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# A novel method for non-invasive measurement of blood pressure in differential and continuous mode during tilt table test

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**Abstract:** This research shows a new non-invasive method for the continuous differential record of the arterial blood pressure (ABP) to be used during the cardiovascular study in subjects with problems of peripheral circulation in tilt test. Different sections are analyzed, including the pressure transducer for the differential measurement of the variable, as well as the blocks (multiplexer, amplifier, and filters) of analog channel connected to the ARDUINO ONE platform to achieve the control of the acquisition of the data; the control of the filling and emptying of cuffs and besides the communication with a station of processing and control of records in an interface developed in C. The obtained results evidence adequate linearity and frequency response, allowing for the study of the blood pressure variable during the development of tilt test.

**Keywords:** tilt table test; blood pressure measurement; continuous differential record.



## 1. Introduction

The cardiovascular illnesses constitute one of the main causes of death at international levels and nowadays their prediction constitutes a challenge [1].

The tilt table test (Figure 1) is a clinical tool for cardiovascular diagnoses, especially during the determination of vagal syncope (neurocardiogenic syncope) [2-4]. In this test, most of the patients without cardiogenic and with syncope of unknown cause, reproduce the vasovagal symptoms (bradycardia and hypotension) before the "orthostatic stress".

The neurocardiogenic syncope happens when the part of the nervous system that controls the blood flow changes the heart rhythm and it reduces the arterial pressure for a short time; then, less



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blood flows to the brain and the result is a faint of people.

The clinical exam has been used for more than 20 years and cardiovascular studies are reported with diverse protocols to explain the variability of the results [5-13].

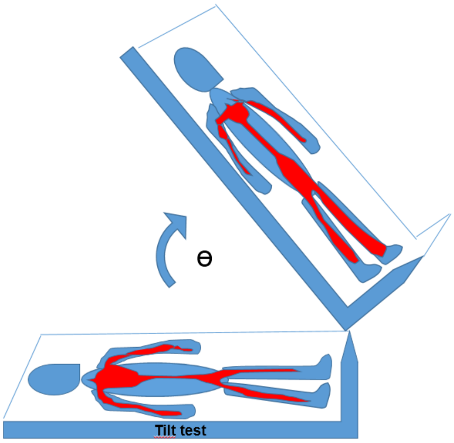



**Figure 1.** Representation of a clinical tilt test (blood pressure changes with different positions).

The test consists typically of two stages: a spontaneous one and a pharmacological one, both varying the grades of inclination. The subject is placed on the bed (0°) and some basal vital signs are previously measured, and then the clinical specialist proceeds to the controlled inclination. In the spontaneous phase, the arterial pressure is measured every five minutes when the subject has more symptoms frequently.

If the patient develops syncope, pre-syncope, or hypotension and/or bradycardia symptoms, the test is considered positive and it concludes in that instant. If the symptoms do not appear after thirty minutes of inclination, the patient is returned to the decubitus position and the clinical specialist proceeds to the pharmacologic stage where certain drugs are applied to the patient.

During the cardiovascular study of patients in tilt table test, it is necessary to characterize the recording of physiologic variables, among those variables is the arterial blood pressure (ABP) [14-17].

Three factors affect the sanguine pulse: the systolic volume of the heart, the compliance of the arterial tree, and the ejection of the heart during the systole. The pressure pulse settles down in an approximate way for the proportion between the systolic volume and the compliance of the arterial tree. Since the blood circulates in an elastic recipient, we can assume:

$$V = Vo + kp \quad (1).$$

where k is the coefficient of elasticity of the vessels and it establishes the proportionality among the pressure and the volume, and $V_0$ is the initial volume without pressure.

When differentiating equation (1), we obtain:

$$\frac{dV}{dt} = k\frac{dp}{dt} \quad (2).$$

Now, it is possible to obtain an expression in function of the flow of the blood:

$$Q = \frac{dV}{dt} + Q_o \quad (3).$$

This model shows that the volumetric speed (Q) of the blood flow from the heart is similar to that of the increment of the volume of the elastic recipient and to the speed of reflux of the blood starting from the recipient. Being based on the Poiseuille equation and the expression for the hemodynamic resistance Rh, and substituting values in the equation (3), we can obtain:

$$Q = k\frac{dp}{dt} + \frac{p}{R_{ho}} \quad (4).$$

Fixing the terms, one can obtain the flow in function of the time:

$$Qdt = kdp + \frac{p}{R_{ho}}dt \quad (5).$$

The integration limits regarding the time correspond to the period of the pulse (contraction of the heart) from 0 until Tp:

$$Qdt = \frac{1}{R_{ho}}\int_0^{Tp} pdt \quad (6).$$

This expression represents the wave obtained during the propagation of the blood flow in a vessel. For specific conditions during the systole, one can determine the dependence of the pressure in the vessel, starting from the flow and the hemodynamic resistance of the vessel:

$$p = p_S e^{\frac{-t}{kR_{ho}}} \quad (7).$$

The obtained model describes the real phenomenon approximately in the ascent of the wave of pressure and also reflects the process for the end of the diastole.

Nowadays, it is possible the intermittent measurement of the ABP for non-invasive methods by means of the use of a pressure transducer and cuff in manual or automatic mode [18, 19]; but in the cardiovascular studies, it is necessary to know and study in continuous way the behavior of this important variable during the interval of time that the tests are applied on the bed on the people under study in the different work positions, fulfilling the AAMI (Association for the Advancement of Medical Instrumentation) requirements for this type of systems [20] .

This research shows a novel acquisition system to continuously record ABP during tilt table test in differential mode (Figure 2) by using a development platform (ARDUINO UNO) and a control interface in C language.

This new alternative allows to obtain better clinical information that the classic systems of ABP intermittent measurement.

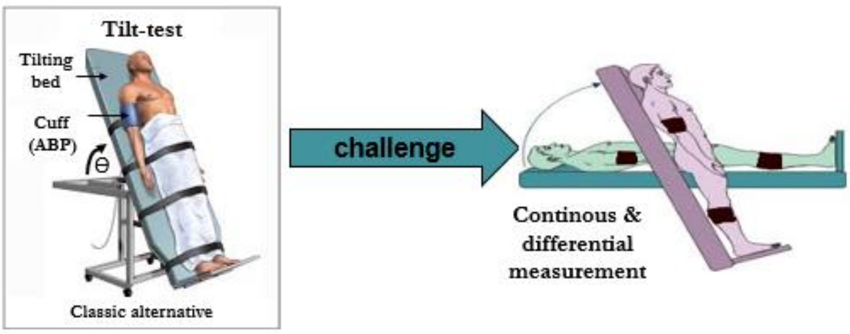



**Figure 2.** Placement of cuffs during a tilt test.

## 2. Materials and Methods

Figure 3 shows the fundamental blocks of a new system proposed for the differential continuous measurement of the ABP variable in tilt tests, starting from the employment of two cuffs placed in the extremities (arm and leg) of people during the tests.

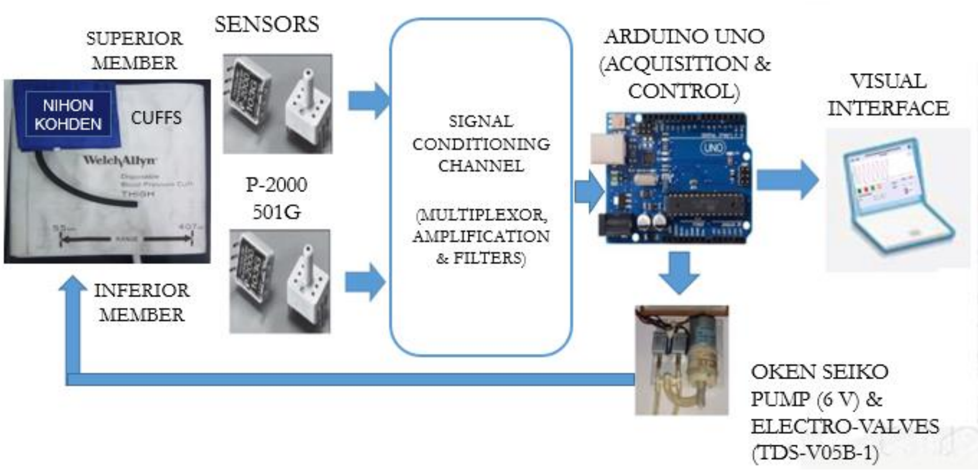



**Figure 3.** Functional blocks of proposed system to continuous differential acquisition of ABP during tilt test.

Two P2000-501G transducers were selected as sensor of pressure (0-32 kPa), and they are placed together to its respective cuffs and coupled to an analogical multiplexer (CI4052), which permits to take alternating samples of each one according to the selected sampling frequency (fm=500 Hz).

An instrumentation amplifier (AD620) and passband filters (0,5 Hz < Bw < 40 Hz) allow for signal conditioning, giving the appropriate levels to the A/D converter of the platform selected with 10 bits of resolution ($error_t < 3$ mmHg). The acquired samples are sent (USB way) to the PC station for their representation.

Figure 4 shows the algorithm development to record the behavior of ABP during the tilt test.

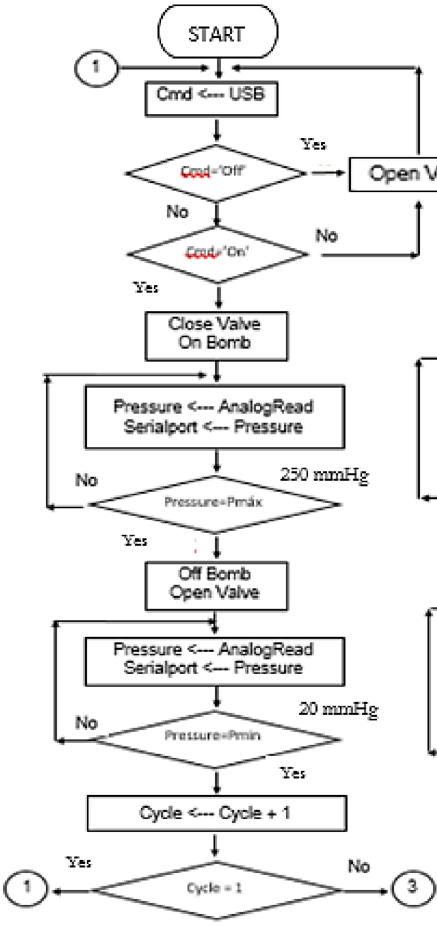



**Figure 4.** Diagram of flow of the ARDUINO program.

Initially, the program carries out a simple verification of the system and prepares the different registers and terminals of the processor that assists the channel control (multiplexor, valve controls, and others). In the first cycle of measurement, the subject is placed on the bed (horizontal position), it is expected by the sending of 'On' command from the computer to close the filled valve and to enable the pump of air, being monitored the cuffs pressure until arriving to the established limit (250 mmHg). Then, the empty valve is activated (3 mmHg/s) and the cuff pressures are acquired. When the pressure decreases below 20 mmHg, the program stops the process and the mean pressure is determined. This value serves as reference for the next measurements during the tilt test.

The interface in the PC shows both registrations simultaneously and the specialist will be able to save the information to later analyze it together with the subject's clinical data.

In case a clinical event happens in the subject that limits the test, it is possible to stop the program ('Off' command) from the PC.

## 3. Results and Discussion

With help of different instruments in the laboratory (Oscilloscope, sphygmomanometer, and others) showed in Figure 5, we evaluated the linearity of four sensors (P2000-501G, COPAL Electronics), obtaining a high linearity as showed in Figure 6.

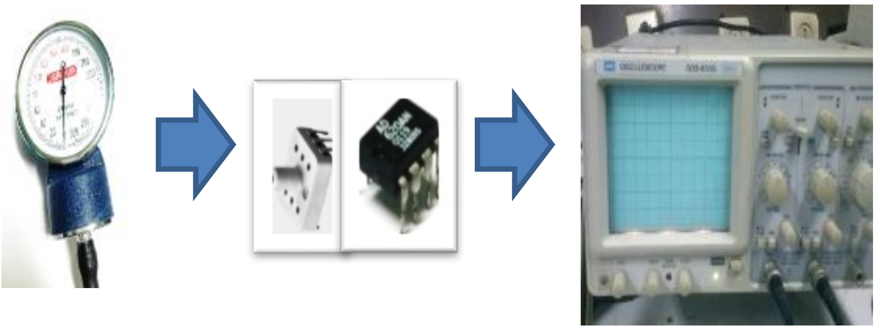


**Figure 5.** Instruments to characterize the linearity of pressure sensors (P2000-501G).

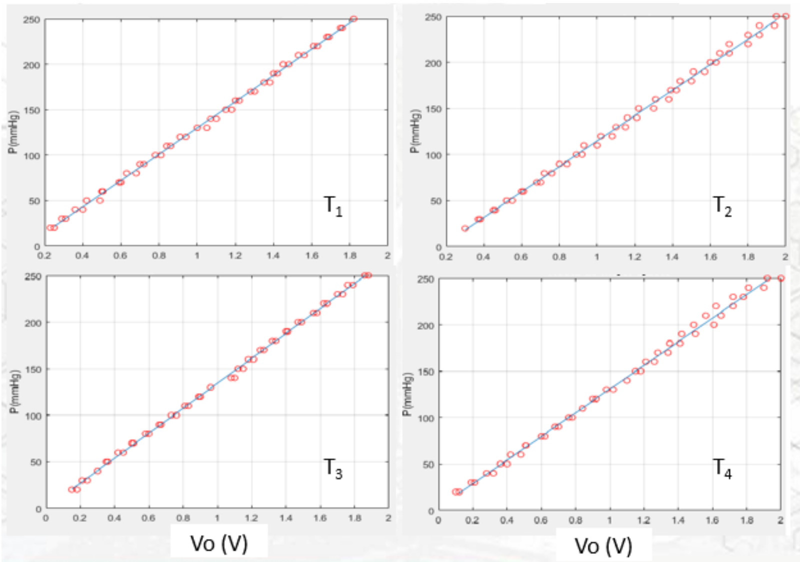



**Figure 6.** Linearity of four P2000-501G sensors of COPAL Electronics.

Figure 7 and 8 show the good linearity and the bandwidth obtained during the verification of acquisition channel using resistors and capacitors with 5 and 20 % of tolerances, respectively.

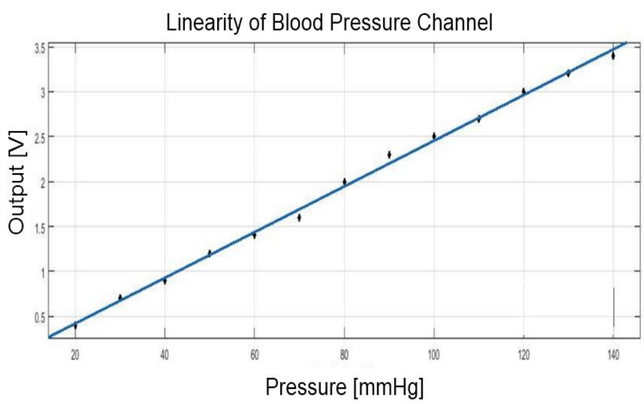



**Figure 7.** Linearity of blood pressure channel (Static characterization).

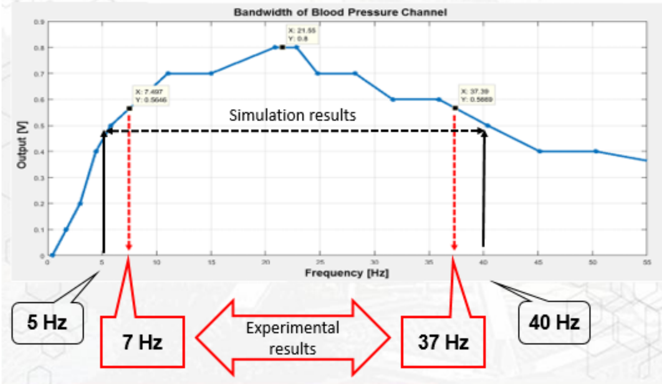



**Figure 8.** Bandwidth of blood pressure channel (Static characterization).

Figure 9 shows the answer of channel obtained during the application of stair pulse in the input.

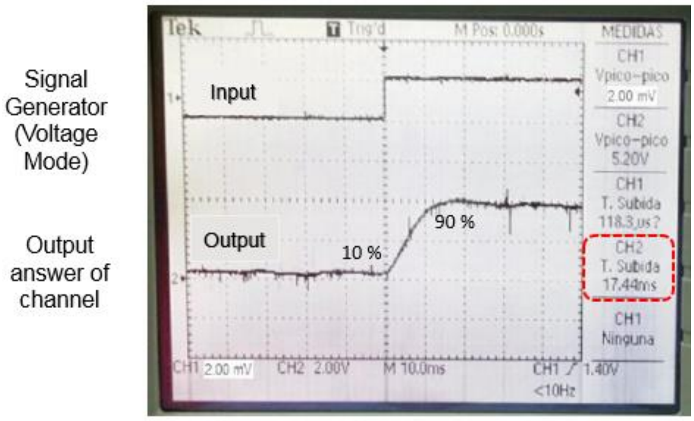



**Figure 9.** Dynamic characteristic of channel to ABP acquisition ($t_s$ < 20 ms).

Figure 10 shows the interface development in C language to obtain the graphic representation of acquired data during the tilt test.

In the higher section there are three general control commands: START, STOP, and EXIT that allow the beginning of the record, the stopping of the acquisition, and the exit of the execution of the program, respectively.

In the inferior section the clinical specialist can introduce the subject's data (name, age, weight, height, and sex), that they have stored at the beginning of the acquisition file. In the left, there are some control commands related with the selection of the address to save the information during records, to review the data saved previously, and to visualize the information in a file saved previously (Figure 11). In the right, the section gives the measurement value of mean pressure in both members (arm and leg) during the tilt test.

In the center of the developed interface, the window shows the ABP records in arm (blue color) and leg (red color) with the pressure samples obtained during the tilt test in continuous mode.

The information stored in the computer can be analyzed with other mathematical tools of more power, such as MATLab to facilitate the spectral-time analysis of different physiological variables obtained during the cardiovascular studies on tilt test.

With this design on ARDUINO UNO platform, it is possible to add new channels to acquire other important physiologic variables, such as electrocardiogram and respiratory frequency. The acquisition in these cases is easier to obtain a continuous record.

If it is necessary to diminish the total uncertainty of the system, it is possible to select a higher version of the selected platform with an A/D converter with resolution higher than 10 b.

In the bibliographic references analyzed, we did not find a similar system to the differential continuous record of ABP variable during tilt table test and nowadays, our research team is developing the digital processing of data acquired to obtain new spectral-time indicators related with the detection of different illnesses of cardiovascular system in people during tilt table tests.

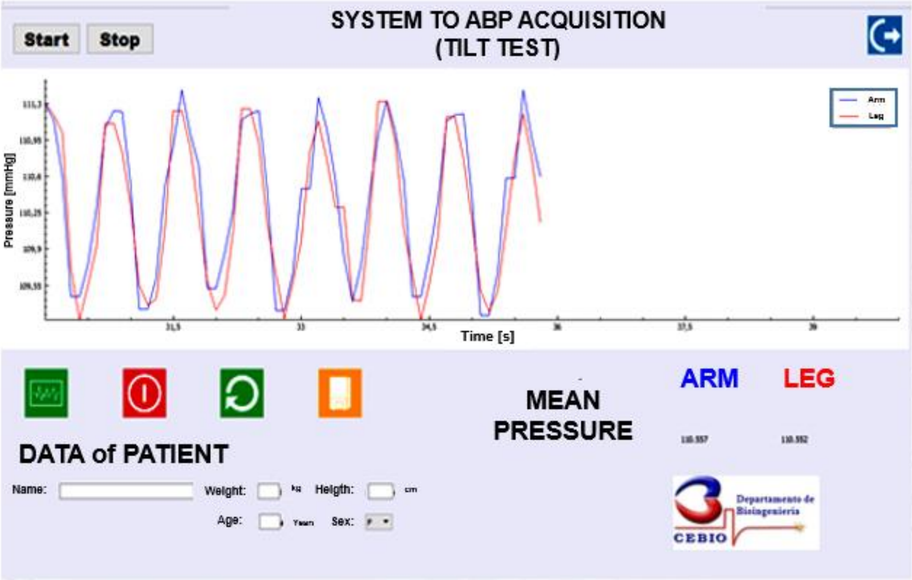
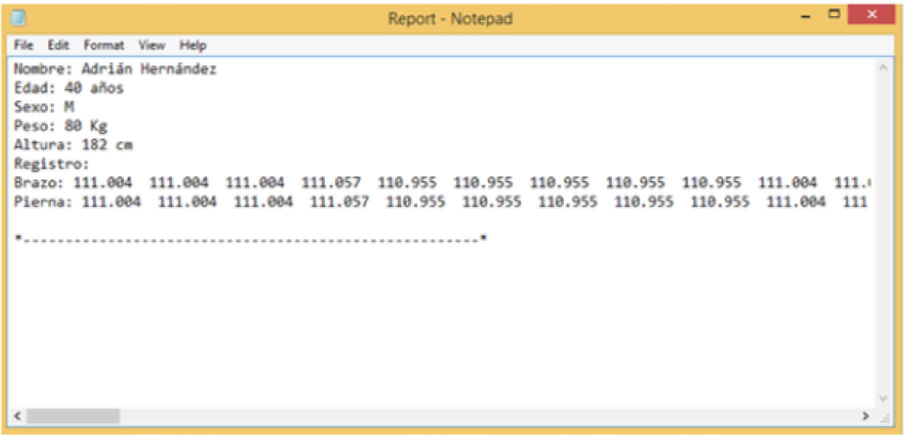



**Figure 10.** Interface development used in tilt test.



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Nombre: Adrián Hernández
Edad: 40 años
Sexo: M
Peso: 80 Kg
Altura: 182 cm
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**Figure 11.** Report obtained during the tilt test.

## 4. Conclusions

In the development of the system for differential continuous acquisition of ABP, different sections have been verified with good results: good linearity and answer of frequency of the channel and easy handling of the control of fill-casting of the cuffs starting from the employment of digital terminals of the platform of development employee. A simple interface has been developed in C language to help of clinical specialists during cardiovascular studies in tilt test.

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## Conflicts of Interest

The authors declare no conflict of interest.

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