Polygraph-Multichannel Recorder that Displays Physiological Changes during Interrogation using Mat Lab

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Abstract:
The polygraph instrument usually measures three to six physiological reactions recorded by three different medical instruments that are combined in one machine. This machine, plots in real time several human biological signals such as pulse rate, galvanic skin resistance (GSR), blood pressure, and breathing rate while the subject is asked and answers a series of questions. This machine, in conjunction with a certified examiner, is then used to analyze a subject’s stress during interrogation with the intent of distinguishing truth from lying. This paper explains constructing a polygraph which measures pulse rate, GSR, and breathing rate. The measurements will be sampled, analyzed, and transmitted to a computer for further analysis using an ARM7 microcontroller-LPC 2148 and the obtained results are plotted using Mat lab.

Keywords: Polygraph, Pulse Rate, Galvanic Skin Resistance (GSR), Blood Pressure, Breathing Rate

I. INTRODUCTION

A polygraph (popularly referred to as a lie detector) is a recording unit which helps the polygraph examiner to decide whether a person is truthful or deceptive regarding a specific issue. Various components are placed on the body of the person being examined thereby connecting him to the polygraph instrument. The components are equipped with sensors to measure and record the physiological indices such as blood pressure, pulse, respiration, and skin Conductivity while the subject is asked a series of questions and is answering them. The belief underpinning the use of the polygraph is that deceptive answers will produce physiological responses that can be differentiated from those associated with non-deceptive answers. The polygraph instrument along with its components is used to collect the physiological data from three major systems which are: The cardiovascular system, the respiratory system and the endocrine system. Skin conductivity (also called electro dermal response or Galvanic Skin Response, GSR) is thought to be an indicator of psychological, emotional or physiological arousal. Respiration in polygraph equipment is typically monitored using pneumatic pressure gauges. The process of breathing stretches abdominal and thoracic gauges and produces variations in air pressure within the gauge which are then captured by an air pressure sensor within the polygraph. Piezoelectric or capacitive breathing sensors incorporated into elastic belts could also be used.

Hardware and Software Requirements

A. Hardware

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B. Software

- Kiel C
- Terminal v1 9b
- Mat lab

II. LITERATURE SURVEY

[1] Tim Balgemann, et.al published how to measure blood resistivity. The blood cells are aligned under high blood flow and under low blood flow and its relation to the impedance. The voltage measurements will vary depending upon physiological changes in the blood and due to the blood pulse itself. It is expected that these measurements will be very small. In order to observe and analyse the signal obtained from the electrodes, the voltage output is passed to a circuit that amplifies and processes the signal. This output signal can be used to calculate the impedance and resistivity of the blood in the finger.

[2] Jorn Bakker, et.al explained that since the GSR module deals with skin response, the reaction to stress factors is governed by the autonomous nervous system. We learnt how to detect changes in stress levels from the GSR sensor data. The paper gave us illustrative examples of noise and other factors affecting the GSR signal and this helped us to design our circuit in such a way that the noise levels can be minimized to the maximum possible extent.“Ideal” noise-free GSR data may be insufficient for accurate determining the level of stress. This suggests that the reliable translation of physiological data gathered by using sensor technology into the “stress level rates” is only possible when additional sources of information are available. Understanding these concepts we were able to understand expected waveforms and output voltages.

[3] Sinha Akarsh, et.al, explains that the Polygraph tests are used mainly by law enforcement agencies to detect deceptions. Many parameters such as blood pressure, pulse, respiration, skin resistance have been used as indicators. We learnt how to interface two simple analog circuits with MATLAB through a low cost microcontroller board for continuous monitoring of the parameters i.e. Galvanic Skin Resistance and Heart Rate.
et al., published the overall working of the polygraph and how the blocks are correlated with each other. This paper also describes an Electronic and Electromechanical Tester (EET) for physiological sensors that allows for accurate and repeatable reproduction of the recorded or computer-generated physiological signals. The tester is interfaced to a personal computer via USB and contains three time-synchronous channels: two electromechanical simulators for testing abdominal and thoracic respiratory sensors, and an electronic simulator for testing electro dermal sensors. All of the simulated physiological channels apply direct physical actuation to the corresponding sensors. This helped us understand how we have to interface our hardware to the PC/Laptop.

RutujaLulkar, NiveditaDaimiwal, explains the importance of optical plethysmograph. The PPG (Photo plethysmography) sensors, are capable of measuring blood volumetric changes in the subcutaneous vessels. Reflectance type of PPG sensor has been used to diagnose the parameters. It helped us understand that detailed analysis of frequency spectrum (FFT) of PPG signal shows a cardiac peak around 1Hz corresponding to 60 pulsations a minute and respiratory peak around 0.25 Hz corresponding to 15 inspiration/expiration cycles per minute thus helping us to understand the cardiovascular system so that we could understand what outputs were expected to obtain to make out our connections were right.

III. DESIGN METHODOLOGY

Block Diagram

![Block diagram of Polygraph](Image)

Working Principle

The polygraph helps to detect whether deceptive behavior is displayed. As seen in figure 1 it is basically a combination of devices in order to displays measurements of heart rate, blood pressure, respiration and perspiration in the fingers. When a person lies or is asked a sensitive question, his or her heart may begin to race, raising the body's blood pressure. The test subject may also hold his or her breath, take in a deep breath, or begin to sweat. These physiological irregularities are detected by the polygraph and interpreted. The measured data or outputs can help decide whether or not sudden changes in the data signify dishonesty. The basic design of the polygraph is shown in the Figure1. The analog circuits: plethysmograph (pulse rate meter), GSR meter, and breathing rate meter, are combined to monitor changes occurring in the body. The outputs of these blocks are then attached to the pins of the ARM7 LPC2148. The microcontroller samples these signals and displays them on an LCD. and the output is checked on the oscilloscope, the corresponding analog voltages are noted down. These signals are sent serially to the PC using RS232 and this will then serve as an input to the MATLAB program with the help of which we will simulate and plot the values.

- **Finger Plethysmograph**

A plethysmograph is an instrument for measuring amount of blood in part of the body. The signal from the finger sensor is quite weak on a large baseline of voltage from scattered reflection from the surface and from all depths within the finger. For this reason, using this signal requires an AC coupled amplifier with a high gain. Using high blood flow, the blood rushes through the finger and the red blood cells (RBCs) align as shown in figure 2b. As these cells are aligned it provides a low resistance path for the current which passes through. During lower blood flow the RBC’s tend to clump together or misalign as shown in (Figure 2a). In this situation the current cannot pass through easily as there is more resistance offered thereby increasing the impedance. It is these impedance and resistivity values that will help us to observe and analyze the signal obtained from the middle electrodes.

- **Galvanic Skin Resistance Meter**

Galvanic Skin Response (also commonly referred to as electro dermal activity (EDA) or Skin Conductance). EDA modulates amount of sweat secreted from the sweat glands. Skin conductance varies with respect to emotional stimulation. Any extremities of emotional arousal (happy or sad) can cause an increase in the skin conductivity. This response is basically a phenomenon where the skin becomes a better conductor of electricity in the presence of externally or internally occurring physiological stimuli. This phenomena is most often measured by placing two electrodes on two adjacent fingers and measuring the voltage in response to a small injection current that runs between the two electrodes across the skin of the palm of the hand where many of the most emotionally reactive sweat glands are found. The NIOSH states “Under dry conditions, the resistance offered by the human body may be as high as 100,000 Ohms. Wet or broken skin may drop the body's resistance to 1,000 Ohms.” adding that “high-voltage electrical energy quickly breaks down human skin, reducing the human body's resistance to 500 Ohms.” To summarize A Relaxed state means High skin resistance or Low electrical conductivity and Stressed state means Low skin resistance with High electrical conductivity.

- **Conductance Instead Of Resistance**

The reason for using conductance instead of resistance lies in the understood model for skin conductivity. As perspiration increases, more sweat glands begin to conduct electricity in a given area of skin as shown in Figure 3. The electrical formula for calculating parallel resistance is: 1/(total resistance)= 1/(resistance1) + 1/(resistance2) etc. whereas for parallel conductance it is: total conductance = conductance1 + conductance2 etc. which is easier to calculate then resistance. The unit for skin conductance is micro Siemens.
To measure skin conductance, a very small voltage is applied across these electrodes (0.5V). By measuring the current that flows, conductance can be measured using Ohm’s law which is the measured current by the applied voltage. By virtue of the Galvanic Skin Response, autonomic nervous system activity causes a change in the skin’s conductivity. Higher arousal (such as occurs with increased involvement) will almost instantaneously (0.2 - 0.5 sec) cause a fall in skin resistance, reduced arousal (such as occurs with withdrawal) will cause a rise in skin resistance.

Breath Rate Meter
The respiratory monitor is designed for low-resource environments. The device calculates a patient’s breathing rate by detecting changes in temperature when the patient breathes through a mask. The respiration rate is measured by using an analog comparator (AC) to compare the amplified voltage across the thermostat to a reference voltage. Since the respiratory signal is approximately equivalent to a sine wave with a DC offset, we choose the reference voltage to be at the DC offset.

ARM Microcontroller

As shown in figure 4, the ARM architecture is a 32-bit RISC processor architecture developed by ARM Limited that is widely used in embedded designs. Because of their power saving features, ARM CPUs are dominant in the mobile electronics market, where low power consumption is a critical design goal.

LPC2148
It is the widely used IC from ARM-7 family. It is manufactured by Philips and it is pre-loaded with many inbuilt peripherals making it more efficient and a reliable option for the beginners as well as high end application developer.

Liquid Crystal Display
A Liquid Crystal Display is a special thin flat panel that can let light go through it, or can block the light. (Unlike an LED it does not produce its own light). The panel is made up of several blocks, and each block can be in any shape. Each block is filled with liquid crystals that can be made clear or solid, by changing the electric current to that block. The LCD uses technology called electro-optical modulation. This means it uses electricity to change how much light passes through it.

Com port development tool
Terminal is a simple serial port (COM) terminal emulation program. It can be used for communication with different devices such as modems, routers, embedded micro controller systems, GSM phones, GPS modules... It is very useful debugging tool for serial communication applications.

TCP/IP Remote Control
Terminal can also act like telnet server and listen on selected TCP port. You can connect to it with any telnet client program from another computer in network (or over internet from different location) and see what's going on in terminal and send commands etc.

IV. DESIGN IMPLEMENTATION

4.1 Plethysmograph

4.1.1 Circuit Diagram
amplify the measured voltage and to filter noise that corrupts the signal. Hence we have employed two stages of amplification. The signal is amplified by the pre-amplification stage and sent to a rectifier stage. The rectifying stage uses a 1N4001 diode to create a half-wave rectifier with a ripple to peak ratio of 0.1V/mV. The rectification is done basically to eliminate the envelope of the high frequency components. The resulting DC signal contains the low frequency changes in voltage that are to be further amplified.

4.1.3 Design
As shown in figure 4.1, the amplifier has a low pass filter to capture the heart rate, which occurs at a frequency as low as 2.3-2.4Hz. Hence we choose $R_f=1\, \text{M}\Omega$ and $C_f=68\, \text{nF}$ we get 2.34 Hz. We use two amplifier stages each having a gain of 100. Since they are non-inverting amplifiers we choose the feedback resistance to be $1\, \text{M}\Omega$ and the input resistance to be $10\, \text{K}\Omega$. The 10K pot is used to control the gain of the system and prevent clipping on large signals.

4.2 Galvanic Skin Resistance (GSR) meter

4.2.1 Circuit Diagram

![GSR Meter Circuit Diagram](image)

Figure 7. Circuit diagram of GSR Meter

Figure 7 gives us the circuit diagram of the GSR meter. Direct current measurements do not provide information about the capacitive properties of the tissue that is discussed in almost any electrical model of the skin.

![Simplified electrical model of the skin](image)

Figure 8. Simplified electrical model of the skin

Such an electrical model is shown in Figure 8. The capacitor $C$ represents the insulating layers of the stratum corneum, and the parallel resistor $R_1$ corresponds to the current path through the sweat gland ducts. $R_2$ represents the resistance of the deeper skin layers and is relatively small. Human skin conductance values are supposedly only linear when voltages applied are below 2.5V. So we used a voltage divider to bring the bridge Vdd voltage to 2.5V. This ensures that the highest voltage across the user would never exceed 2.5V. Probes are connected in parallel across one of the resistors, so when resistance changes the output voltage will also change. The resistances are chosen to be $1\, \text{M}\Omega$. The $0.1\, \mu\text{F}$ capacitor is a smoothing capacitor to remove the 50Hz induced mains hum. The fundamental frequency of this sound is usually 50 Hz or 60 Hz, depending on the local power-line frequency. The sound often has heavy harmonic content above 50-60 Hz. The human body acts as an antenna and the received waves are seen on the scope. The person’s skin acts as a resistance to the passage of electric current. The Galvanic skin resistance oscillates between 10K-10MΩ.

4.3 Breath rate Meter

4.3.1 Circuit diagram of Breath rate meter

![Breath rate Meter Circuit Diagram](image)

Figure 9. Circuit diagram of Breath rate Meter

Figure 9 gives the circuit diagram of the Breath rate Meter. The components are designed based on the criteria mentioned in the next section.

4.3.2 Design Principle

1. Thermistor Measurement

As shown in figure 10. We used a thermistor based measuring system to measure the breathing rate of the patients. The thermistor is mounted inside a mask which is worn by the patient. As the patient breathes the hot air from the patient’s breath changes the resistance ($R_{th}$) of the thermistor. As a result, the voltage across the thermistor ($V_{th}$) will also change proportionally to how the patient breathes. We can therefore use $V_{th}$ as an indirect measurement of how the patient is breathing. To measure $V_{th}$ we used a voltage divider as shown below in Figure 4.5.

![Voltage divider to measure $V_{th}$](image)

Figure 10. Voltage divider to measure $V_{th}$

When the thermistor is at room temperature its resistance is approximately 100 kΩ so we choose $R_1$ to be 100 kΩ. This was chosen so that $V_{th}$ would be about 2.5 V if no one was breathing on the thermistor. We wanted to have 2.5 V be our no breathing voltage so that extreme inhalations or exhalations could be detected with our device.

2. Thermistor Amplification

The thermistor we choose for our project has a thermal time constant of 5 seconds which makes it extremely sensitive. During experimentation we found that the change in voltage from a person breathing on the thermistor was on the order of 10 mV. Since this was too small a change to work with we decided to amplify this change by using an Op Amp with a high pass filter. An Op Amp alone will not suffice because it will amplify the entire signal whereas we only want to amplify the change in voltage. Literature research shows that the average adult male breaths about 15-20 breaths/min and the average infant breaths about 30-60 breaths/min. Our slowest
desired period is about 4 seconds. We choose the time constant for our high pass filter to be 22 seconds. This means that any signal with a period less than 22 seconds will be amplified by our op amp. Using these values we calculated the frequency to be 0.04825(1/(2πRC)). Hence we get a time period of 20.7 seconds, approximately equal to 21 breaths.

3. **Voltage Measurements**

Under battery operation, our device takes a voltage sample across the battery about every minute. Since our device uses a power supply of 5V, a voltage divider is used to drop the voltage so that it is about 2.5V. (100K/ 100K+ 100K)* 5V=2.5V.

4. **DC offset**

Since the respiratory signal is approximately equivalent to a sine wave with a DC offset, we choose the reference voltage to be at the DC offset. However, patients of different ages will have different steady state breathing temperatures, and thus DC offsets. Our circuit produces the DC offset using the two diodes, hence 1.4V is the DC offset.

5. **Power**

Our device can be powered through a standard AC power supply.

4.4 **Interfacing LCD with LPC 2148**

![Figure 11. LCD interface with Microcontroller](image1)

Figure 11 shows the LCD interface with the Microcontroller. The 16x2 LCD is widely used and easily available in market. It has total 16 pins which can be divided into three categories.

1. Power Control pins: 1,2,3,15,16
2. Control Pins: 4,5,6
3. Data Pins: 7 to 14

LCD can operate in two modes.

1. **Command Mode**: In this mode, RS pin is at logic 0 and the data on pin 7-14 represents the command which specifies the actions to be performed like clear LCD, go to home position, blink cursor etc.

2. **Data Mode**: In this mode, RS pin is at logic 1 and data on pin 7-14 represents the data to be displayed on LCD. LCD is slow compared to Micro-controllers and it needs time to perform the operations. To avoid this, LCD has one method known as busy flag. In this, MSB of data pins i.e. Pin 14 is used as busy flag. Once LCD will start performing and actions, it will raise pin 14 high to indicate that it is in busy state. Once the operation is completed, it will bring it down. Controller must check the status of pin 14 before sending further data or command to avoid any loss of data. Here it is necessary to read pin 14 and R/W has to be made high to read. We can save 1 controller pin here. Although LCD is slow, it is able to finish execution of command within few machine cycles. So after giving any command or data, if we provide delay of few microseconds, LCD will finish its task within that much time. So we don’t have to read status of pin14 and we can permanently ground it and save controller pin. Another option is to use LCD in 4bit mode. Here the data will be sent in two nibbles instead of a complete byte at a time. In this, only higher nibble of data pins has been connected with controller and pin 7-10 of LCD are in NC state. In this way, we need only 6 pins (4 bit data bus, RS and E) are required for LCD interfacing.

**Software Module**

**Algorithm for C code and MATLAB**

The following C code is written using Kiel Vision.

- Since we are interfacing the hardware modules to the ARM7-LPC2148 microcontroller we need to write the code for Analog to Digital Conversion.
- In the next step we are interfacing the LCD to the Microcontroller.
- The main program is then written for displaying the values we want on the LCD.
- This has to be established using UART communication where we specify the port, the baud rate.

**Analog to digital conversion.**

1. Initializes the ADC0 Module; Sampling of Analog values according to clkd/4 parameter.
2. Power on the A/D converter 0 and configure the A/D control register of A/D 0.
3. Reads the specified channel and gives an equivalent digital data.
4. Stop the conversion by masking the start bits.
5. Extract the Digital value.

**LCD interface**

1. Initialize D4:D7 pins as output.
2. Initialize RS and EN pins as output.
3. Using the Basic commands for LCD, configure the LCD for displaying the data.
4. Takes string/character/integer/float value on the LCD.
5. Using the inbuilt commands moves the cursor on the LCD to specified position by X and Y.
6. A delay is introduced between each display configuring for the 12 MHz crystal.
7. Clear the screen.

**Main program for displaying the values**

1. Set jumper JP2 to connect RXD0 and TXD0 to RS232.
2. Assign Analog In to P0.28.
3. Assign Direction register bits.
4. Select the appropriate channel and convert the value to volts using \(Val = \frac{(Val*3.3)}{1023.0} \) for ARM 7 microcontroller and \(\frac{1024}{1023.0} \) for conversion to decimal value.
Move the cursor to the specified x and y position, display the string and equivalent voltage on the LCD.

Generate few millisecond delays between each display.

**UART program**
Since there are 2 UARTs initialize the ports setting the baud rate and number of bits and then write functions to send character and string.

**Algorithm for MATLAB**
1. Set the parameters for the axis to plot the Pulse rate, Breath rate and GSR values.
2. Take the input values and generate the waveforms for the various conditions.
3. Use the LMS algorithm to filter the values from the noise content and plot them.

**V. RESULTS AND DISCUSSION**

**Plethysmograph**
Impedance Plethysmography can be used to measure arterial volume change that occurs with propagation of the blood pressure pulse in a limb segment. For this measurement, we assume a constant value of blood resistivity that may change under both physiological and pathological conditions. The changes seen are very marginal (10mV range). The output voltage depends on factors such as the finger being used, ambient lighting etc.

**Figure 12. Output of Plethysmograph.**

When the finger is placed in between the IR LED and the photo diode, the resistance of the diode varies with the intensity of light hitting it, and this intensity depends on the amount of blood in the finger. This change in resistance is transduced into a change in voltage, and in its raw form the voltage range is 0 to 2.5 volts. As shown in figure 12 we have got a output of 1.06 V.

**GSR Meter**
The measurement of sweat, is scientifically known as the measurement of galvanic skin resistance. To measure skin resistance, we attach two electrodes across the 1MΩ resistor. The subject under questioning makes contact with these electrodes with the tips of his middle and ring fingers, and a reading can be taken. Dry skin is not a very good conductor of electricity. If a subject perspires, however, the water and salt from the sweat reduces the resistance of the skin. This decrease in resistance allows a larger amount of electric current to travel along the surface of the skin. Therefore, the voltage recorded by the voltmeter reflects the amount of sweat that was produced in the subject's fingertips. This voltage is also called as **Galvanic skin potential (GSP)**. This voltage varies with the emotional state of the subject.

**Figure 13. a. Output with dry finger (Person is telling the truth)**

**Figure 13. b. Output with wet finger (Person is lying)**

The following points can be concluded from our results. The resistance and conductivity are inversely proportional. That is when the resistance decreases, conductivity increases. As shown in figure 13a normal skin (in calm mood) has high resistance and low conductivity hence the output voltage will be high. As shown in figure 13b when the blood flow to the skin increases in stress, blood vessels becomes leaky and water leaks out to form the sweat. This mechanism removes heat from the body through the evaporation of sweat. When this happens, the resistance of the skin decreases to remove water easily. The moist skin also increases electrical conductivity and hence the output voltage will decrease. This aspect is used in the circuit. That is, skin's resistance and conductivity are directly proportional to the emotional state. In general a **Calm mood** means the person is relaxed, hence there is: Less adrenaline, low blood flow to skin, high skin resistance, low conductivity, and a **Stressed mood** means there is high adrenaline, increased blood flow to the skin, low skin resistance and increased conductivity.

**Breathing Rate Meter**
We connect a thermistor (a thermal resistor that changes resistance depending on its temperature) to the circuit board. This device measures the differing temperatures of the subject's breath. As the body becomes stressed, respiration quickens, temperature rises and the thermistor will measure the increase in temperature.

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http://ijesc.org/
During Exhalation breath will be heavy or hot air. The conductivity in a thermistor increases (resistance decreases) very sharply as the temperature is raised. This is because the conductivity is mainly by flow of electrons. Rising temperatures because increasing numbers of electrons to break free of the bound state so you get rapidly increasing conduction. Hence as shown in figure 14a during exhaling the output voltage is less when compared to voltage during inhalation. During Inhalation, the air around thermistor is cooler. In the cold state the electrons are mainly confined to bound states in the atoms and so cannot move, so no current. Hence as shown in figure 14b we get a higher output voltage.

Serial Communication

Serial communication is achieved using the Terminal v 1.9b software development tool. As shown in the figure we have achieved serial communication from the board to the PC. This will be very useful for the future scope of our project. With the use of the SR-830 lock-in amplifier we can achieve the communication between PC and board, further using these signals we can plot the real time signals in MATLAB.

Our outputs in MATLAB

After measurement, the pulse and GSR and breath signals are plotted in a MATLAB figure Breath rate signal.

The Breath rate signal is a continuous signal, so it is plotted using the comet function, plot and legend functions. The above screen shot shows two plots, one in the presence of noise and the second signal is plotted by filtering the signal. That is, when the subject breathes in, the voltage is high, when the subject breathes out, the voltage is low. So when there is a peak in voltage, it indicates that the subject took a breath. To filter the signal from noise we use the Least Mean Square (LMS) algorithm. It uses the linear adaptive filtering algorithm which consists of the filtering process and an adaptive process. It will calculate the error signal which is the deviation of the obtained output signal from the expected output signal. This error signal will be the noise which can then be eliminated. In order to plot both the graphs we use the draw now function(which updates the figure) and hold on function to retain the previous plotted graph.

GSR signal

The GSR signals are not periodic. Using the voltage divider and parallel resistance laws, we determine the skin resistance and hence determine the conductivity and output voltage. Using the output voltage the waveform is generated. It is
plotted using the plot, legend and comet function. This graph also uses the draw now and hold on functions of MATLAB.

**Plethysmograph**

![Plethysmograph plotted in MATLAB.

As shown in figure 18 the plethysmograph or pulse rate is calculated in a similar fashion to the breath rate. However in this case, the window is narrower since a person's pulse rate is faster than a person's breath rate. In this case, a high voltage indicates a heartbeat. This graph uses the comet, plot and legend functions of MATLAB.

**VI. FUTURE SCOPE AND CONCLUSIONS**

We have implemented the polygraph using three modules which are Plethysmograph, GSR meter and Breath rate meter. Since our project can be implemented in real time applications, the future scope of our project would be to add an audio module. Since the changes in the measurements of the output voltages will be minimal the project may be improved by using a lock-in amplifier for amplifying these outputs above noise level. These outputs of the lock in amplifier can be sent to MATLAB using RS-232 and the waveforms can be plotted in real time. Since the lock-in amplifier is very expensive we found out how the expected waveforms should appear in real time and we wrote the code in MATLAB to achieve the waveforms using our output values as reference.

**VII. REFERENCES**

[1]. Tim Balgemann, Sarah Offutt, Lucas Vitzthum and Josh White “Finger plethysmograph to measure blood resistivity”.


