Review of PPG signal using Machine Learning Algorithms for Blood Pressure and Glucose Estimation

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Abstract. This paper presents an innovative technique for current non-invasive measurement of systolic(SBP) and diastolic (DBP) blood pressures and BGL (blood glucose level). Blood glucose and blood pressure are the most significant factors which marks the health issues, adequate measurement of these parameters is requires by a vast range of people. This paper focuses that the measurement of these parameters can effectively and accurately achieved through photoplethysmography(PPG) which is the one among the non-invasive methods. The analysis of the PPG signals are also made to the check of the accuracy of the device. This review paper focuses on understanding the BP-related features from PPG and explores the growth of this technology in terms of validation, sample size, diversity of topics, based on the datasets used over the period between 2010 - 2019. The data are preprocessed through the normal machine learning techniques and the algorithm of artificial intelligence and neural networks are applied into it. From this analysis, the accuracy of the data is also checked into. All these methods are used for the continuous monitoring and evaluation of the blood pressure and glucose level using PPG signals in a non-invasive ways.

Keywords: Systolic Blood Pressure (SBP), Diastolic Blood Pressure (DBP), Blood Glucose Level (BGL), Photoplethysmography (PPG), machine learning, non-invasive

INTRODUCTION
In human body the Blood glucose level (BGL) and the Blood pressure (systolic and diastolic pressure) were managed at the range of 70-100mg/dl and 120-80mmhg. With the advancement of recent technology, the researchers have invented several invasive and non-invasive techniques.by the insulin produced in the human body. In the current system the measurement of glucose levels craves the invasive method which is more tedious and brings pain for the user.[1] Nowadays there is a common disorder called hypertension among both old age people and youngsters due to their stress in work. This hypertension disorders can lead to several heart disorders like stroke, heart failures, and kidney failures. To prevent this emergency situations we need continuous measurement of the blood pressure in the human body. A real time analysis is very important for this purpose the recent trends and development has been made such as wearable technologies used by human beings, these devices, such as heart rate viability monitoring etc., may perform some advanced tasks. Blood pressure is mechanically assessed by considering the difference in pressure between the blood vessels and peripheral agent obtrusive inflatable cuff (the cuff that crunches the arm). An estimate is developed with the comparison of the pressures. Several methods like interstitial fluid harvesting, pulse arrival time, infrared light spectroscopy and others are invented for the non-invasive blood glucose and blood pressure measurement. An alternative technique to these methods is the adoption of photoplethysmogram (PPG) signals template which is one of the promising non-invasive method. This can be achieved with pulse oximeter.[2]
The requirement of non-invasive technique for the assessment of both is justified with the group of affected people. The requirement for a non-invasive approach for both values to be estimated is justified by the scale of the population affected. For measurements of BGL, SBP and DBP by the Photoplethysmogram signal (PPG), such conditions exist.[3] By irradiating the skin and measuring the changes in light absorption, the PPG signal is obtained. The result is collected as a photoplethysmograph. The absorption of light aims on the heart beat as it is associated with the blood vessels present in the fingers which compress and expand. The output is evaluated by taking the difference between the peak and minimum absorption of intensity of light which is proportional to the cardiac pulse. The PPG signals could also be merged with other modalities for effective outcome. The outcome from the module is kept fixed and at last it is inferred with machine learning module which has the capability to relate SBP, DBP and BGL.[4]

1. PHOTOPLETHYSMOGRAPHY (PPG)

Photoplethysmography (PPG) is non-invasive method of which optical based which aids in the assessment of change in volume of the blood. Hertzman and colleagues in 1937 issued the first paper that describes the measurement of fluctuation of blood in fingers. In order to its candor and booming nature it has been widely utilized in healthcare field. Lot of medical devices have been invented in market commercially which are designed using the same principle. The fundamental PPG system depends only on few components of optoelectronics which illuminate the tissue and consists of a photo detector that converts the irradiant changes that happens in finger where fluctuation in arterial volume of the blood occurs. The first paper explaining the measurement of blood fluctuation in fingers was published by Hertzman and colleagues in 1937. This technology is a low-cost and appropriate tool that can be used in many ways to track the cardiovascular system’s heart rate, oxygen saturation, endothelial function, etc. The various different types of waveforms of PPG which has been noticed and it correlates with pathology cardiovascular and age. As the distension and volume of the arteries are related to the arteries pressure and the pulse waveforms of PPG signal that are common to waveforms of pressure that are generated with the help of tonometry. PPG gives an benefit that it can continuously measure inexpensive, miniature and the optical electronics that are wearable. Addison in 2016 found STT (slope transit time) a single feature which connects PPG signal with Blood Pressure. STT shows steep trend to the pulse wave that rises and it is slope parameter that is evaluated from the peak to foot of the waveform of systole.[5] The PPG signal is collected with the help of Pulse data acquisition method. The PPG signal is recorded for three minutes from the individuals and data are stored BGL values. The collected data was thoroughly observed entirely for the three minutes with baseline drift and the interference of power line. The samples of the signals are corrupted by base line drift, noise and the discontinuity are neglected from the training dataset. The complex can be reduced by extracting window signal of a minute from PPG signal of three minute. Neutral network requires a huge number of data for reliable performance and training purpose. Other than this, the disturbed samples are uniformly distributed from the normal range to high diabetic condition, so that the neural network is created reliably.[6]

1.1. Estimation of blood pressure with PPG

The PPG signals are which are generated from the pulse oximeter. When a cardiac cycle occurs the pressure pulses reaches the subcutaneous tissue, which can distant the arterioles and arteries in our hand, the change in volume of pressure can be detected when we illuminate a white light in the using the led. The PPG signals can be obtained from the fingertip of the human body as shown in fig 1. There are several ways to measure the blood pressure but PPG measurement’s best for continuous measurement as the arterial tonometer is subject to the risk of errors such as sensor displacement and the sensitivity error cuff sphygmomanometer measurement is not possible as it is not continuous measured as there is periodic inflation and periodic deflation, ECG cannot be used as different body sensors should be placed all over the body which would be time consuming and uncomfortable.[7] With the combination of PPG signal with ECG drives various additional parameters that correlates the blood pressure and complements the mechanical work of the cardiac vessels. The optical technology is employed with tissue illumination is achieved by Light Emitting Diode and the light transmission is detected. PPG signal compares the blood in the vessels and the systole and diastole occurs at the two peaks and time difference is related with the arterial stiffness.[8] In addition it also measures the oxygen saturation. The parameters like frequency, amplitude and slope were included in the PPG curve along with its
waveform. The above features were tested and trained using machine learning algorithms after the extraction of the results. Rather than invasive sensor with PPG signal, the PPG signal utilized by a non-invasive and wearable sensor is more efficient.

Figure 1. Features and sites of PPG

1.2. Estimation of blood glucose with PPG
PPG is a novel method for the determination of blood glucose level. The sensor with IR and red Light Emitting Diode collects the PPG signal and absorption is the basic principle used in sensor working. With the basic PPG signal accurate measurement of the blood glucose cannot be achieved as the derived signal has noise artifact contamination. This paper focuses to overcome the artifact by selecting the signal together with its frequency which automatically rejects the contamination of the artifact by depending on morphology of the waveform analysis. Several features can be extracted with PPG signal using various software programs. Photopethysmograph is an optical method where the change in blood volume in micro tissue in vessel is measured in the surface of the skin. Bond deformation occurs and absorption of the photons happens with the energy photons which corresponds to difference in their energy level. The concept of PPG transmission is utilized in the analysis of non invasive blood glucose level. The alteration in blood vessel and viscosity aids in the PPG analysis. The PPG signal composed with NIR Light Emitting Diode and a photodiode with circuits that conditions the signals. The chose wavelength of NIR is widely absorbed by glucose when it is transparent to water. The pulse area under the PPG curve is the total area calculated at the minimum and maximum of the cardiac cycle by the height of the pulse difference. The derivation of the pulse area depends on the Trapezoidal law of integration. In addition, from the beginning and end distance of the PPG waveform and the peak intervals of the consecutive peaks of the systole, pulse intervals are also measured. Finally, the mean values of the characteristics are measured and used in machine learning.

2. METHODOLOGY
The method for the determination of blood glucose level (BGL) and systolic (SBP) and diastolic (DBP) pressures from PPG is shown below.

Figure 2. Block Diagram of proposed system

2.1. Activity detection and signal processing module
The main objective of AD module is to rejects the corrupted parameters (i.e noise, signal loss etc.) of the output signal. The AD module has the some common techniques which was utilized to detect voice in speech technique. This module has robust nature and involves dual aid features. The Finite State Automation (FSA) is used for the segmentation of PPG signals and it involves three states namely S1 (spurious/lack of signal), S2 (PPG-in) and S3 (PPG-out). After a minute of FSA in S2 and S3 the module copies the given samples from vector into frames and to variables and gives the appropriate output.
addition to that spectral entropy and Teager energy is also utilized. The output from AD module is received by SP module. Statics of Spectral entropy plays a major role in the SP module. Correlation and coherence of the signals are evaluated in PPG to give a statistical measurement of the received signal.

2.2. Machine learning module
An another method is also proposed such as non-wearable hydraulic bed sensor which will not be made efficient as that of PPG the continuous evaluation of blood pressure is made because nowadays not only old aged suffers from blood pressure but also the younger ones gets suffered. The data is not publicly available for the initial algorithmic process so the data is extracted from the embedded device which we make the algorithmic process has four stages namely data extraction, feature extraction, feature collection and finally the algorithmic model is applied is applied to the taken dataset. The process of classification takes place in supervised learning with Glucose and Blood pressure with the limited population study which is shown in Table 1, which shows the Mininum, Maximum, Mean, SD and Range of the measured population

### Table 1. Characteristics of study population.

| Measurement | Glucose (mg/dl) | SBP (mmHg) | DBP (mmHg) |
|-------------|----------------|------------|------------|
| Min         | 49             | 90         | 60         |
| Max         | 393            | 180        | 120        |
| Mean        | 139            | 123        | 78         |
| SD          | 66             | 21         | 16         |
| Range       | 343            | 90         | 60         |

The paper mainly focuses on the model for estimating the BGL and BP values and training these values are achieved by the implementation of four non-linear algorithms of regression.[13] The relationship between the PPG signals and the parameters is not clarified by linear regression algorithms compared to nonlinear ones. And the results of linear regression with the paper database are not so successful.[14]

#### 2.2.1. Decision tree regression:
The model decision tree (DT) defines and classifies the basic data and contains a number of tree-like branches and nodes. The most critical factor in the allocation of DT is the commitment of the allocation of data that can pave a path to resolution that may be greater. And these were also ranked for the decision, the final outcome of the decision tree regression should be a real number.[15]

#### 2.2.2. Support vector machine:
One of the prominent technique in machine learning is support vector regression. Unlike other algorithms such as linear regression that works by minimising the absolute magnitude of errors, which is generally known as second power error, it has a specific feature of structural risk minimization. Due to this SVM doesn’t choose local minimum with error function. It makes the available of making nonlinear decisions which utilizes the non-linear kernels.[16] These are used for the kernel process namely radial basis function (RBF) in non-linear regression SVM problems.

#### 2.2.3. Random Forest regression:
This comes under the supervised learning method that uses both the classification as well as regression. Each single node in the standard tree is broken at the point that is best for the greater purpose of resolution. In Random Forest Regression (RF),[17] every node is broken down at the best point, which denotes the set of references randomly selected at the level of a node. This regression falls into an algorithm class that calculates the outcome in the group and the final result is given as an average of the simple estimators. DTR is calculated as the weak estimator in this case. To store the final model, this model requires a vast memory. The method is performed faster because of parallel training in the whole tree model.[18]. The table 2 below mentioned about the Performance of various regession algorithm such as Linear, neural network, support vector and random forest. Depending on the Regression on Blood glucose level, Systolic and Diastolic blood pressure, the performance are calculated and are listed below

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### Table 2. Performance of ML Algorithms (R_{BGL} – Regression of Blood Glucose Level, R_{SBP} – Regression of Systolic Blood Pressure, R_{DBP} – Regression of Diastolic Blood Pressure)

|       | LL | NN | SVM | RF |
|-------|----|----|-----|----|
| R²_{BGL} | 0.52 | 0.54 | 0.64 | 0.88 |
| R²_{SBP} | 0.59 | 0.65 | 0.72 | 0.90 |
| R²_{DBP} | 0.53 | 0.63 | 0.68 | 0.86 |

### 3. RESULT AND DISCUSSION

Studies have shown that hypertension is a significant factor in cardiovascular disease. Continuous blood pressure tests are the safest way to monitor and manage this condition. All android phones have been fitted with PPG signal Sensor in recent days. Photoplethysmograph signal recording does not require special expertise and the hardware used for recording is minimal-cost. Previously the BP is estimated only by using ECG signal which has helped in many ways, but has a limiting factor for the hardware needed to record the algorithm used. [19] The aim of this article is to provide a productive algorithm for the estimation of Blood pressure and BGL non-invasively (ie without calibration and cuff) by the PPG signal that is whether appropriate or inappropriate. The shape of the photoplethysmograph signals often changes so it makes it difficult to extract any useful signal characteristics. For the whole feature, the algorithm is suggested and the extraction is based on the raw signal values, but it doesn't depend on the shape. The characteristics extracted are used as nonlinear regression inputs, as described earlier.

![Figure 3. Results of Clarke’s error Grid analysis](image)

By the four non-linear regression methods, the measurement of BP and BGL values are separated as testing and training data with the cross validation of the algorithms. As described above the extracted feature vectors are used as inputs for non-linear regression algorithms. [17] The model's non-linear algorithm output is measured by parameters that have been closely observed. The findings rely on machine learning principles of estimating parameters with real blood pressure and glucose values. The acquired data that was simulated is used for expressing and as frequency function. A Clarke grid is presented and the scatter plot was divided into five regions. [20]

The created regions quantifies the reference values of the blood glucose accuracy and compared with different errors of the predicted values. An alternate interpretation of the error that was expected is correlated with the five regions of the grid. Details of the grid were previously mentioned. The percentage of different points in each area is depicted in Fig 3. The result shows that region A covers 87.7% points and the 10.3% data were given to the B region with the 20% of reference sensor. But in region B doesn’t
lead to treatment that is inappropriate. Although the estimation is inaccurate by 20% of the value, but it
had never missed the hypoglycemia or hyperglycemia cases. It has been noted that region C contains no
points this proves the false positives of either of the diseases. 2% of points have been fallen in D region,
this indicates that the detection of hypoglycemia or hyperglycemia diseases is impossible. At last there
was no point in region E, which makes possible for the concept of prediction errors. The approximate
final value of the R2 BGL coefficient was 0.90, and the RSS is measured as 10% of the variance of the
sample.[21]

A model is only certified as the best estimator if it gets the minimum value of ME and SD in the
production. The low mean error in the performance of the learning algorithms is a minimum error in the
standard deviation range. ME is the most critical parameter for comparing the accuracy of the algorithm
and is similar to each of its values for different algorithms. This is the key justification for selecting the
right algorithm that generates the least SD error. Based on the outcome we can accurately determine the
unknown parameters effectively.

4. CONCLUSION
The blood glucose level measurement is one of the important factor in the health care sectors. When a
finger is pricked three to six times a day, the invasive procedure causes discomfort and the risk of
infection is high. To overcome this non-invasive suits for the betterment of the life. A noninvasive BGL
measuring system using PPG with NIR Light emitting diode is used. This paper provides a non-invasive
technique developed for the photophlythesmograph signal estimation of the BGL and the results were
obtained with the help of models of non-linear regression. The future work is to design a non-invasive
product that can estimate blood glucose. The use of PPG which is finger based and its measurements
courages the study which tests PPG signals from various sectors. This paper recommends the wrist
based studies which also aid in the development of the smart wrist watch. Most of the analyzement and
studies concentrate on the working pregnant women and hypertensive patients and their betterment in the
diagnosis in upcoming years. By collecting more informations at various optimal situations will be
productive in comparing with the single PPG source. The future needs more work which can form a
innovation in the intra-arterial catheterization along with the PPG signal assessment of BP. In earlier days
the linear regression was chosen for the outcome of the result. But it was failed due to several errors. Then
the given data successfully tested and trained using non-linear algorithm models. As the non-linear
algorithms is efficient and it correlates the outcome obtained from SD module. We can also use
MATLAB for training the data in addition to it. This algorithm gave accurate results for the estimated
BGL, BP values

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