designed for monitoring heart rate without the need for physical contact.[6, 7, 8]

In Ref.[4] a fiber optic constructed sensor pad was proposed to monitor heart rate in people diagnosed with sleep apnea. The system was able to obtain accurate measurements of cardiac activity in its normal state, but was unable to detect abnormalities caused by sleep apnea. In Ref.[5], 76 subjects were tested for 50 days with a sensor system placed on a patch that transmitted the obtained data to an online database. The system obtained heart rate readings within a range that the author considered acceptable. However, due to the size of the system, its battery did not last long and needed to be replaced every 3 days. In Ref.[9] a system based on an FPGA development board was designed. An optical sensor was used to measure heart rate by plethysmography. The signal obtained had a ninety percent accuracy.

Regarding monitoring systems without physical contact, in Ref.[6] a system that uses Doppler radar has been proposed, whose e ectiveness was tested in a system that simulates the biometric signals of an infant. However, the results were favorable only in normal behaviors of the simulated signal. In another work, the author proposes a system that uses a dual array of antennas to compensate for the noise of the signal obtained.[7] Other research focused on the development of radar antennas that allow obtaining signals for monitoring vital signs inside a car[8].

In the systems of references [7] and [8] promising results were obtained, the only important disadvantage of both is the size of the designed system, which could make them unfeasible for use in various environments.

In the this work, a system is proposed that seeks to use a small size Doppler radar module, which allows it to be easily placed and used in diferent environ-ments. The operating principle of the radar module and the selected settings for signal conditioning required for heart rate measurement will be described. The tests carried out with the sensor will also be explained and the results obtained will be analyzed.

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II. MATERIALS AND METHODS

A. *System configuration*

The selected radar module is the HB100, a low cost commercial module used in motion detection applications for security systems. It emits microwaves at a frequency of 10.525 [GHz]. It is composed of a transmitter antenna, a receiver antenna, a dielectric resonator oscillator and a microwave mixer to obtain its output signal (see Figure 1)

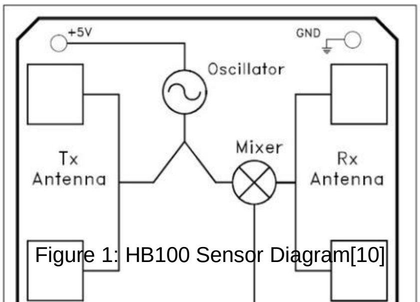

Figure 1: HB100 Sensor Diagram[10]

For the conditioning of the output signal, a modified version of the amplification circuit recommended by the specification sheet of the module was implemented (see Figure 2). The circuit is designed so that the radar emits microwaves continuously. It is made up of a series of band-pass circuits.[10] The component values used were modi ed to obtain a high pass frequency of 1 [Hz] and a low pass frequency of 3.2 [Hz]. The rst bandpass has a gain of 825 and the second one has a gain of 100. This con guration was done to get a total gain of the circuit of around 80k, that ampli es the output signal of the radar module to values suitable for its use. The modi cation of the bandpass frequency was made to be able to detect only the heart rate signal, which has a range of average values from 1 [Hz] to 3 [Hz], depending on the state of the person.

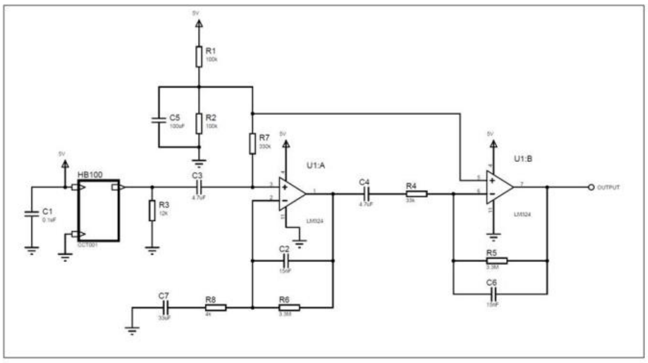

Figure 2: Conditioning circuit, continuous wave operation.[10]

The computer selected to receive the data from the sensors was the Rasp-berry Pi 4B of the company Adafruit. It is designed for different types of tasks and has 40 general purpose pins. In order to carry out the data acquisition of the radar module, it was necessary to implement the digital analog converter MCP3008. It has the capacity to have up to eight inputs of analog signals and sends the information to the computer communicating through the use of the SPI communication protocol.

Python programming language was used to generate the signal processing program code and data storage. The data obtained by the analog converter is stored in a CSV le and then ltered with a digital Butterworth bandpass lter.

To carry out comparative tests, two existing systems on the market were used: the AD8232 module, which is a heart rate monitor, and a pulse oximeter.

B. *Methodology*

A series of comparative tests of the designed system were carried out, com-paring it with the module AD8232 and pulse oximeter. The objective was to compare the values obtained by the three systems.

For the measurements, the designed system was placed in front of a test subject. The subject was seated and in a state of rest. The radar module was placed at a distance of 30 [cm] and at torso height. The AD8232 module was connected to the subject via three electrodes placed at three different points on the torso. The pulse oximeter was placed on the index finger of the left hand. Five series of measurements were made with a duration of 15 seconds each. Heart rate values obtained by the devices were recorded. The oximeter readings were used as a basis for comparison.

III. THEORY

The Doppler Radar uses a transmitting and a receiving antenna. Microwaves are emitted towards an object. If it is in motion, the scattered or reflected microwaves are a reflected by the Doppler effect, which causes a shift in their frequency. If the object or any of its components remained stationary, the reflected waves do not suffer this shift.

The radar processes the reflected waves and obtains the difference between the frequency of the emitted waves and the frequency of the received ones as an output signal. Showing a frequency change in the periodic output signal.

The frequency shift caused by the Doppler effect, considering that the line of motion of the deflecting object forms a theta angle with the emitter's wave beam, is determined by the following equation:

$$f_D = f_t - f_r = f_t \cdot 2 \cdot \frac{u}{c} \cdot \cos\theta \quad (1)$$

Where f_t is the transmitted frequency, f_r is the received frequency, c is the speed of the waves and the product u cos is the velocity component of the re ecting medium along the direction of the emitted wave beam.[11]

During cardiac activity, a person's chest wall undergoes displacement. This displacement is in the range of 0.02 - 0.05 [cm], By placing a Doppler radar device in direct line with the torso, the waves emitted by the radar are affected by the Doppler effect as they are reflected by the chest wall during displacements . When the reflected waves are captured by the receiving antenna, the device obtains the difference in frequency, which allows having a signal whose morphology can be interpreted in the same way as a conventional electrocardiogram.

IV. RESULTS

TEST N.	HR (Proposed system) [bpm]	HR (AD8232) [bpm]	HR (OxImeter) [bpm]
1	104	100	100
2	102	100	107
3	101	100	103
4	101	96	103
5	100	100	95

Table 1: Comparative test

Comparing them with the oximeter readings, the proposed system and the AD8232 obtained readings below 5% percentage error.

V. DISCUSSION AND CONCLUSIONS

The comparative test showed that the proposed system is capable of obtain-ing heart rate values with an error percentage within an acceptable range for its use.

In this work, a Doppler Radar module was used to obtain heart rate signals. A comparative test was performed with two commercially used heart rate mea-surement systems. The measurements obtained by the system had a máximum error rate of 5%. These results were considered acceptable, validating the use of the sensor for the purpose proposed in this work. The obtained heart rate signals continued to present considerable noise, further digital processing had to be performed. In the analysis of the comparative test, it was assumed that the signal morphology of the proposed system represents the signal of cardiac activity in an acceptable way. As future work, it will be necessary to make modifications to the conditioning circuits to reduce the noise obtained from the base signal. It will be determined if the morphology is acceptable or modifications must be made to the system to obtain a more adequate signal.

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