A Novel Heart Rate and Non-Invasive Glucose measuring device

Shashanka Venkataramanan, Divyata Kamble, Aditi Bairolu, Akash Singh, Rama Rao

***Abstract*— At the cross section of the fields of biomedical devices and signal processing, is the work of a novel heart rate and non-invasive blood glucose measuring device capable of measuring these vital medical parameters in parallel.**

This paper describes different non-invasive methods used to measure these parameters involving concepts from signal processing. The concept of Near Infrared (NIR) photoplethysmography is used to measure the change in the light absorbed by illuminating the skin to compute the pulse rate of a person combined with the help of a proposed novel algorithm while blood glucose is measured optically with the help of an Infrared LED (wavelength of 940 nm) in which the amount of light received by the photodiode determines the glucose concentration in the blood. The paper focuses on making a remote, cost effective device capable of efficient measurement combined with a user-friendly GUI. The proposed device also uploads the measured values on the cloud for authentic diagnosis by physicians for far-away patients' lacking state of the art diagnosis.

***Index Terms*—Heart rate measurement, Near Infrared Photoplethysmography, Non-invasive blood glucose, User-friendly GUI.**

I. Introduction

THIS work discusses the conception, design, and prototyping of a device capable of measuring heart rate and blood glucose non-invasively. With the ability of the device to display the measured values in a user-friendly GUI and upload the same on the cloud for authentic diagnosis makes it a novel approach. The development of this device includes making it easy-to-use, cost effective and efficient all at the same time.

The proposed device uses Near Infrared spectrum beam of wavelength 940 nm. The device has been designed to obtain higher accuracy for measuring heart rate and blood glucose using pigtail IR laser fibers of wavelengths 1310 nm and 1550 nm. Unlike the use of an adaptive SWSVD, band-pass filter and notch filter stages [1], this device is designed using a high pass filter and an active low pass filter discussed in section II A. Various concepts discussed [2] [3] [4] utilize an algorithm which does not give stable results and with a deviation of more than 5%. The methodology not only involves measuring heart rate and blood glucose of patients with normal range of values but also people who are diabetic. The concept discussed [5] does not consider measuring heart rate above 110 BPM and produces garbage values even though the device seems quite stable compared to existing devices which is one of its drawback. The major advantage of the proposed device over the existing devices is its ability to adapt to tunable wavelength and give accurate readings as the wavelength of the IR beam increases from 940 nm – 1550 nm. Also, a comparative analysis was performed where the stability of the proposed device was analyzed when subjected to variable wavelength, spectral width and beam width.

The existing devices available measures each of the medical parameter individually and displays the data on a display unit such as an LED or an OLED monitor. The proposed device aims to measure both heart rate and blood glucose at the same time in parallel along with a novel display technique i.e. with the help of a user-friendly GUI.

II. Methodology

A. Heart rate measurement

Heart rate is measured with the help of Near Infrared Photoplethysmography. From Fig 2(a) we observe that the electronic circuit consists of 4 stages involving a simple IR LED transmitter, a Photodiode, High pass RC filter and a Low pass RC amplification filter [4] [7]. The IR LED transmitter and receiver are biased with 150Ω and 33KΩ respectively giving satisfactory results. The next stage involves high-pass filter, a simple first-order RC circuit with a lower frequency bound of $(2\pi R0C0)^{-1}$. The low-pass filter is implemented as an active filter to facilitate amplification as well. The high-pass filter has a cut-off at $(2\pi R2C2)^{-1}$ and amplifies (R1 + R2) / R2 times. Here R0 is the resistance of the high pass filter and R2 is the resistance of the low pass filter which is 68kΩ and 680kΩ respectively while C0 and C2 are the capacitance of high pass and low pass filter with values 1uF and 100nF respectively as shown in Fig2. The high-pass filter frequency and the low–pass filter frequency are chosen such that we end up with a band-pass filter to amplify the 2Hz frequency because that is the steepness of the PPG pulse signal [8]. An LED is attached as a debugging tool such that the output blinks in synchronous to the heart beat which has been observed with multiple patients.

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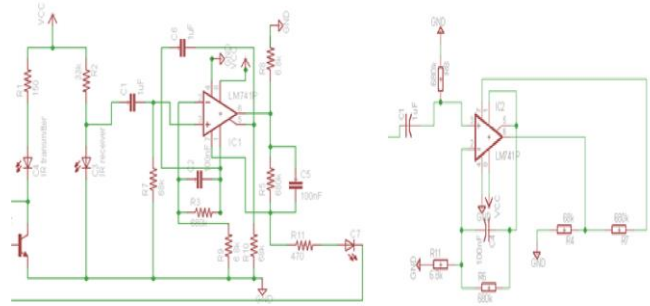
(a) (b)

Fig.1: (a) The placement of the finger for effective measurement of heart rate, (b) The sensor arrangement as implemented on the proposed device.

The PPG pulse is measured with the index finger tip placed on the IR sensors as shown in Fig1(a). The placement and stability of the index finger tip are one of the major challenges faced during heart beat measurement since it has been observed that a slight disturbance can disturb the count thereby resulting in false measurements. As a design challenge, we have developed a casing embodying the IR LED and photodiode such that the placement of the finger is stable and the measurements do not change with external lighting conditions.

B. *Non-Invasive Blood glucose measurement*

Non-invasive methods for monitoring blood glucose levels are more superior to the current invasive method. Nowadays, a portable, non-invasive and a cost-effective glucose meter is highly demanded by the society. There are many approaches to design non-invasive glucose meter. Towards this, one of the design is the use of near infrared method using finger probe. This method is safe as there is no direct electrical contact between the patient and the device and the patient is not subjected to harmful radiations. Optical methods come out to be trustworthy, painless, cost effective and are popular method for glucose measurement [10] [12] [14] to provide a non-invasive measurement approach. The research paper [13] [15] published mentioned that, to evaluate and anticipate glucose concentration, is possible by using glucose spectroscopy between wavelengths 940 nm to 2450 nm. Therefore, to setup system for transmission and reception of NIR rays, a reflective optical sensor is used with the fingertip as the body site. The circuit is set up using near infrared (NIR) spectral range to measure the blood glucose non-invasively. The data recorded show differences of voltage value related to their blood-glucose alterations. To improve the accuracy of the sensor, finger cap is made so that it is not affected by external noise and the designed sensor gives accurate results [11]. This signal conditioning part consists of a filtering stage to filter out noise and amplification stage. Linear regression is done and predicted glucose value is measured. As shown in Fig.3, the signal conditioning of the output signal from the sensor, operational amplifier IC MCP 602 having single supply low power dual operational amplifier are selected.
A gain of 101 and cutoff frequency of 2.5Hz is designed for the filter. For amplification of the sensor signal, the non-inverting amplifier is used, having required voltage gain around 101 and a required high input resistance [9]. The signals from the sensor are being amplified to produce high



(a) (b)

Fig2: (a) The Eagle schematic depicting the circuit for heart rate measurement. A low power dual op-amp MCP602 is used to amplify the low magnitude signals from the fingertip, (b) The eagle schematic representing filtering stage for non-invasive glucose measurement.

signal to noise ratio (SNR) approximate to glucose concentration value displayed per difference in the voltage received.

$$Av = 1 + (R6 / R11) \tag{1}$$

where R6 is 680KΩ and R11 is 6.8KΩ
High pass filter of cut off frequency 0.5 Hz is used to remove baseline drift or low frequency signals and it is given by

$$\text{Cut off frequency } Fc = 1/(2\pi * R6 * C4) \tag{2}$$

where C4 is 100nF

A novel approach of linear regression as mentioned in Section III (B) is used which enables us to predict the proper curve fit for the data samples. Here, a data sample for 15 patients were recorded using invasive method and regression was applied to find a linear curve fitting to predict the blood glucose of patients using non-invasive method. An algorithm was also developed to map the voltage from the sensor to the blood glucose and the result was verified using predicted value from the regression model.

III. ALGORITHM

To display the data of the measurement on the GUI and upload the same on the cloud, it is essential to compute and map the voltage value into an equivalent unit for ease. Here a novel algorithm has been proposed for measuring heart rate, and blood glucose non-invasively.

A. *Heart rate measurement*

Algorithms used to measure heart rate were studied from various resources [2] [5] [6] involving measuring time difference between 2 adjacent peaks and computing the measured value in BPM. But such computations are less feasible especially when computed just after exercise since the time difference between 2 peaks is relatively small and the algorithm does not account for the same. Here, a novel algorithm is proposed which measures heart rate in BPM post processing.
Step1: Read 600 ADC samples from the sensor in a sampling time of 8msec and store it in an array of equivalent size.

Step2: Compute the peak voltage by computing the maximum value of reading from the array.

Step3: Filter out all other values except the peak value by making it 0 and store the peak value in a variable.

Step4: Repeat the steps to obtain 3 distinct peak values from the ADC values.

Step5: Consider time of peak1 as T1, peak2 as T2 and peak3 as T3.

Step6: Compute the difference between the time periods.

$$T1' = T2 - T1 \text{ and } T2' = T3 - T2$$

Step7: Compute the average of T1' and T2' to obtain time per each beat (peak voltage value) and convert it into beats/min by multiplying it by 60,000 as a conversion factor.

$$BPM = 60{,}0000 \div (T1' + T2'/2)$$

$$BPM = 2*60{,}000 \div (T1' + T2') \quad (3)$$

($\because$ 1min = 60,000msec and the sampling time is in msec)

B. Non-invasive glucose measurement

The proposed algorithm for blood glucose measurement is based on the concept of regression. Based on the voltage readings of the patients and their blood glucose computed invasively, we predict their blood glucose non-invasively.

The following is the algorithm for non-invasive blood glucose measurement.
Step1: Read the ADC values from the sensor. If the readings are below a certain threshold, treat it as noise and read the values again, till the values are over the threshold.

Step2: Use the values from step1 and compute the regression equation.

Step3: Using the equation computed in step2, predict the blood glucose of the patient and display the result.

IV. EXPERIMENTAL SETUP

The optical sources used in this experiment is dual wavelength laser source with wavelength 1310 nm & 1550 nm and IR Led source with wavelength 940 nm. Laser source provides narrow line width of pulse whereas LEDs have high spectral width of pulse. The laser line width is measured as 2 nm, whereas LED line width is measured as 45 nm. Laser with narrow line width corresponds to high degree of monochromaticity which is required in many biomedical engineering applications like laser absorption based spectroscopy. The experimental setup was considered to analyze the response of IR LEDs of different wavelengths with respect to the arteries to compute heart rate efficiently. The setup shown in both Fig3(a) and Fig3(b) operate at almost the same power of 2mW and 2.25mW respectively such that there is no ambiguity in setup.

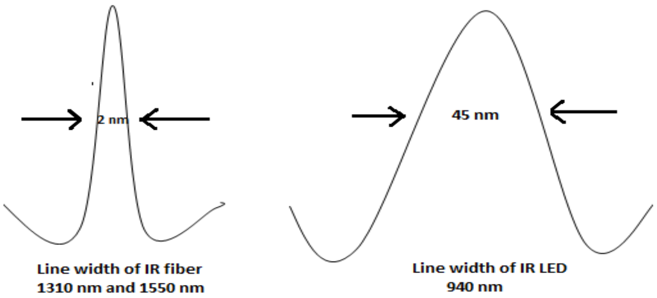
(a) (b)

Fig 3: (a) The experimental setup involving the use of 1310 nm and 1550 nm pigtail IR fiber for heart rate measurement, (b) The experimental setup involving the use of 940 nm IR LED with a photodiode.

(a) (b)

Fig.4: (a) The IR beam width of a 940 nm IR LED (highlighted in red) as seen on an IR detector, (b) The IR beam width of 1310 nm and 1550 nm pigtail IR fiber (highlighted in red) as seen on an IR detector.

As mentioned in the research paper [1], we observe that using a high wavelength IR beam involves high penetration into the skin thus preventing the risk of excessive scattering of the beam of light away from the photodetector. From Fig.4 (a) we observe that in our proposed method, a skin area of around $10mm^2$ is exposed to the 940nm IR LED, while from Fig 4(b), we see that with the use of the pigtail IR fibers our skin is exposed to a pinhole area of $1mm^2$. For good measurement accuracy, deep penetration of light beam into the blood sample is needed. Therefore, if penetration of optical beam inside blood sample is deep enough, we can obtain better accuracy of results. With increasing optical frequency (decreasing optical wavelength), the penetration of beam inside tissue is less. The tissues have different absorption and reflection spectrum, depends on various modes of interaction between electromagnetic wave and tissue. Low frequency (High wavelength) EM radiations are high penetrating as photons do not have enough energy to be absorbed by atomic transitions and molecular resonances. The surface area of skin which is exposed to photons prove very crucial for accurate measurement of parameters. Although same power of optical sources with different wavelengths are used but interaction area of photons and skin is different for LED and laser source. A low divergence thin beam obtained from laser contains high photon density in very small area of cross section, while LED have higher divergence and low photon density. Thus, high density photons contained in small area can penetrate



(a) (b)

Fig 5: (a) spectral bandwidth of 940 nm IR LED, (b) spectral bandwidth of pigtail fibers of wavelength 1310 nm and 1550 nm respectively

deeper inside the tissue as compare to LED source. For this purpose, fiber pigtailed laser diode is used for this experiment. The laser beam is coupled to single mode fiber which has core size of 5 µm. The single mode fiber provides very thin laser beam with high photon density which improves accuracy of measured parameters. The experimental setup also included the use of photodiode GM4 having a peak sensitivity at 1300nm. The photodiode is used to generate response from the light scattered after reflection from the pigtail IR fibers of 1310nm and 1550nm each. The major advantage is that since GM4 has a high sensitivity range (400nm – 1600nm) with its peak sensitivity at 1300nm, it can generate an equivalent photocurrent on reception of IR photons from 940nm IR LED and the IR laser fibers of 1310nm and 1550nm.

V. CLINICAL EXPERIMENTS AND RESULTS

The proposed measuring device for heart rate and blood glucose has been tested using 3 different wavelengths as mentioned in Section IV. Pathology tests were conducted to verify the authenticity of the device which have been shown in the following sub-sections.

A. Heart rate measurement

Using the algorithm described in section III. (A), we compute the heart rate for various patients. Before displaying the result digitally, we first analyzed the waveform output of the circuit with the help of a digital oscilloscope which gave us the result as shown in Fig 6. Fig.7 shows the stability analysis of the heart rate measurement of a healthy patient for 10 iterations. The results are tabulated in Table I. Analysis was done to see the effect of the area of the skin exposed to the IR beam and the effect of line width on the stability of the device. These results were experimentally performed and tabulated in Table II and Table III respectively.

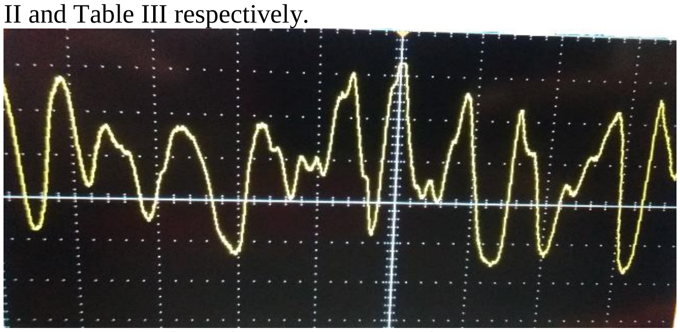


Fig6: Output waveform of the processed signal from the proposed heart rate measuring circuit as measured on a digital oscilloscope. Here the output waveform is generated when the index finger is placed on the sensor as shown in Fig1 (a).

TABLE I: HEART RATE MEASUREMENT DATA WITH DIFFERENT WAVELENGTHS

Sr. No	**Heart rate (in BPM) by proposed method (λ=940nm)**	**Heart rate (in BPM) by proposed method (λ = 1310 nm)**	**Heart rate (in BPM) by proposed method (λ=1550 nm)**	**Heart rate (in BPM) measured by manual counting**
1	77	79	78	78
2	65	78	78	78
3	78	78	78	78
4	81	81	79	78
5	78	75	75	78
6	78	74	78	78
7	78	78	79	79
8	79	78	77	78
Mean	76.7500	77.625	77.750	78.12
Std. deviation	4.89	2.1998	1.2817	0.35

TABLE II. EFFECT OF AREA OF SKIN EXPOSED TO IR BEAM ON THE STABILITY OF PROPOSED DEVICE

Sr. No.	Heart rate (in BPM) when the skin is exposed to an area of $5cm^2$ by 940 nm IR beam	Heart rate (in BPM) when the skin is exposed to an area of 2 mm^2 by 1310 nm and 1550nm IR beam
1	78	78
2	75	78
3	74	79
4	79	78
5	68	79
6	78	78
Mean	75.333	78.333
Std. Deviation	4.0825	0.516

TABLE III. EFFECT OF LINE WIDTH ON THE STABILITY OF THE PROPOSED DEVICE

Sr. No.	Heart rate (in BPM) using an IR beam of line width 45 nm	Heart rate (in BPM) using an IR beam of line width 2 nm
1	78	78
2	75	78
3	74	79
4	79	78
5	68	79
6	77	78
Mean	75.1669	78.333
Std. Deviation	3.9707	0.516

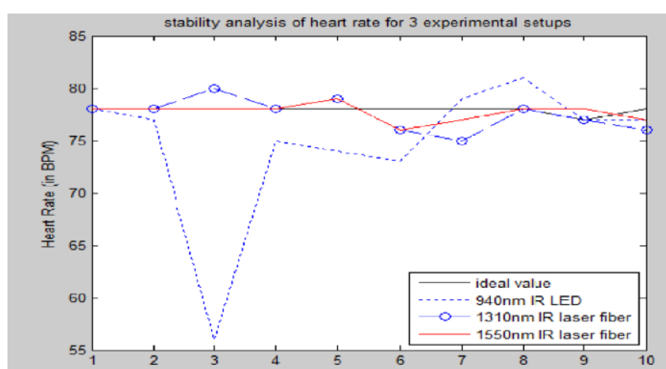


Fig 7: Stability analysis of heart rate of a healthy patient using the 3 different expe6imental setups

B. *Non-invasive blood glucose measurement*

The proposed system determines the method for the prediction of blood-glucose level for human using non-invasive methods. By using this voltage value in regression polynomial model, glucose concentration can be predicted. Using the data from invasive method regression analysis is carried out to generate an efficient curve fit for the given data set. The graph in Fig.8 represent the Linear regression model and its equation. Table IV shows the predicted values from the regression curve for patients and their invasively tested blood glucose.

TABLE IV. BLOOD GLUCOSE BY PROPOSED METHOD Vs CONVENTIONAL PRICK METHOD

Sr. No.	Blood Glucose by proposed method (mg/dl)	Blood Glucose by pricking (mg/dl)	Error
1	64.34	62	2.34
2	69.49	71	1.51
3	71.65	72	0.35
4	72.62	73	0.38
5	74.33	76	1.67
6	75.56	77	1.44
7	83.00	86	3.00
Mean error	72.9986	73.8571	0.8585
Std. deviation	5.7388	7.2440	

The use of Raspberry Pi 3 model B, enables us to compute the data parallelly and instead of displaying results one by one, we have developed a user-friendly GUI capable of displaying the results as shown in Fig.9 taking in various details of the patient like name, age, sex, weight and height. The GUI runs in the first script while the heart rate and glucose measuring algorithm runs in the second script such that the GUI subscribes to the data published by the latter.

Linear regression is used to generate a curve to predict future values based on the given data set. The predicted curve for blood glucose value is given by

$$y = 35.26 + 38.29*x \qquad (4)$$

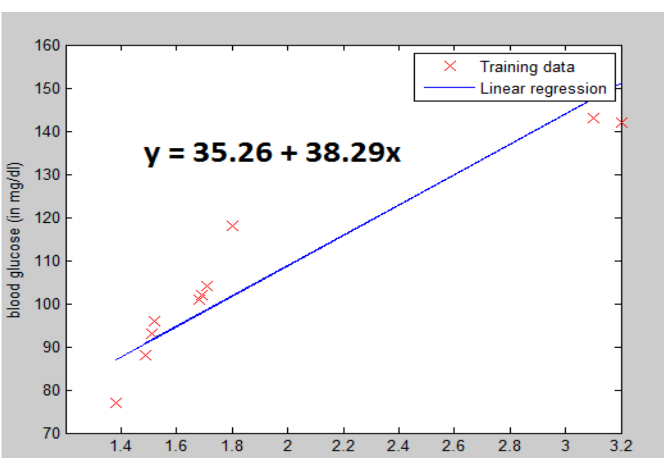


Fig 8: The prediction curve for the glucose values by linear regression.

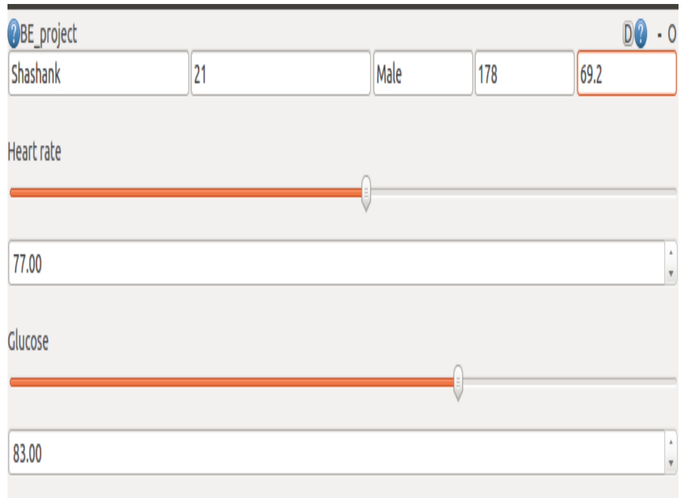


Fig.9: Data being displayed on the GUI computed from the proposed method for heart rate and blood glucose respectively. Parameters such as name, age, sex, height (in cm) and weight (in kg) are initially given to create a database for the users.

where y is the predicted blood glucose value (in mg/dl) and x is, the voltage reading (in V) of the patient when he places his finger on the device.

VI. CONCLUSION

Using different experimental setups to compute heart rate and non-invasive blood glucose were a useful case study as it helped to analyze the effect of IR wavelength for effective diagnosis. We observed that, due to the narrow spectral bandwidth of 1310 nm and 1550 nm pigtail IR fibers, the penetration power of the IR beam into the skin was greater as compared to the 940 nm IR LED which affected the scattering on the photodiode. Also, the fact that since the beam width of the pigtail IR fibers was very small, the area of skin exposed was minute as compared to the IR LED which enabled in improved stability of the device as shown in Fig.6. The sensitivity of the photodiode also played an important role in stability analysis where improved stability was observed for the photodiode with high sensitivity range (900 nm –1600 nm) as compared to a smaller sensitivity (900 nm –1100 nm). However, this adds to the disadvantage of the system design as photodiodes with high sensitivity ranges are usually bulky due to which the system cannot be designed to be portable and compact. Furthermore, photodiodes with high sensitivity ranges and IR LEDs with wavelengths in mid- Infrared spectra are costly which adds on to the major disadvantage of the system as the proposed method focuses on efficient medical diagnosis for people lacking state-of-the-art diagnosis.

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