Electronic Device for Arterial Pulse Waveform Semiology

Octavio Diaz-Hernandez and Livier Baez-Rivas

***Abstract*—The visualization of the arterial pulse waveform has been a problem to clinical physicians because normally, the medic has to imagine the pulse from palpation. But in this work we provide a simple electronic device, designed and assembled from elements such as operational amplifiers, resistances, and commercial capacitors, among others. We use analogic filters (active and passive), compensators, amplifiers, a common fototransistor and a light emitting diode as sensor, which is in contact with a human arterial pulse palpation site (wrist or neck). In the results it is possible to see a clear signal from an arterial pulse waveform in an oscilloscope screen. Finally, remain in the future work to integrate a display to see the waveform in other devices, also to perform arterial pulse waveform semiology automatically.**

***Index Terms*—Arterial pulse waveform, semiology, operational amplifiers, electronic device.**

I. Introduction

In clinical medicine, the semiotics is a physician´s tool for diagnosis of probable syndromes in a patient. Among the signs and symptoms in a patient, the semiotics studies the arterial pulse (AP). The AP is an indirect sign of the pressure of the vascular system, and it has been studied since ancient times, e.g. in the Traditional Chinese Medicine [1]. The AP is observed by physicians to look for some evidence of health or disease, but its detection need large amount of practice and has a subjective component that may varies with the physician criteria [2]. Modern physicians have two kind of technic to measure the AP, the invasive and the non-invasive [3], [4], in the first, it is used a needle in the interior of the artery to measure the pressure, waveform and oximetry with very specific and, sometimes, complex devices [4]. It is worth mention that invasive technics are mostly used in controlled environments such as the intensive care within a hospital, and should be perform by trained personal only, additionally the risk of bleeding, infection and thrombosis are higher that the non-invasive technics [5]. In the second case, in the non-invasive technics, it is used the palpation to feel a probable waveform, intensity, and frequency, but with electronic devices, now is possible to perceive the pulse indirectly through oximetry [6].

In this work, the main objective is to design a simple electronic circuit to acquire the waveform of the arterial pulse in order to visualize possible alterations. The circuit is the main core of a device, which is projected to be used in common examination room or doctor office, besides the personal who uses it, will not require specialized medical training.

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II. Related Work

Measurement of health parameters is an important necessity for physicians during clinical examination, and a great opportunity for engineers to propose medical devices, in this paper, we centered our attention in the arterial pulse. In this section, we mention some other researchers that have proposed other devices to measure pulse. In [7], Almen *et al.* uses the principles of plethysmography to monitor pulse rate of the patient as he/she undergoes training and displays the result on the LabVIEW-based pc application. In [8], Ates *et al.* uses a red and IR (Infrared) LEDs (light emitting diode) sent signals to the photodiode, and then a ratio between the signals (red and IR) received by photodiode is analyzed to estimate the oxygen saturation value (SpO2), the algorithm of the estimation is performed by a fuzzy logic method. In [9], Corciova et al developed a medical device for a monitoring peripheral hemodynamics with plethysmography using the impedance technique. Their system combines the analog amplifiers with digital signal processing to acquire real time monitoring. In [10] Dai, Y. and J. Luo designed an oximeter using infrared spectroscopy, but their novelty was to integrate a wireless technology (bluetooth) and applications on a smartphone, which processes pulse wave signal with digital algorithm, calculates the value of oxygen saturation (SpO2) and pulse rate, and finally presents them along with pulse wave graph visually through the smart mobile APP interface. In [11], Khandoker *et al.*, developed a simple and low cost oximeter photoplethyasmograph device which has been interfaced with mobile phone through USB (Universal Serial Bus). The mobile device is used to display the patient's blood oxygen saturation and pulse rate, and thus reduced the cost. In [12], Lin *et al*., designed and implemented a wearable and wireless finger base-type pulse oximeter using the tissue optical simulation technique and the Monte Carlo method. And they founded that can facilitate precise a SpO2 measurement even in a fingertip-type pulse oximeter.

III. Theory Background

A. Physiology

In the modern physiology, there is a concept named Vascular Pressure Wave (VPW), which is arisen from the heart during the systole and is originated in the descending aorta. Then it travels through the vessels walls of the periphery arteries much faster that the blood stream itself. The

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original systolic wave bounds in the peripheral veins and runs backwards centripetally forming a second wave. In the periphery arteries the pressure wave can be palpate as the arterial pulse (AP). The main features of the AP are frequency, rhythm, intensity, shiftiness, symmetry, and width. The waveform of the AP is shown in the Fig. 1.

Fig. 1. Normal waveform of the AP.

B. Semiotics

Semiology or semiotics is the field of clinical pathology that studies signs and symptoms of syndromes, diseases and their consequences. The arterial pulse (AP) is the most fundamental sign in clinical medicine, and has since been identified with the physician and the art of medicine. The AP can be perceived from any artery, but in order to be feel by the outside, the artery needs to be superficial and to be located on a plane, in this manner, the most common and palpable pulses are two: the radial artery pulse, which is located at the wrist between the *brachioradialis* and *palmaris tendons*. Also the carotid artery pulse, which can normally be felt in the neck by pressing the fingertips against the side of the windpipe, or *trachea* [6].

C. Types of Arterial Pulse

Pulsus alternans is a variation in pulse amplitude occurring with alternate beats due to changing systolic pressure. The main cause of *pulsus alternans* is failure of the heart left ventricle, and is more common with faster heart rate. It may be seen in patients with severe aortic regurgitation. Also *pulsus alternans* is often triggered by ectopic beats. See Fig. 2.

Fig. 2. Representation of Pulsus alternans.

Another finding can be that systolic arterial pressure normally falls during inspiration, called *pulsus paradoxus*. See Fig. 3.

Fig. 3. Representation of Pulsus paradoxus.

The *pulsus paradoxus* is correlated to the inspiratory decline of left ventricular stroke volume and is an important physical finding in cardiac tamponade, chronic obstructive pulmonary disease, morbid obesity, hypovolemic shock, and infrequently in constrictive pericarditis and restrictive cardiomyopathy.

Pulsus bisferiens is characterized by two systolic peaks of the aortic pulse during left ventricular ejection separated by a midsystolic dip. See Fig. 4.

Fig. 4. Representation of Pulsus bisferiens.

It is difficult to establish with certainty that the two peaks are occurring in systole with simple palpation (*pulsus bisferiens*) versus one peak in systole and the other in diastole (*dicrotic* pulse). It is frequently observed in patients with hemodynamically significant aortic regurgitation, mixed aortic stenosis and aortic regurgitation, occasionally is felt in patients with a large patent ductus arteriosus or arteriovenous fistula. Pulsus bisferiens is rarely palpable but often recorded.

The *dicrotic pulse* results from the accentuated diastolic dicrotic wave that follows the dicrotic notch, see Fig. 5. It may be found in severe heart failure, hypovolemic shock, cardiac tamponade, conditions associated with a decreased stroke volume and elevated systemic vascular resistance.

Fig. 5. Representation of dicrotic pulse.

Nevertheless, *dicrotic* pulse is occasionally noted in normal individuals, particularly after exercise. A *dicrotic* pulse is frequently confused with *pulsus bisferiens* at the bedside; it is almost impossible to distinguish between these two types of pulse configurations without a pulse recording.

Finally, another finding at physical examination can be a disparity between two or more amplitude of the peripheral pulses (e.g. radial vs femoral), which may be consequence of obstructive arterial diseases, aortic dissection, aortic aneurysm, takayasu disease, coarctation of the aorta, and supravalvular aortic stenosis.

IV. The Elecronic Circuit of the Device

The measurement of the blood oxygenation is widely applied to estimate the arterial pulse waveform and uses plethysmograph principles and the differential optic absorption between two hemoglobin molecular forms: the oxyhemoglobin (HbO_2) y la deoxyhemoglobin (RHb). It is made an analysis of an optical signal obtained from the vascular bed and this signal is modulated by the blood volume because of the heart's pumping. In the plethysmograph sensors, the emitters and receptors disposition are mainly two: transmission and reflection.

In the first case, the emitter and the receptor are opposed and receives the signal clearest but they should be placed on very specific places of the human body, e.g. fingertips, earlobe. In the other hand, the reflection disposition can be placed on almost any place where a pulse can be feel, but the signal is weaker. The pulsatile places of interest are the wrist (radial artery pulse) and the neck (carotid artery pulse). In this manner, the challenge was to clear the signal as possible by using operational amplifiers (OP-AMPs) configurations and other electronic devices. The circuit was implemented a voltage follower (stage 1) and an amplifier with variable gain (stage 2). The next step was the design of a *low pass filter* with

a cutoff frequency of 3 Hz (stage 3). Next there is a compensator (derivative OP-AMP configuration) which had a 1.8 hz frequency (stage 4), the compensator eliminate noise from the signal. Finally, we added a non-inverting amplifier, post compensator, (stage 5). *See appendix A: Circuit*

A. Calculus of the Gain and Numeric Analysis

After the test for obtain the signal, we added the different stages.

1) The follower

In this configuration (Fig. 6) did not use any resistances.

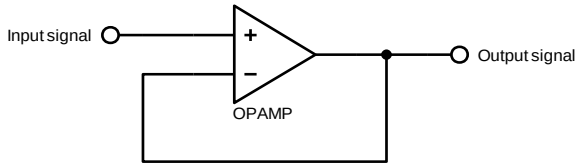

Fig. 6. OPAMP follower configuration.

$$\text{Gain} = 1 \quad (1)$$

2) Non Inverting Amplifier

The gain was between 4.5 and 6 and it is applied the equation (2) for the configuration shown in Fig. 7.

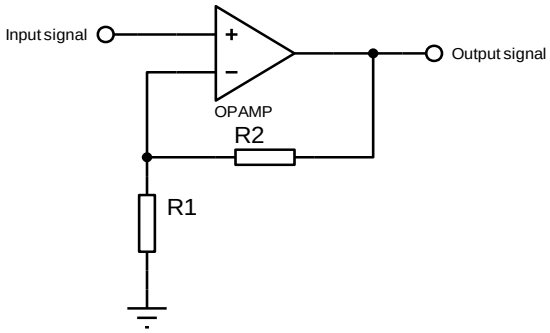

Fig. 7. OPAMP Non inverting amplifier configuration.

$$\text{Gain} = (R2/R1)+1 \quad (2)$$

where the R2 was between 3.5 and 5 kΩ, while R1 was 1 kΩ.

3) Low pass filter

In order to calculate the resistance (R), in the low pass filter configuration (see Fig. 8) we applied the equation (3).

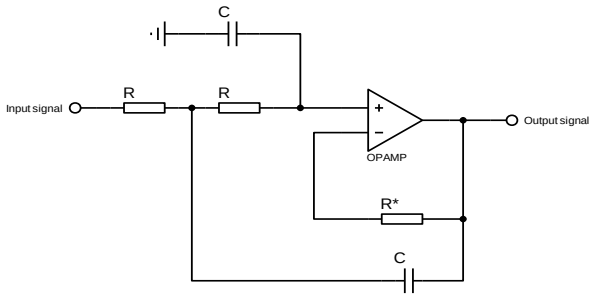

Fig. 8. OPAMP Low pass filter configuration.

$$F_C = 1 / 2\pi R C \quad (3)$$

where F_C is the *cutoff* frequency in hertz, C is the capacitor in microfarads, which was fixed in 33uF and the frequency in 3 Hz in order to eliminate noise from other biological signals such as intestinal movements, breath, or cardiac signals, among others. Then the resistance R was of 1.2kΩ. Additionally, the R^* is a dampening circuit to avoid instability around cutoff frequency, and it has 5.6 kΩ.

4) Compensator (derivate)

For the compensator (see Fig. 9) we use a derivative configuration of the OP-AMP, the frequency was fixed on 1.8 Hz (F_d) and 10 uF for the capacitor. The resistance was calculated with (4).

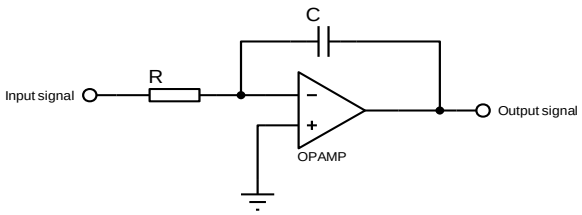

Fig. 9. OPAMP Derivator configuration.

$$R_d = 12\ F_d\ C \quad (4)$$

Then the resistance was 8.84 kΩ approximately and we implement it with a potentiometer (variable resistance).

5) Non-inverting amplifier (post compensator)

Finally, we added a non-inverting amplifier with a gain of 3.2 and we use equation (2) to calculate the resistances. The R2 was 2.2 kΩ, while R1 was 1 kΩ

V. Test and Result

In the next photographs (see Fig. 10-Fig. 14), we show the test on a healthy person in the various stages mentioned earlier.

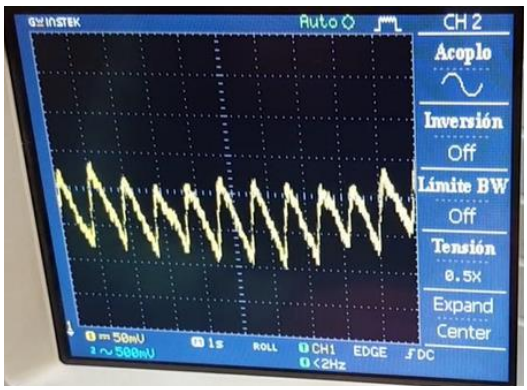

Fig. 10. Output signal from sensor, 50 mV per division.

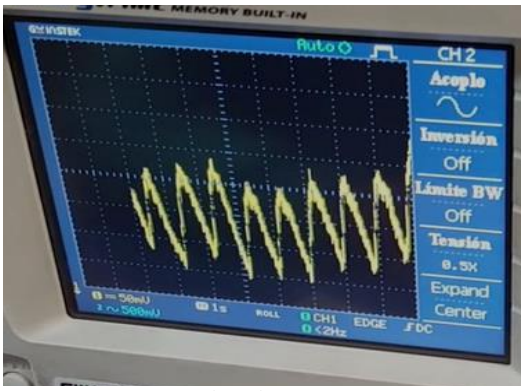

Fig. 11. Output signal from follower, 50 mV per division.

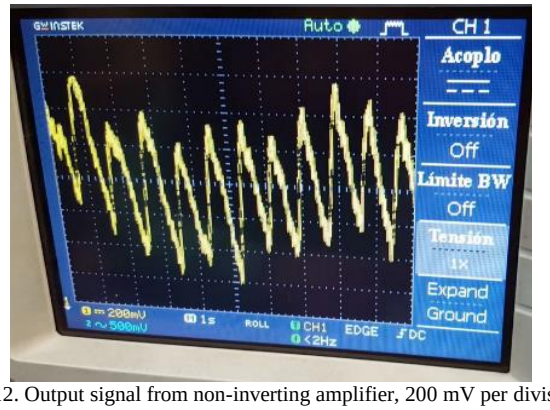

Fig. 12. Output signal from non-inverting amplifier, 200 mV per division.

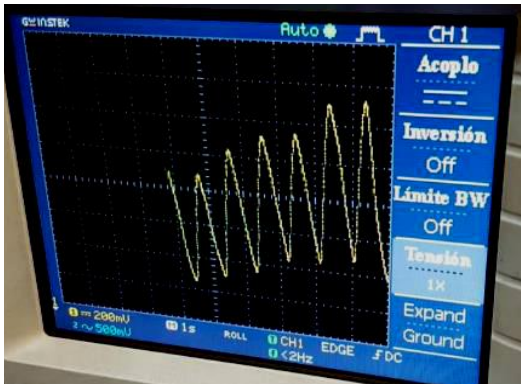

Fig. 13. Output signal from low pass filter, 200 mV per division.

Fig. 14. Yellow signal, output from low pass filter, 500 V per division. Blue signal, output from compensator (derivate) with a derivate frequency of 1.8Hz, 1 V per division.

As seen in the Fig. 14 (in yellow), the signal is clear and concordant with the normal arterial pulse waveform.

VI. Conclusion

We have measured arterial pulse waveform with a device built with simple hardware and other passive elements. The tolerance of the elements, such the resistance, capacitors, and amplifiers is acceptable. Other devices, as the "Pulse Sensor," which is based on a photodiode (APDS 9008) and an Operational Amplifier, are more expensive or inaccessible, this is why our device has advantage. In one hand, the components can be easily found and bought, and in the other, it can be assembly in a simple breadboard. This device is expensive in comparison to ours, approximately the circuit with the APDS 9008, can be bought in 38 US dollar, and our design around 10 US dollar. We will compare them in a later study. The results show that is possible to clear a noisy signal (such as arterial pulse waveform measured through the skin and other tissues) and make it readable for anyone with or without medical training. For example, the cardiologist can make a physical examination of any arterial pulse waveform with this hardware. Additionally, it is possible to calibrate the device with different gains in order to visualize the pulse through different layers, such as skin, fur, or adipose tissue. The isolation of the circuit is important due to electromagnetic waves there are in our environment nowadays, we achieve a clean signal despite we worked on a laboratory full of power sources, radiofrequency and wireless internet; afterwards we will test our circuit in a doctor office. The next step of the design is the integration of a display, such as a LCD (Liquid Crystal Display), a mobile device, or another handheld device. Also remains as ongoing work, the possibility to automatically achieve a diagnosis of the arterial pulse waveform with a programmed algorithm. The semiotics of the arterial pulse can lead to cardiac or vascular conditions and it is relevant to provide to the physician of a method for objective evaluation, which come to be available in common clinical examination room, and not only in the intensive care units, within hospitals of research facilities.

Appendix A: Circuit

The sensor used in this project is composed by a Light Emitting Diode (infrared) and a fototransistor, also we made tests with an fotodiode as receptor, with very similar results. The first input signal labeled as "Sensor" in Fig. 15 is connected to the collector of the fototransistor.

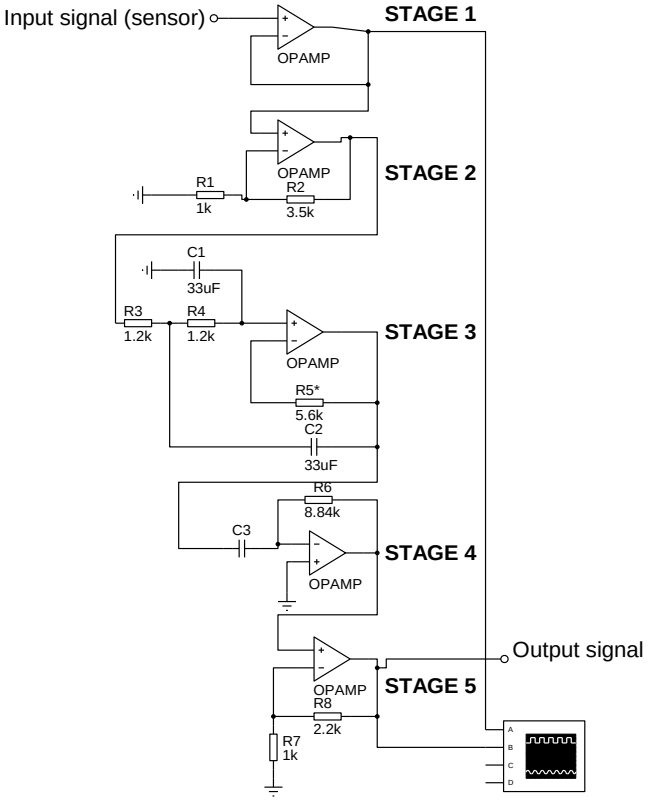

Fig. 15. Schematics of the main circuit.

Also, the stages are shown in the next Fig. 16, where also place the sensor and the measured signal.

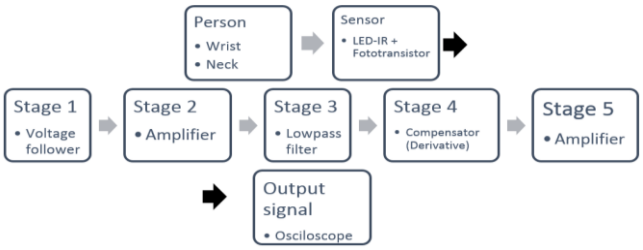

Fig. 16. The system with input and output signals.

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