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# Development of an Electrical Impedance System for Measuring Respiration & Heart Rate

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**Abstract:** Heart rate and respiration rate, two major vital signs, are measure of physiological & mental condition of an individual. In this thesis, a novel technique is described for simultaneous measurement of both the respiration and heart rate using electrical impedance measurements. An electrical impedance measurement device consisting of current drive and voltage measurement circuitry was designed and developed. The current drive circuitry was used to inject an alternating current of 1mA (p-p, constant) at 10 kHz into the thorax through two electrodes. The corresponding voltage drop across two other electrodes were amplified and recorded on a PC after rectifying, smoothing and minimizing noises using filters. Since the applied current was constant, the measured voltage was proportional to the transfer impedance of thorax. The technique developed will have potential application in continuous and automatic monitoring or both respiration and heart rate simultaneously.

**Keywords:** Current Drive, Electrodes, Amplified, Rectifying, Filters, Transfer.

## I. INTRODUCTION

Human bodies consist of a number of biological systems that carry out specific functions necessary for everyday living. These systems act together in a synchronized manner to build the functioning of human body. The biological systems include different parts and the function of that system can be carried out by the coordinated acts of the parts. If any parts give way their task then the system may miscarried their functions. There are some body parts of human which plays role in various biological system of the human body. The circulatory system is an essential biological system of human body, which is also considered as the body’s transport system. It is made up of organs that transport blood throughout the body. Heart is an essential part of the circulatory system of human body [1]. It is also considered as the most energetic organ of human body. Heart is basically a hollow muscular pump (Figure-1). The main purpose of heart is to prompt blood throughout the body. This stream of blood throughout the body provides transportation for oxygen and nutrients to every cell. With each beat of heart blood is sent end-to-end of the body through aorta. Aorta branches into smaller arteries, which then outgrowth into even smaller vessels. These smaller vessels are known as capillaries. At the capillaries, blood reaches nearest to the body tissue and yields nutrients and oxygen to the cell and also takes in carbon dioxide, water and waste from the cell.

After providing the nutrients and oxygen the deoxygenated blood and the waste products collected from the cell carried away from the cell through veins. These veins bring the blood back to the heart, which pumps it to the lungs to pick up oxygen and eliminate waste carbon dioxide. This exchange of oxygen and carbon dioxide at the lung is the part of another biological system of human body, known as respiratory system. Heart rate together with respiration rate is indicative of many diseases. The heart rate can vary according to the body's physical needs, including the need to absorb oxygen and excrete carbon dioxide. Respiration helps us to maintain the quantity of oxygen and carbon dioxide in the body. Electrical impedance of lung tissue changes as a function of air content. In this method, electrical impedance of the thorax was measured using four electrodes placing electrodes on the chest surface. The electrical impedance of the thorax changes during breath in and breath out [2] giving a pulsatile wave shape from which respiration rate was calculated. Since heart is a major organ of thorax, it was assumed that the thorax impedance will change during blood pumping of heart. Intuitively, the changes of electrical properties of heart during blood pumping are relatively smaller compared to that of lungs during breathing.

Therefore it was expected that the impedance variation due to heart beat will be superimposed in the pulsatile wave shape due to respiration. The present work was taken to develop necessary instrumentation for impedance measurement from thorax and to extract the heart rate from the pulsatile impedance variation of human thorax. Simultaneous measurement of respiration and heart rate will be helpful in identifying child pneumonia in the early stage. Electrical impedance of lung tissue changes as a function of air content

[3]. An electrical impedance based respiration measurement system was developed by Parvin S for monitoring neonatal respiration rate without upsetting the baby [4]. A simple respiration measurement system was developed and demonstrated at Dhaka University day'2013 exhibition arranged by the "Department of Biomedical Physics &Technology" [5].

## II. METHODS AND MATERIALS

Respiration is achieved through the mouth, nose, trachea, lungs, and diaphragm. Oxygen enters the respiratory system through the mouth and the nose. The oxygen then passes through the larynx (where speech sounds are produced) and the trachea which is a tube that enters the chest cavity. In the chest cavity, the bronchial tubes (the smaller branches of bronchi, which are also smaller branches of trachea) lead directly into the lungs where they divide into many smaller tubes which connect to tiny sacs called alveoli. The lungs also contain elastic tissues that allow them to inflate and deflate without losing shape and are encased by a thin lining called the pleura. The chest cavity or thorax is the airtight box that houses the bronchial tree, lungs, heart, and other structures. The top and sides of the thorax are formed by the ribs and attached muscles, and the bottom by a large muscle called the diaphragm. The chest walls form a protective cage around the lungs and other contents of the chest cavity.

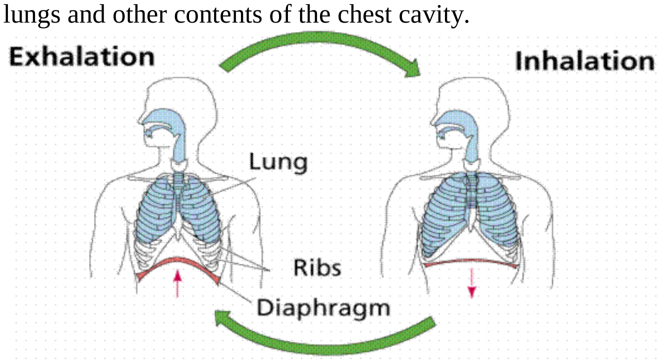


**Fig.1. Diaphragm Position for Inhalation & Exhalation.**

The diaphragm, which separates the chest from the abdomen, plays a lead role in breathing. When we breathe out, the diaphragm moves upward (Fig.1), forcing the chest cavity to get smaller and pushing the gases in the lungs up and out of the nose and mouth. When we breathe in, the diaphragm moves downward toward the abdomen (Fig.1), and the rib muscles pull the ribs upward and outward, enlarging the chest cavity and pulling air in through the nose or mouth. Air pressure in the chest cavity and lungs is reduced, and because gas flows from high pressure to low, air from the environment flows through the nose or mouth into the lungs. The movement of the diaphragm and the volume of the air intake will give rise to the chest impedance. Every time we breathe in or breathe out, the volume of air in the lung will vary. These variations will also give a variation in the chest impedance. As we know the heart is also situated at the thorax. Pumping or beating mechanism of heart involves the contraction of heart muscles. Blood from the body enters the right atrium through the inferior and superior vena cava. Blood from the lungs enter the left atrium through the pulmonary vein. The heart beat is initiated and maintained by special muscle cells known collectively as the pace maker or sinoatrial node.

The pace maker is ideally placed in the muscle of the right atrium. The pacemaker sends a wave of excitation through the muscles of the right atrium and to the muscles of the left atrium. The excitation results in the contraction of both atria (plural for atrium) at the same time resulting in blood rushing across the tricuspid and bicuspid valves into the right and left ventricles. The wave of excitation travels across the bundle of his in the septum. The wave of excitation then reaches the ventricles which cause contraction at the same time. The tricuspid and bicuspid valves are both closed during contraction of the ventricles causing blood having reached the ventricles, to be forced into the aorta from the left ventricle, and into the pulmonary artery from the right ventricle. These flows of blood through the heart will also arise some variation in the chest impedances.

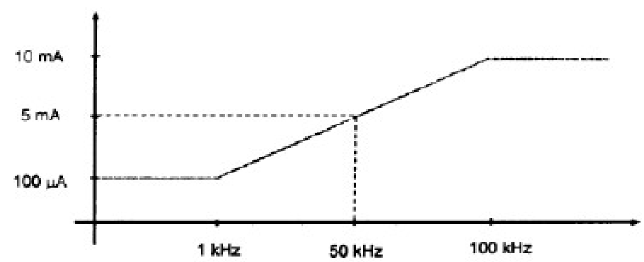


**Fig.2. Permissible Current through the body.**

From the Fig.2, we can assume an ac current of mA at the order of few KHz is acceptable for biomedical measurements. I have chosen an ac current of 1mA (P-P) [5 & 6] at a frequency of 10 KHz. The basic idea is to measure the variations in chest voltage, (Fig.3) which will give us the variations in impedance at that place using the Ohm's law. To measure impedances using Ohm's law we need a system which will measure the voltage across area and the current flow through that area. In that case we can provide a constant current and measure the voltage or provide a voltage source and measure the current. But due to the large variation in contact impedance and the constant current source will be appropriate for any non-invasive [7] biological measurement system [7 & 8]. The system consists of a constant current source and the potential measured in response to the constant current passed through the tissue. The potential is directly proportional to its impedance [9].

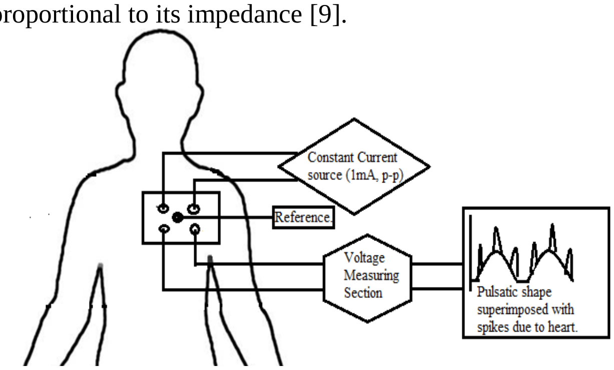


**Fig.3.Basic Idea of the project.**

The constant current block shown in Fig.3 consists of an oscillator circuit and in order to keep the current constant against a large and variable impedance of biological tissue a Howland current source [10 & 11] is used. But the voltage measuring sections includes the following parts shown in Fig.4.

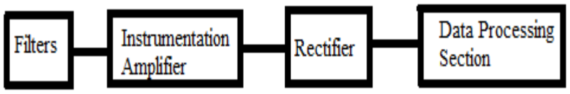


**Fig.4.Voltage measuring Section.**

We have assumed the minimum respiration rate as 5/minutes and the minimum heart rate [5] will definitely be higher than the value of respiration rate. The respiration frequency = 5/60 = 0.083. The cut-off point [12] for the high-pass filters are chosen according to the respiration frequency. And the low-pass frequency parameters are chosen keeping in mind that the maximum heart rate [13] of an individuals. And the gain of the amplifier is chosen [14] as a variable one to cover a large variation as shown in Fig.5.

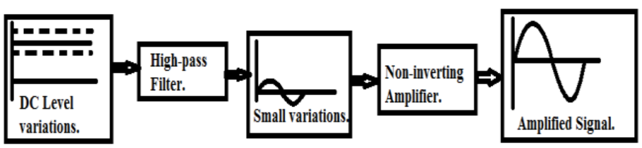


**Fig.5.Data Presentation section.**

## III. RESULTS

The electrodes are placed in a rectangular arrangement at the left side of the chest (as the position of the heart is slightly left side from the midline of the thorax. We have placed the electrodes are placed at a separation 5cm (Fig.6). The electrodes are placed in such a manner that, the current injecting electrodes are placed side by side (5cm separation [9]) and the voltage measuring electrodes are placed 5cm below the current injecting electrodes. There is another electrode placed in between the electrode, which is the reference electrode. The readings are taken keeping the subjects steady and relaxed in a chair.

**Fig.6.Experimental set up.**

After the device is properly grounded, the electrodes are placed at the chest surface of the subject. At first the heart rate and respiration rate of the subject are measured manually. The observed responses corresponding to the subjects are as follows as shown in Figs.7 and 8.

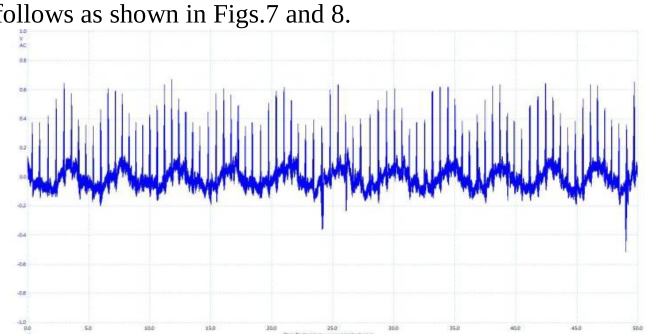

**Fig.7. Observed variations (Subject-1).**

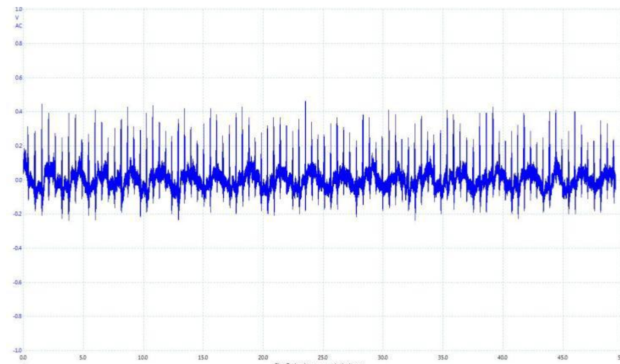

**Fig.8.Observed variations (Subject-2).**

The results obtained from the experiment are compared with the results manually observed. The observed variations in impedances signals are very noisy. But in order to get respiration rate and heart rate separately from the observations the noises should be reduced. In order to reduce the noises some modifications can be made, which will be effective to eliminate the noise in such a manner that we can perform FFT and calculate the respiration and heart rate separately. To observe the system response we have used picoscope (an USB based oscilloscope). And in order to avoid the 50Hz noises, a laptop is used. And the observed variations may also include the ECG spikes (Fig.9). It will also make an additional application but it will also introduce some noise.

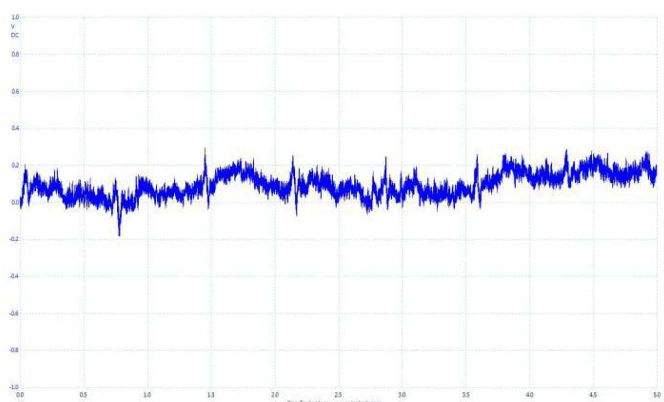

**Fig.9.ECG spikes.**

The position of heart is a major concern for the project. The heart & lung both are located at the thorax but they are not exactly in the same place. While we placed the electrodes in a smaller region, the heart contributions in impedance variations[15] are pretty much higher than the lung contribution. While we considered a larger region), the lung contribution in impedance variation is higher than the heart in that larger area.

## IV. CONCLUSION

The Heart rate measurement from the respiration measurement system proposed and established in this paper is developed keeping the view in mind that a system, which will provide more accuracy, greater flexibility and cost effectiveness over the conventional systems. Also the less hardware system will provide greater reliability over time. This paper aims to demonstrate the idea based on technological and biomedical issues as designing of a new heart rate measurement system. There are many research works performed on the issue of heart rate and respiration rate measurement. But the idea of an alternate method, which may provide information on both heart rate and respiration rate simultaneously, may bring about a great achievement on the field of medical science and technologies. A variety of physiological needs have to be met in order to remain healthy and these includes maintaining the right amounts of oxygen and carbon dioxide in the internal environment and maintaining the right volume of fluids which contribute to sustaining blood pressure. Both cardiovascular and respiration are very important physiological parameters for human body. The proper functioning of these two systems ensures the proper maintaining of other organs. Developing a measurement system providing information on both cardiovascular system and respiration process of an individual will bring us the physical and mental condition of that individual.

The components used on the system are based on the basic knowledge on electronics. The idea was to measure the impedance variations at chest due to the passage of blood through the heart and the air density at the lung. Measurements of impedance using Ohms law associate with a current and voltage. Here keeping the current constant the voltage variations are measured. These variations further processed using the software provides us the information associated with the variations. Biomedical signals are associated with large noise contributions. Detecting a small variation from comparatively large and different types of changes is concerned with the signals. Proper filtering and amplification are required on that purpose. As concern with the medical instrumentation, the patient’s safety is a major concern. So, further modifications will be required to get the proper information along with user’s safety. The equipment used in the developed system requires less maintenance and also very cost effective for the people. The further research on the project will provide a great advancement on the field of biomedical engineering. This also provides a great opportunity on diagnostic purpose for both third world countries and developing countries.

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