Pulse Transit Time Measuring Device

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Abstract

Sleep apnea is a disorder affecting many children, causing them to awake from sleep in order to unblock their airways. Pulse transit time is used to detect the presence of the disorder and its severity. Currently, only tests conducted in sleep labs can test for sleep apnea and record its affects on the body. The work on this project will be in improving a device created by a previous engineering group that measures pulse transit time. The ultimate goal of the is to create a device that can be taken home from the hospital and operated by the family to help record the affect of the disorder on their children.

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Background Information

Sleep Apnea

Sleep apnea is a sleep disorder in which the patient pauses in breathing during sleep. The word apnea refers to the pausing of breath, and each apnea could last from 10 to 30 seconds, thus a breath could be missed. This problem could occur repeatedly during a night of sleep, lowering the sleeping quality. Patients experience symptoms such as snoring and restless sleeps. Moreover, they would have poor day performance, loss of concentration, anxiety and other negative health effects. Researchers have shown that people who are over the age of 40 are at higher risks of sleep apnea. However, it can affect people at any ages.

This sleep disorder has three different forms of apneas – central sleep apnea, obstructive sleep apnea and mixed sleep apnea. The central sleep apnea causes paused breath by the lack of effort in breathing. This is due to the failure of neurons in sending signals to indicate inhalation. In effect, the level of oxygen delivered to tissues decreases and not enough oxygen is available for cell respiration. On the other hand, obstructive sleep apnea is where the air path inside the throat is blocked by an object, such as the tongue. As the muscles relax during sleep, the airway collapses and the patient enters a light sleep stage or awakening. Most patients suffering from obstructive apnea have trouble getting into a deep sleep state. Even though the light sleep time maybe numerous, it is still not as effective as deep sleep. Next, mixed apnea is the combination of central and obstructive sleep apnea. While obstructive sleep apnea takes place during sleep, central sleep apnea is often developed. Patients experience problems breathing and constantly wake up from sleep as a result of long term obstructive apnea.

The direct result of the paused breaths in sleep apneas is the decrease in oxygen concentration inside the blood. Furthermore, the level of carbon dioxide would increase. The worst-case scenario is when the oxygen level becomes so low that causes brain damage, and eventually leads to death.

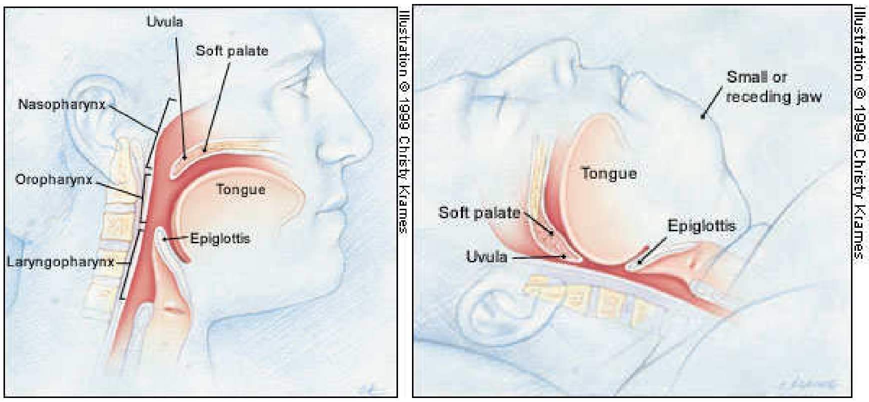


Figure 1: The left figure shows a normal trachea opening. The right figure shows that of a person who has multiple obstructions.

Pulse Transit Time

Pulse transit time is a noninvasive method of measuring respiratory changes in children with breathing sleep disorders (Smith et. al., 2003). Pulse transit time is measure as the time it takes for the blood to go from the heart to the periphery. It is measured by use of both an ECG machine and a pulse oximeter. An ECG machine generates a curve based on the depolarization of the heart while the oximeter measures the pressure wave, or pulse, at the tip of the finger (Pagani et. al., 2003). A value for pulse transit time is given by calculating the difference in time between the peak of the R wave from the ECG and the peak of the pressure wave from the oximeter (Figure 2).

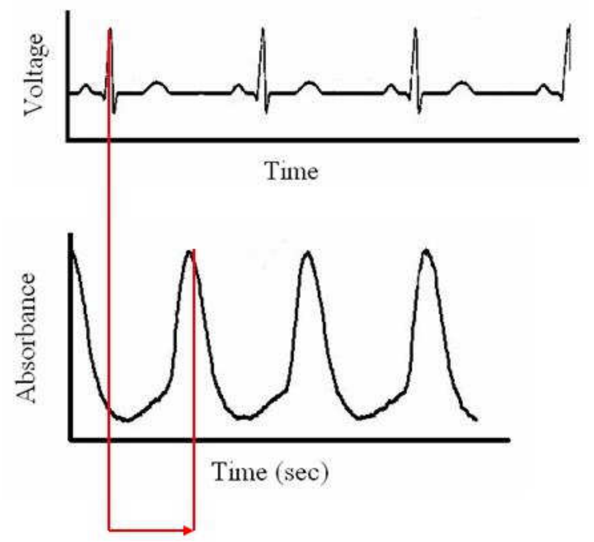


Figure 2: Calculation of pulse transit time from ECG and oximeter graphs.

The change in pulse transit time is used in two ways. First, as blood pressure decreases, pulse transit time increases. This increase results from the obstruction of the respiratory airwave, helping to diagnose sleep apnea. Second, the increase of blood pressure as the obstruction clears lowers pulse transit time. The decrease is caused by the arousal from sleep needed to unblock the airway. The decrease can help diagnose the severity of the apnea (Katz et. al., 2003).

Motivation

Some consequences of prolonged speen apnea are hyperactivity, poor daytime performance, loss of concentration and other negative health effects. This sleep disorder can occur in both adults and children. In order to detect this disorder, patients need to participate in sleep studies at sleep centers. This is a rather expensive study to operate on a day-to-day basis, which is not economically feasible. Furthermore, sleep centers are not specifically for sleep apnea studies. Thus, a small, portable instrument that is able to conduct sleep studies at home would largely benefit the patients. This medical device must be able to detect pulse transit time (PTT), which indirectly measures the time difference between heart contraction (systole) and the flow of blood at the fingertip. Ideally, this device should be as small as a flash drive that needs a low power supply. In addition, the number of wires should be reduced to allow more room for the patient to move. This allows easy access and operation, and the patient can self-detect sleep apnea in earlier stages.

Client Requirements

There are several requirements that our client has presented that must be taken into account while designing the project. First, the design must be able to be used with children. Our client is in pediatrics and wants to use the device to assess sleep apnea in children. This requires the device to be small, as to not cause discomfort for the child while sleeping. A miniaturizing of the device will allow families to conduct the tests at home over several nights, resulting in better data. Secondly, the design must be compatible with the previously designed system. The previous system was design by a biomedical engineering student in a previous semester. The prototype accurately measures pulse transit time by the use of ECG and oximeter readings.

The client has also given us three specific things he would like improved. The most important improvement is the incorporation of flash memory into the device. This memory will allow the data collected to be stored onto a memory stick which could be used to upload the data at a different time, eliminating the need for a bedside laptop computer. Next, he wants an improved LabView software program. The current software cannot account for when the recording device misses a beat due to patient movement. This inability causes the cascading of all data after the skipped beat. The new program should be able to edit out the skip beat and continue to graph regular beats as if no skipped beat occurred. Last is the printing of the current circuit. Research shows though that the existing circuit needs several improvements in order to reduce the noise from surrounding frequencies. Once the circuit is improved, the printing will be an easy step and lead to a miniaturizing of the device. Because this step is relatively more simple than the others and last in client priority, more thought and effort will be given to the flash memory and the LabView program.

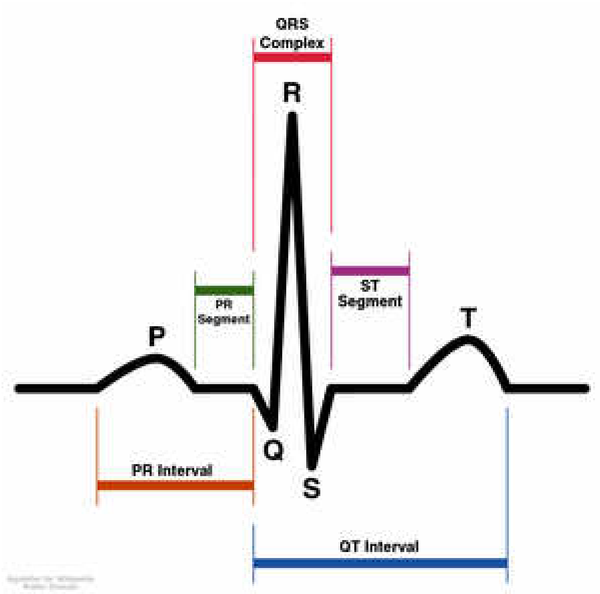
Problem Statement

Current instruments used in the measurement of pulse transit time are inefficient for home use. An existing product with working ECG and pulse wave circuits along with software to analyze the data has been provided. The primary goal will be to optimize the existing setup for use at home. This will be performed by miniaturizing the circuit, reducing the signal to noise ratio, and improving of the already existing software. These tasks will attempt to be rectified by numerous design additions.

Existing Set up

The ECG

The ECG was invented to measure heartbeats by Willem Eitnthoven in 1901, for which he was awarded the Nobel Prize in Medicine in 1924. With each heartbeat, the cardiac tissue releases ions that depolarize the tissue. This creates a voltage of about 1 mV that can be measured with various leads attached at the body. Six ECG leads may be placed around the body in 30-degree intervals to measure the activity of the various sections of the heart based on the spatial readings. These readings form discreet waves representing the various stages of a heartbeat. The P wave represents the current that causes the atrial contraction in which both the left and right atria contract simultaneously. The QRS complex represents the contraction of the left and right ventricles, a much stronger contraction of greater muscle mass. This results in a much greater reading on the ECG spanning a very short duration of time. Repolarization can be seen by observing the T wave that dips below the neutral voltage in re-establishing an action potential.



The small 1mV voltage generated at the peak of the depolarization is measured by the ECG and fed into the circuit. This small voltage is easily distorted from interfering electric fields from surrounding electronics or muscles. The signal fed into the circuit is filtered through a three-stage cascade: a buffer, a differential amplifier, and a bandpass filter. Resistors are used to ensure that minimal current is drawn from the body. Operational amplifiers are used to combine the signals from two leads and amplify the output voltage of this stage. The next stage involves a differential amplifier that uses the Common Mode Rejection Ratio (CMRR) to determine how much noise is passed through this stage of the circuit. The bandpass stage uses to obtain desired frequencies by eliminating common interfering frequencies. The bandpass frequency is set to filter out frequencies that are out of the 160 mHz to 58.9 Hz range. This helps reduce the distortion of 60Hz noise from other devices and frequencies generated by muscle movement. This bandpass does filter some of the frequencies generated by the heart; however, the QRS complex, which is of primary interest in measuring pulse transit time is passed through the circuit at about 5-15Hz.

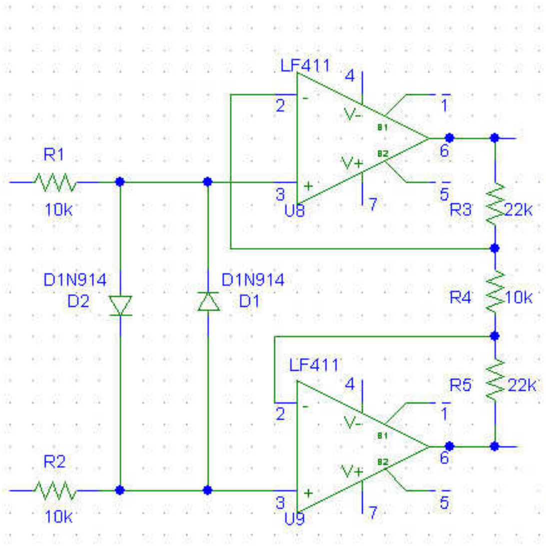


Figure 3: <u>The buffer stage of the ECG circuit</u>. The patient would be connected to v_a and v_b inputs. R1 and R2 add extra input impedance. The op amps provide high input impedance as to not load the patient and draw a lot of current that would distort the ECG signal. Diodes, D1 and D2, are used to minimize damage to the circuit from transient voltages. The gain for each buffer in this figure is 22k/10k=2.2 V/V.

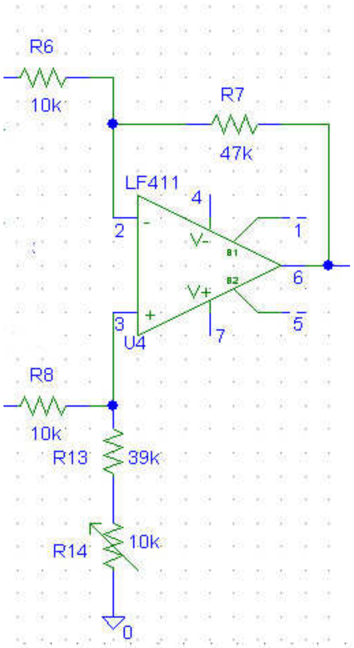


Figure 4: The differential amplification stage of the ECG circuit design. **The potentiometer located at R14 can be adjusted to match R7 so that the common mode gain is minimal. This will improve the common mode rejection ratio (CMRR). The gain of this stage is 47k/10k = 4.7 V/V. Nodes *c* and *d* are the inputs from the output of the buffer stage. A**

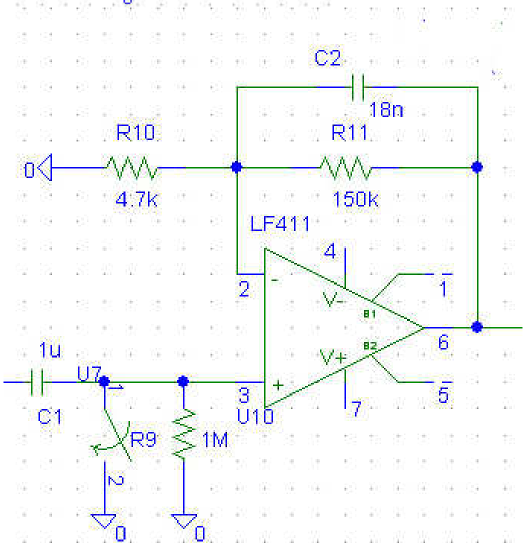
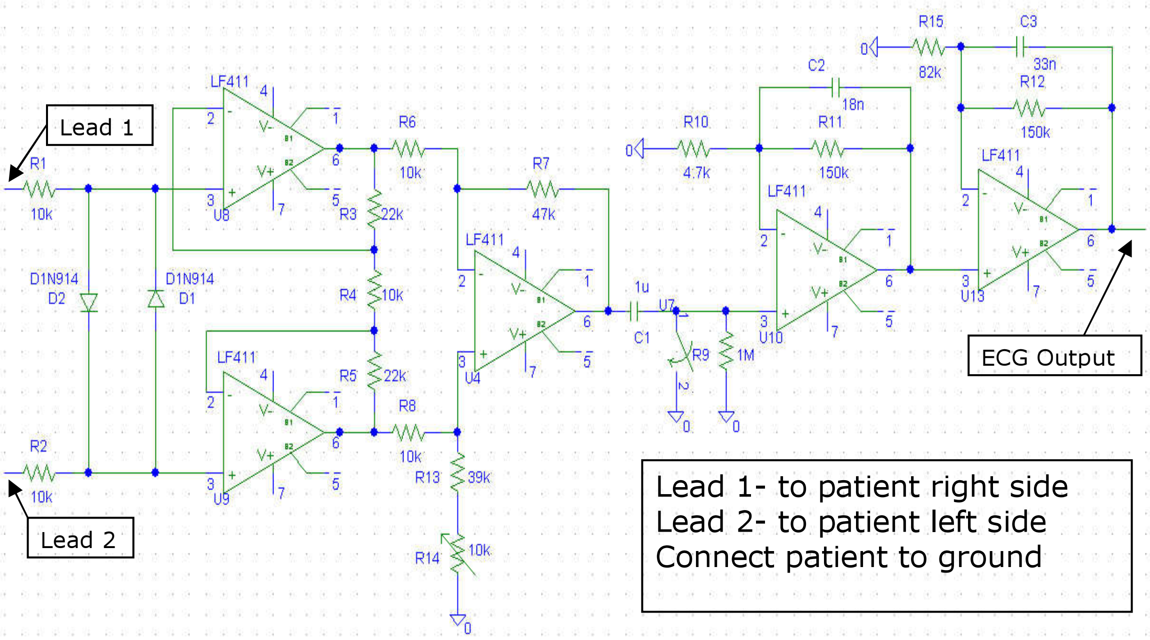


Figure 5: The bandpass filter for the ECG circuit. **C1 and R9 make a highpass filter with a cutoff frequency of 160 mHz. C2 and R11 make a low pass filter with a cutoff frequency of 58.95 Hz. Node e is connected to the output of the differential amplifier. A voltage source of ±15 V/200 mA is used to power the op amp.**

Figure 6: Current overall all circuit design of an ECG



Lead 1- to patient right side
Lead 2- to patient left side
Connect patient to ground

Plethysmograph:

A plethysmograph is a device designed to measure changes of volume in a tissue or organ. For the fingertip, it is used as a non-invasive measure of the amount of blood arriving at the fingertip due to the pressure wave created by the contraction of the heart. The device's LED emits light at two wavelengths: 650nm and 805nm. The light waves pass through the finger and the remaining light is picked up by a phototransitor. A common finger plethysmograph is manufactured by Nellcor. The configuration of the serial connection to the circuit is shown in the following diagram:

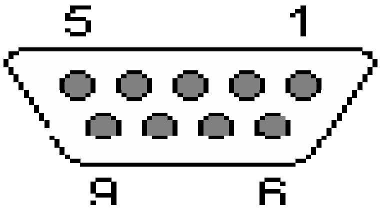


Figure 7:

Wire connections:

Pin 2 = Red (ground for LED)

Pin 3 = Black (power supply for LED)

Pin 5 = Orange (ground for phototransistor)

A 1-4 mV signal is fed into the circuit, requiring several stages of operational amplifiers to process the signal. All op amps are powered by a +/- 15 V/200mA source, which also power the LED. The signal first passes through a bandpass filter to eliminate DC offset. Another filter is designed to filter common 60 Hz noise, similarly to the ECG circuit. Another bandpass filter is used to further reduce the noise. In the next stage, the signal is amplified to the required voltage of 4-8 V as required for measurement by the software. A final stage involves cutting out low frequencies produced by the motion of the finger.

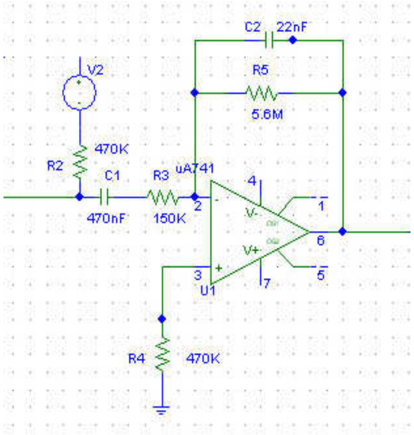


Figure 8: The first stage in the fingerplethysmograph circuit. It is an inverting bandpass filter with calculations. R2 and C1 create a HPF. C2 and R5 create a LPF. R5 and R3 provide gain. A voltage source of ±15 V/200 mA powers the op amp. The input of the circuit is connected to the finger probe.

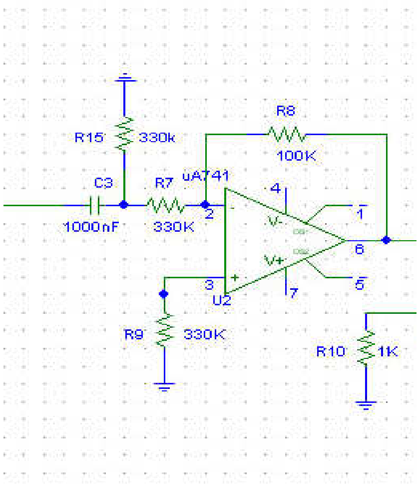


Figure 9: The second stage in the finger plethysmograph. It consists of a HPF, with R15 and C3 to setting the cutoff frequency at 0.4288Hz. A voltage source of ±15 V/200 mA powers the op amp. The input of the circuit is connected to the first bandpass filter.

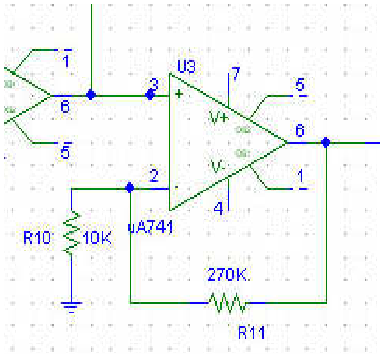


Figure 10: The third stage of the finger plethysmograph. R10 and R11 provide a gain of 28 V/V. A voltage source of ±15 V/200 mA powers the op amp. The input of the circuit is connected to the output of the second stage of the circuit.

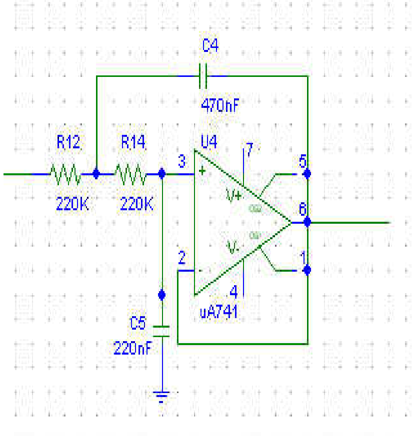


Figure 11: The final stage of the finger plethysmogaph circuit. The diagram is a sallen-key low pass filter, with a 2.32 Hz cutoff frequency. A voltage source of ±15 V/200 mA powers the op amp. The input of the circuit is connected to the output of the second stage of the circuit.

Existing LabVIEW

LabVIEW is a platform and development environment for a visual programming language from National Instruments. This graphical programming software lessens the complexity of software programming and coding. The language used by LabVIEW is called "G", or the data flow language. In order to collect data, the interface is connected with different function-nodes by wires. The wires gather data and input them into LabVIEW, and the software records the data as waveforms. It is important that the user connects the nodes and any other outlets before opening the software. This will allow the components to be detected before the program starts running. In addition, there are three components, or virtual instruments, in LabVIEW. This is because its appearance and operation imitates a physical instrument, such as an oscilloscope. These instruments include block diagram, front panel and connector panel.

The former BME students have created a LabVIEW setup to calculate PTT and display it to the user. It also includes sampled ECG and plethysmograph waves. The program was programmed in LabVIEW 7.1. The configuration of the program is indicated as the following:

- BoardNum = the DAQ's board number from InstaCal installation
- LowChan = 0
- HighChan = 1
- Count = 1000 = (number of seconds you would like to calculate PTT for) / [(# of channels) * (rate)]
- Rate = 100 = (# of channels) * (highest desired sampling rate)
- Range = +/- 10 V
- Cont/Sngl = SINGLE

With the configuration properly entered, the program is initiated by clicking the RUN button. The ECG and plethysmograph waves are input to the program using VIs from Measurement Computing's Universal Library for LabVIEW. Next, the program uses a high-pass filter to eliminate low frequencies in the ECG and plethysmograph signals. The frequency is set to 0.05 Hz. Meanwhile, the threshold level is used to detect the peaks and frequencies of the QRS complex and plethysmograph waves for each heartbeat. For the interpretation of the data, the difference between the QRS complex peak and plethysmograph wave peak is taken, and it is calculated to be PTT.

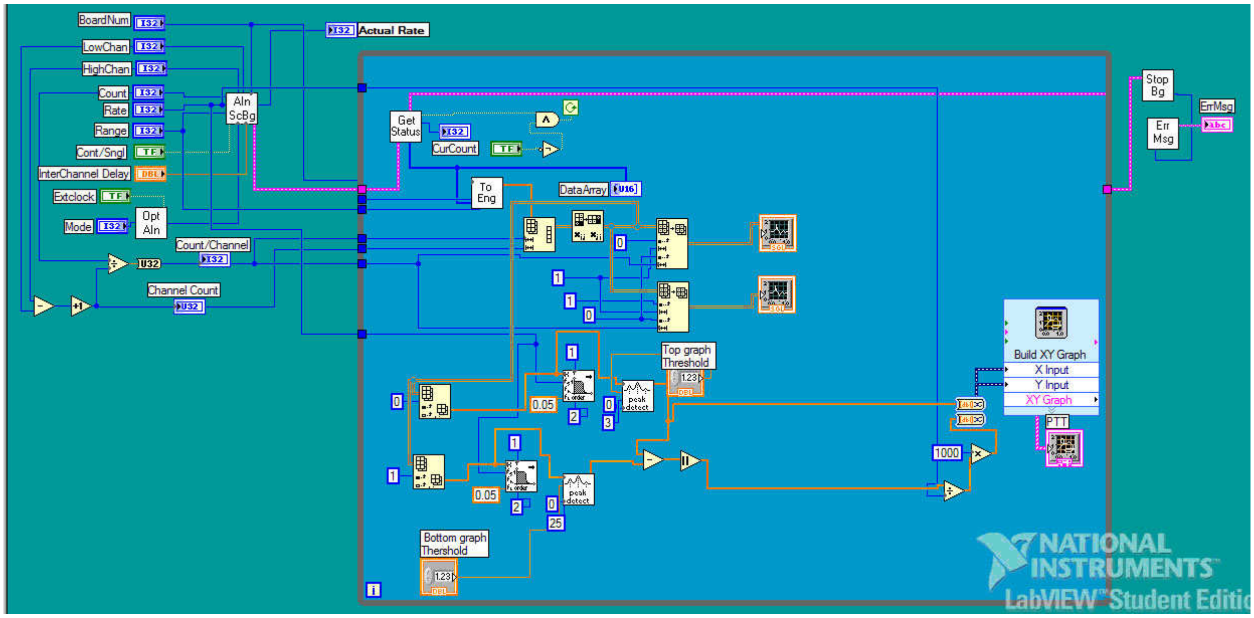


Figure 12: Block Diagram – on of the LabVIEW VIs.

Proposed Design

Memory

The proposed design setup will look to improve upon the problems that have been inherited from the previous group.

One aspect that needs to be improved is the overall portability and usability of the system. As it stands right now the system has is quite cumbersome for an individual to have to wear during sleep. There are numerous wires that may become entangled with the patient or other parts of the bed. Also at the present time wires must be connected from the patient to the device to a laptop computer that is used to record the data. This laptop computer presents more problems with the setup as wires may become entangled and the laptop may be slide off of the table. So potentially this device setup could be very costly, if problems occur.

The way that the previous problem mentioned is intended to be rectified is by the addition of flash memory into the system. The addition of flash memory will allow the removal of the laptop computer from the setup, which could greatly remove additional costs that might be brought on by problems occurring. Also with the addition of flash memory the patient will be able to fasten the device to their waist, and by placing the wires under their clothing, will have a much more comfortable sleeping experience without of the constant entanglement of wires. Once all of the data for the nights sleep is taken the memory can be removed from the system and transferred to a computer at a later time to be analyzed.

In order to implement a flash memory collector into the setup, three specific devices must be added to the circuit. First, an analog to digital converter which allows for the output voltages from the ECG and the finger plethysmogram circuit to be converted into binary that can be read by the computer. The second element that needs to be added is a microcontroller. The microcontroller is the “brains” of the operation. The microcontroller must be programmed to write the voltage outputs from the circuits to the memory storage device. Finally a flash memory interface will be added to the design. This is how the flash memory will attach to the circuit and the element that will transfer the data to the memory card.

The analog to digital converter is an important piece of the setup and some requirements that need to be meet in order to work with the circuits. The resolution of the ADC determines the accuracy that can be achieved with the converter. This is important because it will allow our client to best determine PTT. The use of an 8-bit ACD will allow for resolution of 20mv to be detected. Since an 8-bit converter will have $2^8 = 256$ "states", and the output ranges of the circuits are 0-5 volts the resolution will be equal to (5-0)/256=19.5mV. This will be more than sufficient for the client to use in his data collection.

The microcontroller is the major element of the design. The microcontroller must have at least an 8-bit ADC and 6 IO slots. The IO slots will allow for devices to be connected to the microcontroller. The inputs needs are: input from ECG circuit, input from finger plethysmogram circuit, and output to the flash memory. In actuality only 3 IO slots are need, but currently the smallest number of IO slots in most microcontrollers on the market is 6. The current microcontroller that fits the needs of our system is the Cypress CY8C27143.

Figure 13: Cypress CY8C27143

Another problem that is introduced is the programming of these microcontrollers. Currently it is very difficult to program microcontrollers without the help of a computer interface. With the use of a computer interface the use can program in C or Basic and then transfer the data to the microcontroller with the use of a USB device. One of these USB devices currently available is the MikroElektronika PSoCprog2. This device costs $75 and will allow the user to program

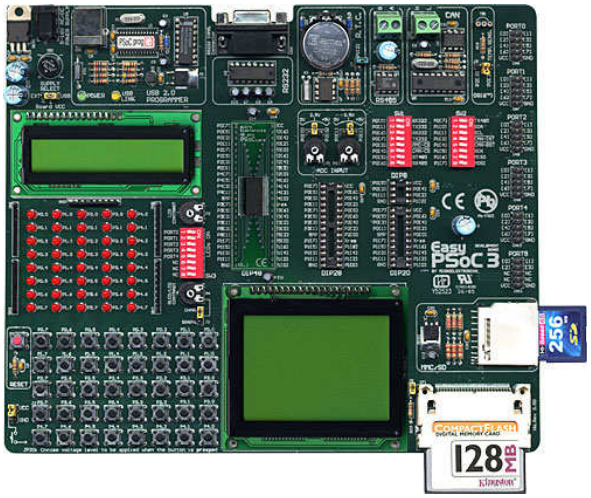
Figure 14: MikroElektronika PSoCprog2

Cypress microcontrollers in many types of more user-friendly software setups.

Finally the compact flash interface must be added to the circuit. This could be accomplished by the addition of the MikroElektronika Compact Flash Board. The cost of the board is $18, plus the additional cost of the compact flash card itself. This device allows a way for the microprocessor to “talk” with the compact flash card.

Another option to consider is the purchase of a developmental kit which has all of the previous elements built into one “board”. Since all of the elements are connected already the programming of the system will be much easier compared with the installation of numerous elements. In addition, these developmental kits come with USB connections and software that can be loaded onto a computer to program the microcontroller. One of these units is the EasyPSoC3 by MikroElektronika. The cost of the entire unit is $169.00 with everything included.

Figure 15: MikroElektronika Compact Flash Board



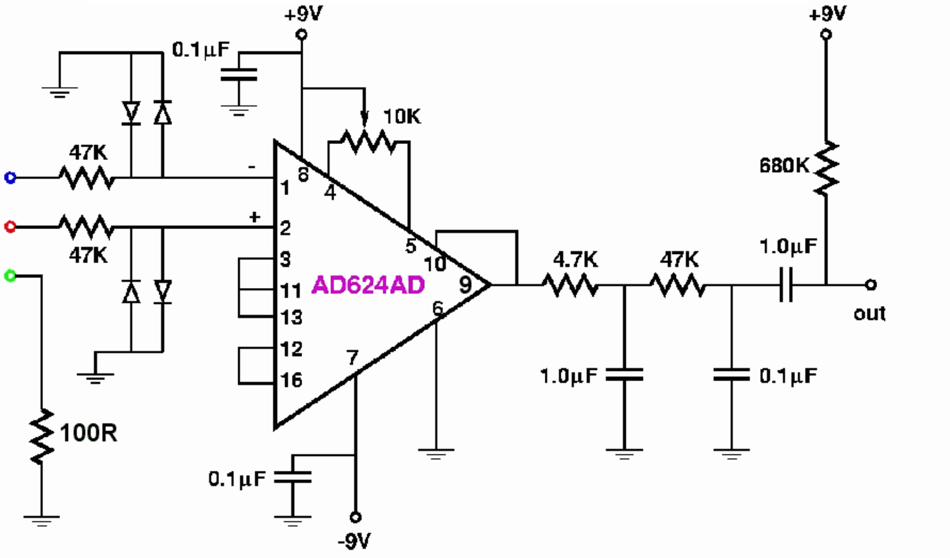
Both of these setups, the individual elements and the combination of all the elements in the developmental kit, will provide a very similar system, thus the client will be presented with both ideas and then decide the direction the setup will go.

ECG Circuit

The next piece of the existing setup that needs to be addressed is the noise that the circuits are receiving at the present time. Especially the ECG circuit tends to pick up noise from the surrounding 60 Hz frequencies that are present everywhere in the home. Therefore, this circuit will try to be improved in order to increase the signal to noise ratio.

The current ECG setup utilizes the use of op-amps in the circuit. This can be a problem when used for an ECG for two reasons. “First, when two electrodes are placed at widely separated locations on the skin, our epidermis acts like a crude battery, generating a continuously shifting potential difference that can exceed two volts. The cardiac signal is puny in comparison. Even worse, your body and the wires in the device make wonderful radio antennas, which readily pick up the 60-hertz hum that emanates from every power cable in your home. This adds a sinusoidal voltage that further swamps the tiny pulses from your heart. And because these oscillations lie so close to the frequency range needed to track your heart's action, this unwanted signal is hard to filter out (Carlson).” In addition, a common mode rejection ratio of 100 decibels is needed in order to ensure no more than 1% error in the voltage measurements.

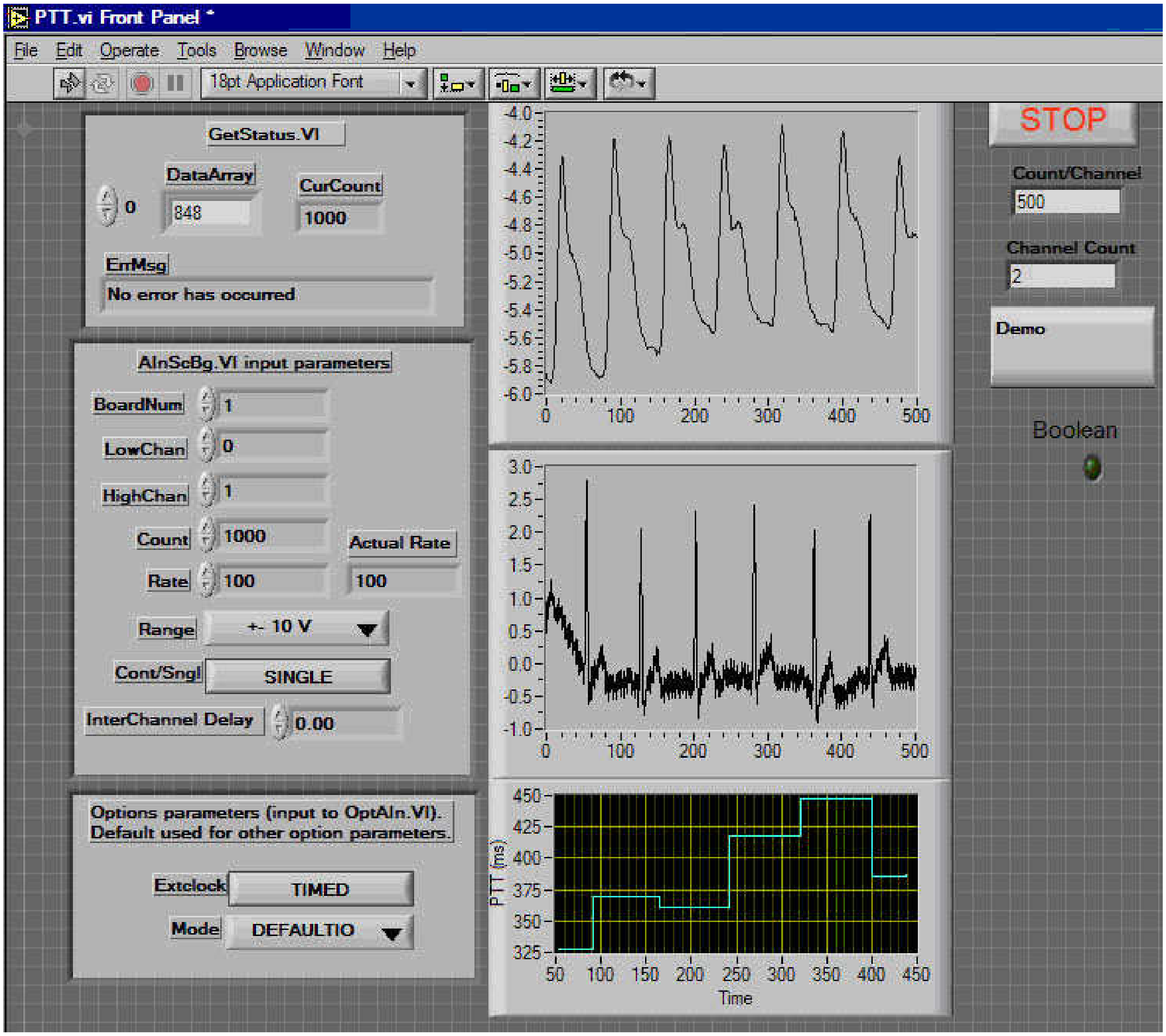
Figure 16: Proposed ECG Circuit



Due to the special need for high amplification and a common mode rejection ratio of close to 100 decibels, an instrumentation amplifier is the device of choice. One such device from Analog Devices the AD624AD ($23.75) offers a gain which can be set to 1,000 with a CMRR greater than 110 decibels. The use of this device will clean up much of the signal while at the same time providing the gain needed for the system.

Proposed LabVIEW setup

Although the previous BME team has already created a usable set of configurations to collect and interpret the data by using LabVIEW, there are still some flaws that would not get the accurate data. In order to generate a set of accurate data, some modifications must be made. One option is to create waveform templates by using LabVIEW. For example, this software can create ECG waveforms that imitate a human's ECG signals. Next, we could collect a patient's ECG signals with LabVIEW. By combining the two ECG waves, and new set of ECG wave is generated. This is a specific ECG wave is of this patient, and it would only be used for this patient. Thus, this new ECG wave could be run during the testing period. This allows us to distinguish between the actual ECG waves or random distorted waves due to noises, because the patient's ECG will match the modified ECG wave. Still, the elimination of low frequencies must be kept in order to reduce the complexity of the data. Moreover, the thresholds detection also needs to be used to figure out the actual peaks of QRS complex and the plethysmograph waves. This would decreases the chances of collecting undesirable data. Therefore, we could gather better data points to figure the PTT.



GetStatus.VI

DataArray 0 848

CurCount 1000

ErrMsg: No error has occurred

AInScBg.VI input parameters

BoardNum 1

LowChan 0

HighChan 1

Count 1000

Rate 100

Actual Rate 100

Range +- 10 V

Cont/Sngl SINGLE

InterChannel Delay 0.00

Options parameters (input to OptAIn.VI).
Default used for other option parameters.

Extclock TIMED

Mode DEFAULTIO

Count/Channel 500

Channel Count 2

Figure 17: The interface of LabVIEW, which is able to calculate PTT.

Future Work

The microprocessor options must be presented to the client to determine the amount of money that he is willing to spend on the system. This will give us the best idea if we should proceed with the individual elements or the developmental board. In addition, a micro processing professor on campus has been contacted and is willing to help us with the setup of this system.

To add the instrumentation amplifier we must first determine how the element can fit into our current system. This will involve the analysis of the circuit to determine the best possible way to add the amplifier.

The LabView software must become understand in its current state before we will be able to work on fixing the code. So we must first start with understanding fully the code already written and then work on implementing the skipped beat code.

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