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Using Photoplethysmography for Blood Pressure Estimation with Telemedicine Application

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Abstract

A cuffless approach to obtaining blood pressure measurements is examined by using dual photoplethysmography (PPG) signals with one being on the finger and another located near the wrist area. Timing differences between the finger and wrist location are collected at different points on the PPG waveform based on the systole and diastole locations. Regression analysis is used to analyse the collected data. A telemedicine application is utilized via saving data to a database which is accessed by a webpage or Android phone application showing blood pressure and PPG graphs. This allows viewing of data beyond the immediate user.

1.Introduction

Heart disease is a major contributing factor to fatalities around the world, and is a leading cause of death in the United States next to cancer [2]. One of the earliest signs of heart disease is related to blood pressure readings. A high blood pressure reading can give signs of potential cardiovascular problems. Early and frequent measurements of blood pressure for at risk populations can help alleviate and prevent future complications. With blood pressure measurement being such an important factor for cardiovascular health, there is a lack of new products for monitoring becoming available based on changing technology. Examples include new methods of measurements, telemedicine, automated measurements, and integration with sensor networks.

Traditional blood pressure measurement involves using a cuff based measuring device wrapped around a person's arm or wrist [4]. The cuff is inflated until circulation ceases and released slowly to obtain systolic and diastolic blood pressure measurements with results given in millimetres mercury (mmHg).

While traditional measurement devices are easily available to purchase, many present information only available to the immediate user. The results cannot easily be shared via electronic communication methods because no such interface exists on most devices.

Due to the limitations of current blood pressure devices, a new implementation of estimating blood pressure is examined. The purpose of the study is to develop an innovative system that can take advantage of current technology to provide more to the end user. The system developed incorporates a cuffless approach using photoplethysmography sensors. The removal of a cuff caneliminatediscomfort factors for elderly and users with low pain tolerance or weakness. The system also contains a database in order to provide telemedicine capabilities through the internet. Such capabilities can allow for remote monitoring of a user by physicians through a webpage or Android phone application.

2. System Implementation

The system functions by using multiple PPG sensors to capture a pulse waveform from the wrist and finger and utilizes software to estimate blood pressure of the user based on the recorded waveforms. The data is sent to a PC so that it can be stored in a database that allows for retrieval from a webpage or Android phone application. A conceptual diagram of the system is shown in figure 1.

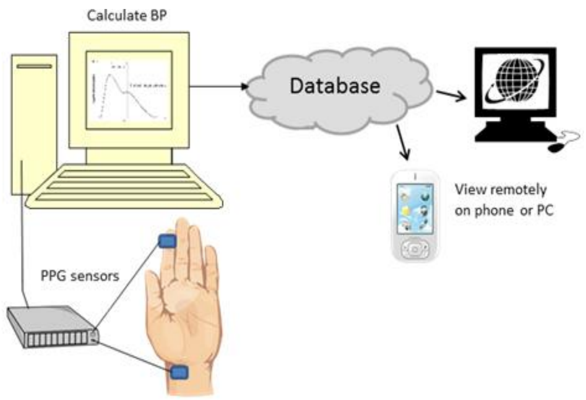

Figure 1. System conceptual diagram

Hardware

The hardwareincludes the PPG sensors, signal conditioning, and the microcontroller. The hardware functions to detect pulse waveforms, amplify and filter the waveforms to a useable voltage by the analog to digital converter on the microcontroller, and send to a PC via communication peripheral on the microcontroller.

The PPG sensors are constructed based on the theory of light response to the body'sbiological tissue.Interaction of biological tissue with light can scatter, absorb, or reflect light [1]. The tissue is comprised largely of water that absorbs light mainly in the ultraviolet and the longer infrared wavelengths. However, there is a window in the spectra of water that allows red and near infrared light to pass more easily. Therefore, infrared emitters and detectors at these wavelengths can be used to observe blood volume changes.

In the system developed, a reflective technique was used for the PPG sensor setup. This setup places an infrared emitter and photodetector side by side.The infrared emitter emits light into the skin. As blood flows, light is absorbed and the light not absorbed is reflected to an adjacent photodetector operating at the same wavelength as the emitter. The reflective operation isn't limited by site placement and allows for use outside of the finger periphery. The emitter was a single infrared LED and the detector was a phototransistor. A phototransistor was used due to having an internal current gain and not having to require a transimpedance amplifier as opposed to using a photodiode receiver.

The filters and amplifiers constructed were designed around the PPG pulse waveform characteristics.The PPG signal carries both an AC and DC component. The AC element is the pulsatile component of the PPG waveform which is attributed to cardiac synchronous changes in blood volume with each heart beat[1]. It is superimposed on the DC component. The DC component relates to the average blood volume, and is much larger than the AC component.

For this study, the AC component of the PPG waveform was the one of interest due to its shape being representative of the hearts cardiac cycle, including the systole, diastole, and closing of the aortic valve as indicated by the dicrotic notch. A labelled figure of the waveform is shown in figure 2.

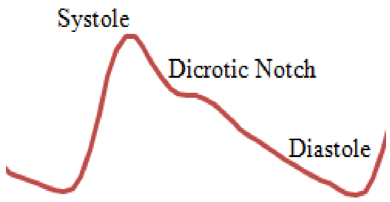

Figure 2. AC PPG waveform component

The output of the phototransistor is first passed through an active high pass filter amplifier. This eliminates the DC component of the PPG leaving only the AC component available for amplification. The AC component is amplified so that it is visible in the voltage range and within the limits of the voltage rails on the operational amplifier.

Any noise with the PPG signal is also amplified, therefore a low pass filter is implemented to eliminate high frequency noise, power line interference from electronics operating at 60 Hz, and keep the fundamental frequency components of the PPG signal intact. An active filter is implemented to isolate the input and output signal, to prevent any loading effects of the PPG signal going into the microcontrollers analog to digital converter.

The microcontroller is an AVR controller in the ATMega chipset. It is used to convert the analog PPG signals to digital and send the digital data through a communication peripheral to the software interface operating on a PC.

Software

The software includes the microcontroller code, graphical user interface (GUI) software, database, webpage, and Android phone application.The software is primarily responsible for collecting the PPG waveforms, estimating blood pressure based on the graphs, saving to a database, and providing telemedicine functionality.

The microcontroller code sets up the analog to digital converter in the microcontroller and sends the converted PPG signal to the PC.Due to the microcontroller only having one analog to digital converter with multiplexed channels, the software will have to wait for one channel to finish conversion before switching to the second channel, otherwise ghosting effects may occur on previous readings leading to false data. Ghosting is when remnant measurements of a previous channel are appearing on new measurements, either adding to or subtracting from the new measurement [3]. This is due to the internal capacitor of the analog to digital converting not fully charging or discharging before the next channel is switched by the multiplexer of the microcontroller. The transmission of data also has to be managed by the software since two different sensor values are going to be transmitted by one UART channel to the PC. The transmit buffer of the UART must first be clear before sending any new data.

The GUI is implemented through LabVIEW software from National Instruments to develop a virtual instrumentation (VI) interactive program.The program takes the data from the microcontroller and graphs both the finger and wrist PPG in real time. This allows for viewing of both PPG signals simultaneously to observe the best waveform before capturing an interval snapshot for analysis. The captured waveforms are shown from a three second interval and the systole peaks with the diastole valleys are marked. The differences between the finger and wrist peaks and valleys are taken and used to estimate blood pressure. Figure 3 displays a captured waveform with marked peaks and valleys.

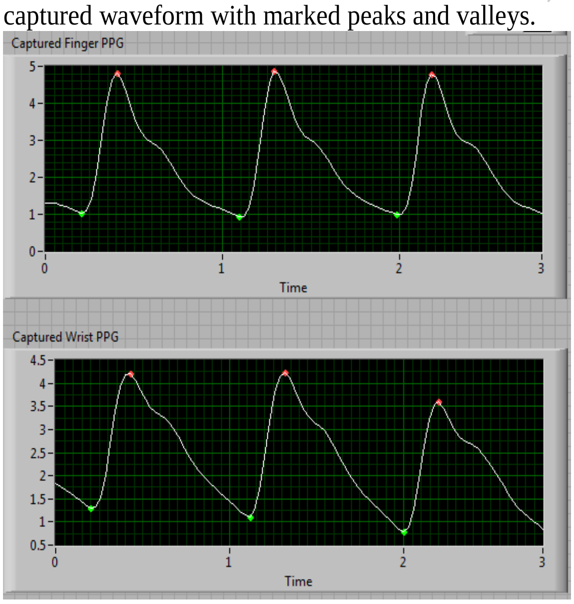

Figure 3. Captured PPG Waveform with Peaks and Valleys

The recorded waveform and blood pressure estimation are saved to a database from LabVIEW to be made viewable by the webpage and Android phone application. The webpage was constructed using Hypertext Markup Language(HTML) with Hypertext Preprocessor (PHP) scripts to retrieve the appropriate data from tables in the database by executing SQL statements. Graphing functions were achieved by using Java scripts to encode the data and insert into a graph. An example webpage is shown in figure 4.

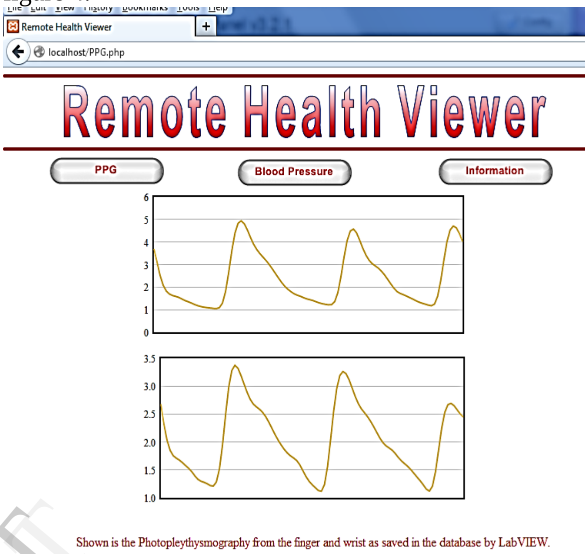

Figure 4. Webpage Example

The Android phone application was created using App. Inventor from the MIT Center for Mobile Learning. The application serves as a remote way of observing information from the databases through the use of mobile broadband. The phone application uses buttons for the user to quickly select through data and observe the PPG graphs and blood pressure readings. An example of the Android phone application is shown in figure 5.

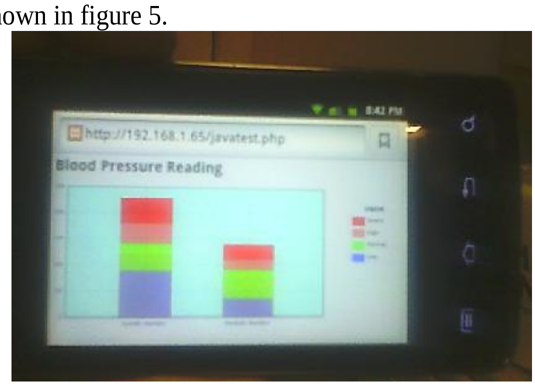

Figure 5. Android Phone Application

Blood pressure estimation& results

The estimations of blood pressure are done by recording differences between finger and wrist in multiple systole peaks and diastole valleys along with a control measurement taken from an Omron blood pressure device. Regression analysis is used to obtain a best fit equation for systolic and diastolic estimates using multiple peak and valley locations as the x, dependent variable, and the control measurement as y, the independent variable.It was found that a nonlinear regression line fit gave the best equation for the recorded data. The line fit is shown in figure 6.

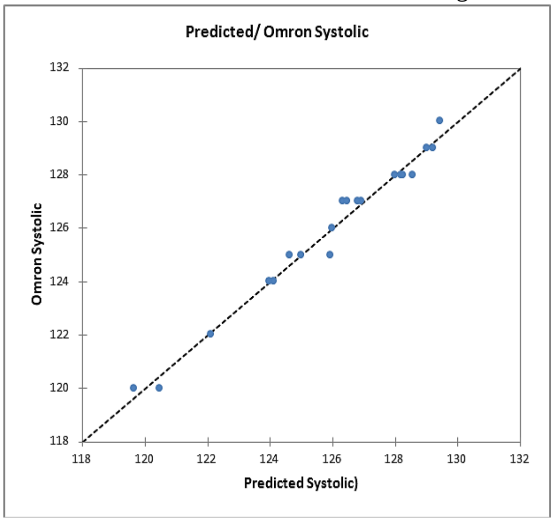

Figure 6. Line Fit Test Data

The equation was inserted into LabVIEW and the LabVIEW estimated blood pressure was compared to the control. A new equation was found based on the results to optimize the estimations in LabVIEW. Table 1 gives results showing the LabVIEW estimates and the control values as well as the differences between them.

Table 1. LabVIEW Estimates vs. Control

Test Systolic	Test Diastolic	Omron Systolic	Omron Diastolic	Sys Diff	Dia Diff
123	67	127	70	-4	-3
123	65	124	70	-1	-5
123	67	127	62	-4	5
125	66	128	63	-3	3
122	67	124	66	-2	1
123	64	125	70	-2	-6
124	69	120	69	4	0
126	69	120	72	6	-3
125	65	120	66	5	-1
121	68	120	64	1	4
125	65	122	66	3	-1
129	67	122	70	7	-3
126	68	127	73	-1	-5
125	66	125	68	0	-2
125	67	129	65	-4	2
126	65	122	66	4	-1
125	67	122	63	3	4
129	67	123	65	6	2
121	67	121	72	0	-5
125	66	129	69	-4	-3

From the table, the largest difference in systolic blood pressure estimation is +7, while the largest diastolic difference is -6. The average absolute difference for the systolic estimations compared to the control was 3.0 while the diastolic was 2.7.

Factors affecting the estimations include body movement and sensor placement. Slight body movement can lead to different shapes in the PPGsuch as alternate amplitudes and amplitude slopes. This results in skewed peak detection from LabVIEW. While estimates are still given, they show a larger difference between the control.Care was also taken for consistent sensor placement, but small changes in placement can affect the estimates.

3.Conclusion

This study showed a potential implementation of cuffless blood pressure estimation based on PPG theory. It was discovered that blood pressure estimates can be achieved using differences at key points on PPG signals from the finger and wrist. While individual results were shown to vary from the control, the average difference was not above 3 for both systolic and diastolic estimates.

Also demonstrated wasa telemedicine application using a database to save information from the LabVIEW program so that it could be made available to a webpage and Android phone application. This revealed howthe use of the internet and smartphones can be integrated with a medial system.

4. References

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