A Novel Method for Blood Flow Measurement using Plethysmography

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Abstract

The objective of the project is to measure the blood flow in human limbs and to study the blood flow characteristics using an innovative methodology called Impedance plethysmography. It is also called as impedance test or blood flow or impedance phlebography. It is a non-invasive test that uses electrical monitoring in the form of resistance (impedance) changes to measure blood flow in veins of the leg. Information from this test helps doctors detect deep vein thrombosis. Using conductive jelly; the examiner strategically places two or four electrodes on the patient's calf. These electrodes are used to measure the impedance of the body and it is amplified. It is used to detect blood clots lodged in the deep veins of the leg, Screen patients who are likely to have blood clots in the leg, Detect the source of blood clots in the lungs (pulmonary emboli). It measures the blood volume changes in the human physiology which is used to detect the cardiovascular problems in the human.

Keywords: ***non-invasive; cardiovascular; plethysmography; Vein thrombosis; thrombophlebitis***

I.Introduction

In earlier days, External transducers were used for various measurements but at times instead of an external transducer, the living system itself can be made to modify an externally applied electrical signal. For such measurement, the living system may be termed as an active transducer. A representative example of active transducer measurement is electrical impedance plethysmography[1]. This technique has been applied to the measurement of the blood content of fingers and limbs, measurement of volume changes of the lungs during breathing and estimation of changes in the stroke volume. The basic principle underlying the plethysmography measurements is that the impedance of the body segments under study changes during respiration and cardiac activity. Fundamental principles underpinning the study of cardiovascular physiology can be emphasized by measuring blood flow and also measure the resistance offered by the body to the flow of blood and in turn we can also estimate the diabetes level, which is the major contribution from our project. Measurement of blood flow provides valuable information about function and regulation of the circulation. Blood flow (Q) is dependent on and resistance (R) to the flow of blood. Therefore, measurements of blood flow can reflect changes in cardiac output, mediated by heart rate and/or stroke volume, although in some circumstances regional blood flow may change independently of any alteration in cardiac output. Such physiological changes are rapidly evoked in response to a variety of stresses, including physical exercise, drugs, changing posture, and local or systemic heating and cooling, that may be used to examine homeostatic control mechanisms. The Plethysmography is essentially a volume recorder that detects subtle changes in the volume of an organ over time. In this project we convert this into a function of resistance and deduce the other parameters that are

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essential for the measurement of blood flow. This Resistance undergoes minute changes when blood flow within the body changes[3]. All these measurement are taken from a number of people and then we relate it to their corresponding body weights and physique, if the values are not found to be optimum then the patient is found to be having diabetes or not.

A. Intention

This method is very much helpful for biomedical purposes, because Plethysmography techniques do not necessitate any surgical work. This technique is used for measurement of blood flow in the infants or in born because it is a non surgical method and cause no pain, no blood loss [5]. This method has advantage over the measurement of the lung volume changes and estimation of stroke volume changes in the aged peoples. The advantage is due to non surgical method which will not cause any strain for the aged people. This is used to indicate the presence or the absence of venous thrombosis[6][8]. It is an alternative to the venography method. This method is very convenient and easy to use.

B. Innovation

The inconvenience caused to the people due to the venography method has been overcome in this method of impedance plethysmography[1][5]. There is no any special dye is injected into the bone marrow or veins. The dye has to be injected constantly via a catheter. Therefore a venography is an invasive procedure. Normally the catheter is entered by the groin and the doctor moves it to the required place navigating through the vascular system. This method innovatively found a solution for those problems.

II. Exsisting Methods

The problem addressed in this communication concerns the availability of an appropriate instrument for non-invasive measurement of blood flow in human limbs. The most common method used for determination of blood flow in humans is venous occlusion plethysmography, a technique used by physiologists for close to a century. This method is an invasive method herein a dye is being introduced into the veins. This dye is tracked and blood flow is being monitored. Modern venographic methods use electronic devices and monitors for the tracking of blood flow. Early plethysmography consisted of either or air-filled compartments in which the limb segment was sealed. These devices also have their respective advantages and disadvantages. Changes in air volume are influenced by body temperature, therefore requiring a correction factor to enable accurate volume determination[1][2]. The accuracy in blood flow measurements yielded by water plethysmographs and strain gauge plethysmographs is, however, not quantitatively different Because air-filled plethysmographs may also be used to examine the influence of temperature perturbation on blood flow, we chose to explore this method in the present communication[4]. Air-filled plethysmographs were traditionally constructed from glass or brass and other metals to form either conical or boxed-shaped designs. By use of these materials, some of which are no longer appropriate, the Air-filled plethysmograph would prove difficult to manufacture in great numbers.

A. Constraints in the Existing Methods

The venography method is an invasive method wherein it is inappropriate to be used for blood flow measurements among infants, aged people and weaker patients as this method needs to tear the vein. Another major disadvantage is that this method needs good electronic infrastructure for and this adds up to the complexity. In the air filled plethysmography changes in air volume are influenced by body temperature, therefore requiring a correction factor to enable accurate volume determination. Hence the accuracy is a major constrain here, but often we end up in circumstances where we need precise values. Also the inclusion of many parameters makes this method more complex. Application of finger plethysmography requires some limiting considerations[6][8]. Firstly, PWA is determined by a number of hemodynamic factors including arterial inflow, venous outflow, cardiac stroke volume, venous return to the heart as well as alterations of autonomic neural control. Moreover, the position of the finger relative to the heart level, arm and hand movements (e.g. in sleep studies after arousal), and pre-constriction of finger arteries (e.g. low surrounding temperature, excitement, and stress), may affect the signal[7]. Finally, the agreement between baseline digital blood flow and PWA has been reported to vary to a great extent between Subjects. Therefore, only within-subject changes in PWA during a limited time interval were evaluated in the current study In order to overcome these problems we developed a new methodology called Impedance Plethysmography – Blood Flow Measurement at Foot.

III.Impedance Plethysmography

Impedance plethysmography, also called impedance test or blood flow or impedance phlebography, is a non-invasive test that uses electrical monitoring in the form of resistance (impedance) changes to measure blood flow in veins of the leg. Information from this test helps doctors detect deep vein thrombosis (blood clots or Thrombophlebitis).

A. Purpose Impedance plethysmography may be done in order to:

- Detect blood clots lodged in the deep veins of the leg.
- Screen patients who are likely to have blood clots in the leg.
- Detect the source of blood clots in the lungs (pulmonary emboli)

Accurate diagnosis of deep vein thrombosis (DVT) is critical because blood clots in the legs can lead to more serious problems. If a clot breaks loose from a leg vein, it may travel to the lungs and lodge in a blood vessels in the lungs[9][11]. Blood clots are more likely to occur in people who have recently had leg injuries, surgery, cancer, or a long period of bed rest.

B. Precautions

Because this test is non-invasive, it can be done on all patients and is easy to perform. However, the accuracy of the results is affected if the patient does not breathe normally or keep the leg muscles relaxed. Compression of the veins because of pelvic tumors or decreased blood flow, due to shock or any condition that reduces the amount of blood the heart pumps, may also change the test results[10][12]. Both false-positives (e.g. when thrombi are non-occlusive) and false negatives have been reported using this technique, which justifies over a period of seven to ten days for patients with initial negative results. Success rates for this test have been estimated at anywhere from 65-66% to 92- 98%.

C. Description

Using conductive jelly, the examiner strategically places two or four electrodes on the patient's calf (the four-electrode configuration yields a more uniform and precise current density and consequent measurement result). These electrodes are connected to an instrument called a plethysmography, which records the changes in electrical resistance that occur during the test and produces a graph of the results. The patient must lie down and raise one leg at 30 degree angle so that calf is above the level of the heart. The examiner then wraps a pressure cuff around the patient's thigh and inflates it to a pressure of 45-60 cm of water for 45 seconds[5][6]. The plethysmograph records the electrical impedance that corresponds to change in the volume of blood in the vein at the time the pressure is Exerted and again three seconds after the cuff is deflated. This procedure is repeated several times in both legs. This test takes 30-45 minutes, costs an estimated $50-$100, and results can be available within a few minutes. Impedance plethysmography works by measuring the resistance to the transmission of electrical energy (impedance). This resistance is dependent upon the volume of blood flowing through the veins. By graphing the impedance, the doctor or technician can tell whether a clot is obstructing blood flow.

D. Preparation

Patients undergoing this test do not need to alter their diet, change their normal activities, or stop taking any medications[9][10].

E. Aftercare

The patient may resume normal or postoperative activities after the test.

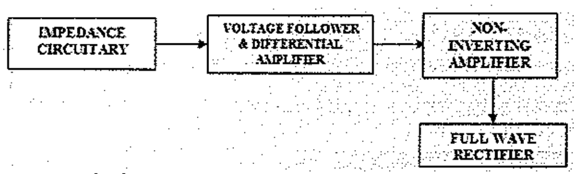


Figure 1. Block Diagram of Impedance Plethysmography

A . The Non-inverting Op Amp

The non-inverting op amp has the input signal connected to its non inverting input, thus its input source sees infinite impedance. There is no input offset voltage because VOS = VE = 0, hence the negative input must be at the same voltage as the positive input. The op amp output drives current into RF until the negative input is at the voltage, V_{IN}. This action causes V_{IN} to appear across RG.

The voltage divider rule is used to calculate VIN; VOUT is the input to the voltage divider, and VIN is the output of the voltage divider. Equation (1) is written with the aid of the voltage divider rule, and algebraic manipulation yields Equation (2) in the form of a gain parameter. When RG becomes very large with respect RF, (RF/RG) Ò!0 equation (1) reduces to equation (2).

$$V_{IN} = V_{OUT} \frac{R_G}{R_G + R_F} \quad \text{------ 1}$$

$$\frac{V_{OUT}}{V_{IN}} = \frac{R_G + R_F}{R_G} = 1 + \frac{R_F}{R_G} \quad \text{------ 2}$$

Under these conditions VOUT = 1 and the circuit becomes a unity gain buffer. RG is usually deleted to achieve the same results, and when RG is deleted, RF can also be deleted (RF must be shorted when it is deleted). When RF and RG are deleted, the op amp output is connected to its inverting input with a wire. Some op amps are self-destructive when RF is left out of the circuit, so RF is used in many buffer designs. When RF is included in a buffer circuit, its function is to protect the inverting input from an over voltage to limit the current through the input ESD (electro-static discharge) structure (typically < 1 mA), and it can have almost any value (20 k is often used). RF can never be left out of the circuit in a current feedback amplifier design because RF determines stability in current feedback amplifiers.

Notice that the gain is only a function of the feedback and gain resistors; therefore the feedback has accomplished its function of making the gain independent of the op amp parameters. The gain is adjusted by varying the ratio of the resistors. The actual resistor values are determined by the impedance levels that the designer wants to establish. If RF = 10 k and RG = 10k the gain is two as shown in Equation 2, and if RF = 100 k and RG = 100 k the gain is still two. The impedance levels of 10 k or 100 k determine the current drain, the effect of stray capacitance, and a few other points. The impedance level does not set the gain; the ratio of RF/RG does.

B. *Voltage follower with Differential Amplifier*

The differential amplifier circuit amplifies the difference between signals applied to the inputs. Superposition is used to calculate the output voltage resulting from each input voltage, and then the two output voltages are added to arrive at the final output voltage. Op amp input voltage resulting from the input source, V_1, is calculated in Equations. The voltage divider rule is used to calculate the voltage, V_+, and the non inverting gain equation is used to calculate the non inverting output voltage, V_{OUT_1}.

$$V_+ = V_1 \frac{R_2}{R_1 + R_2} \quad \text{------- 3}$$

$$V_{OUT1} = V_+(G_+) = V_1 \frac{R_2}{R_1 + R_2}\left(\frac{R_3 + R_4}{R_3}\right) \quad \text{------- 4}$$

The inverting gain equation is used to calculate the stage gain for V_{OUT_2} in Equation[5]. These inverting and non inverting gains are added in Equation.

$$V_{OUT2} = V_2\left(-\frac{R_4}{R_3}\right) \quad \text{------- 5}$$

$$V_{OUT} = V_1 \frac{R_2}{R_1 + R_2}\left(\frac{R_3 + R_4}{R_3}\right) - V_2 \frac{R_4}{R_3} \quad \text{------- 6}$$

It is now obvious that the differential signal, $(V_1 - V_2)$, is multiplied by the stage gain, so the name differential amplifier suits the circuit. Because it only amplifies the differential portion of the input signal, it rejects the common-mode portion of the input signal. A common-mode signal is illustrated in Figure. Because the differential amplifier strips off or rejects the common-mode signal, this circuit configuration is often employed to strip dc or injected common-mode noise off a signal. The disadvantage of this circuit is that the two input impedances cannot be matched when it functions as a differential amplifier, thus there are two and three op amp versions of this circuit specially designed for high performance applications requiring matched input impedances.

C. *The Full Wave Rectifier*

The first building block in the dc power supply is the full wave rectifier. The purpose of the full wave rectifier (FWR) is to create a rectified ac output from a sinusoidal ac input signal. It does this by using the nonlinear conductivity characteristics of diodes to direct the path of the current. If we consider a simple, piece-wise linear model for the diode IV curve, the diode forward current is zero until Bias >= $V_{threshold}$, where $V_{threshold}$ is 0.6 V to 0.8 V. The current increases abruptly as V_{bias} increases further. Due to this turn-on or threshold Voltage associated with the diode in forward bias, we should expect a 0.6 to 0.8 V voltage drop across each forward biased diode in the rectifier bridge. In the case of the full wave rectifier diode bridge, there are two forward biased diodes in series with the load in each half cycle of the input signal. The maximum output voltage (across load) will be V_{in} - 2 $V_{threshold}$, or ~ Vin - 1.4 V. Since some current does flow for voltage bias below $V_{threshold}$ and the current rise around is $V_{threshold}$ is more gradual than the piece-wise model, the actual diode performance will differ from the simple model. In reverse bias (and neglecting reverse voltage breakdown), the current through the diode is approximately the reverse saturation current, Io. The voltage across the load during reverse bias will be $V_{out} = Io\ R_{load}$.In specifying a diode for use in a circuit, you must take care that the limits for forward and reverse voltage and current are not exceeded.

IV. Software Simulation

A. Implementation Of Virtual Instrumentation

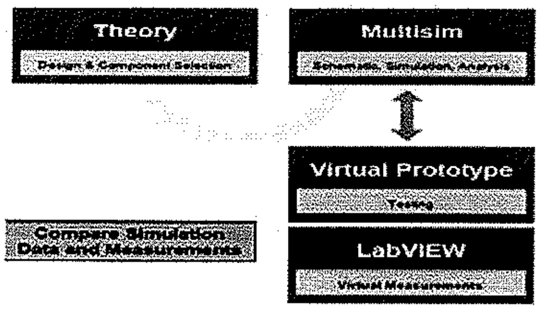


Figure 2. Overview of Simulation

Graphical based schematic capture and integrated SPICE simulation

– Digital and Analog Co-simulation

• Thousands of components immediately ready for simulation

• Create custom components and models

• Virtual Instruments for immediate testing

• Advanced analyses for design validation

Virtual instrumentation allows us to use mainstream computer technologies combining it with innovative software and flexible hardware. This makes it possible for us to develop computer based instrumentation solutions. The concept of virtual instrumentation enables students, engineers and scientists to build powerful applications for increasing productivity and performance by Reduces programming complexity. Virtual Instrumentation also makes way for implementation of ideas forehand to the main interfacing of the project. As a result the margin for errors are reduced, moreover a lot of time is saved as we get to know the behavior of the circuit elements and their output accurately.

B. Multisim interface

Multisim is the schematic capture and simulation application of National Instruments Circuit Design Suite, a suite of EDA (Electronics Design Automation) tools that assists you in carrying out the major steps in the circuit design flow. Multisim is designed for schematic entry, simulation, and feeding to downstage steps, such as PCB layout.

C. Introduction to schematic capture

Schematic capture is the first stage in developing your circuit. In this stage you choose the components you want to use, place them on the circuit window in the desired position and orientation, wire them together, and otherwise prepare your design. Multisim lets you modify component properties, orient your circuit on a grid, add text and a title block, add sub circuits and buses, and control the color of the circuit window background, components and wires.

D. Simulation window of multisim

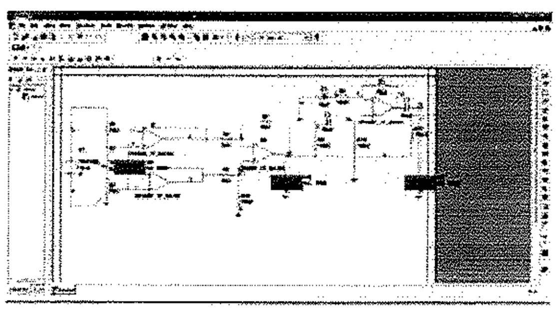


Figure 3. Simulation using Multisim

V. Results and Conclusions

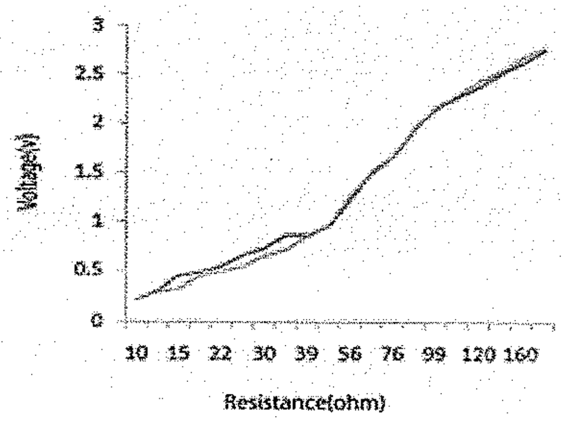
A. RESULTS

Table1: corresponding error is tabulated for the impedance

IMPEDENCE ZΩ	CALCULATED AMPLIFIER O/P V_1 (VOLTS)	MEASURED VALUE V_2 (VOLTS)	% OF ERROR $((V_1-V_2)/V_1)*100$
10	0.221	0.23	-4.07
13	0.31	0.30	3.20
15	0.442	0.34	23.07
20	0.4862	0.45	7.44
22	0.553	0.50	9.58
25	0.663	0.56	15.5
30	0.729	0.66	12.9
33	0.862	0.732	15.08
39	0.862	0.866	-0.46
44	0.972	0.98	-0.82
56	1.23	1.28	-4.06
69	1.518	1.50	1.18
76	1.672	1.68	-0.47
88	1.96	1.98	-1.02
99	2.17	2.19	-0.92
100	2.27	2.31	-1.76
120	2.39	2.45	-2.51
156	2.52	2.56	-1.58
160	2.63	2.69	-2.28
220	2.76	2.79	-1.08

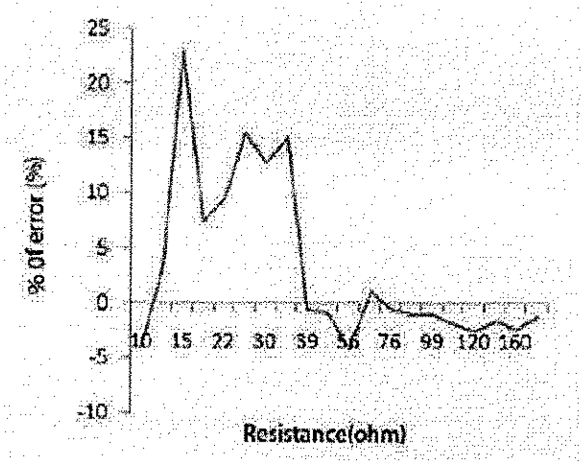
$$\Delta v = \frac{\rho L^2}{Z}\Delta Z$$

Normally, inflating the pressure cuff will cause a sharp rise in the pressure in the calf because blood flow is blocked. When the cuff is released, the pressure decreased rapidly as the blood flows away. If a clot is present; the pressure in the calf veins will already be high. It does not become sharply higher when the pressure cuff is tightened. When the pressure cuff is deflated, the clot blocks the flow of blood out of the calf vein. The decrease in pressure is not as rapid as when no clot is present and the shape of the resulting graph is different, all of which is indicative of obstruction of major deep veins.



Graph 1: Resistance vs. Voltage

Graph 1 is plotted with resistance in x-axis and Voltage in Y-axis. This Graph is Plotted based on the above tabulated readings w.r.t the impedance in ohms and Calculated amplifier outputs V1 and V2.



Graph 2: Resistance vs. % of error

The Graph 2 is plotted with resistance in x-axis and % of error in Y-axis. The Graph is Plotted based on the above tabulated readings w.r.t the impedance in ohms and % of error.

B. Advantages

The Impedance plethysmography method involves the measurement of the electrical parameters of the body and then this value is directly transduced into an equivalent desired value as per our requirements thus the accuracy of the measurement is high. Using water as a medium for displacement lends itself to studies concerned with temperature perturbation that are more difficult to conduct using mercury-in-Silastic strain gauge plethysmography or air plethysmography. One example of such a study is to examine the influence of local temperature changes on predominantly skin blood flow in different body positions. The technique of limb plethysmography has many more applications for both research and teaching. The instrument proves to be robust, accurate, and inexpensive to manufacture in numbers with the assistance of a standard University workshop. Students evaluated use of the plethysmograph positively as an aid to learning.

C. Limitations of the plethysmograph and areas of potential improvement

There are limitations to all experimental techniques and the one presented here is no exception. The main limitation of our simple plethysmograph design is lack of a mechanism to control water temperature, which is known to influence forearm blood flow measurement. Other investigators have built plethysmographs complete with an external water bath into which cold or warm water is added without affecting the volume of water in the plethysmograph proper. This design would, however, complicate the construction procedure tremendously andmake it difficult to produce the device in any great numbers.

VI. Conclusion

Determination of blood flow by finger plethysmography provides a tool for continuous non-invasive assessment of changes in digital blood flow. This project is an alternative way to measure the blood flows in a very accurate manner and it is less expensive. This method will be robust and accurate. This simple plethysmograph design is an alternative to other commercially available equipments. Thus we implemented/simulated the working of this impedance plethysmography in Multisim and we stored the results in Lab view which can be used for the reference later. Finally the obtain P_v was converted into blood flow in ml with respect to length of the vein (e.g. 3ml for 5cm).

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