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PPG BASED BLOOD PRESSURE MONITORING AND PREDICTION USING MACHINE LEARNING

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Abstract

In today's world, stress plays a significant role in every person's life. Blood pressure is a vital health indicator in human beings. Hypertension is a prevalent chronic disease that is affected by one-sixth of the total population in the world. Variations in blood pressure will lead to many critical conditions such as stroke and heart attack. Blood pressure has an inevitable part of every treatment. Hence knowing such a vital health indicator prior can help in the diagnosis and treatment of disease in advance. The main disadvantage of the conventional method is that it provides only static values for time instants. Hence to overcome this, a system that deals with the prediction of the future blood pressure values using a machine learning technique is proposed. The proposed system uses the PPG technique for collecting pressure values from the fingertip, a microcontroller that processes the signal to pressure values and finally the prediction of values by the machine learning algorithm. The pressure values are obtained from an embedded unit and these values are used for creating a database which in turn given to the machine learning algorithm. The best prediction algorithm with the highest accuracy is selected. The main advantage of the system over the existing system is that the future health status of a person can be understood in advance. Hence personalized actions can be recommended to control and improve the elevated or dropped blood pressure levels.

1. Introduction

Each organ in human body requires oxygen to work properly. Oxygen is delivered by arteries as the blood flows through a portion of the body. Factors like smoking, caffeine, discomfort, extra salt in the diet will render the artery wall thinner. As a result, the blood cannot circulate through the vital tissue, so the organs of the body can't function properly. This situation may cause a cardiac attack, coronary artery disease, chronic kidney disease, loss of hearing, etc. For most hypertension situations there should be no signs or warnings in the body. Yet it may contribute to severe health issues and can often lead to loss of life. That's why they even call a silent killer. Hypertension impacts mainly the aged and often residents in rural areas who are ignorant of it. Although instruments such as the blood pressure cuff enable them to monitor their blood pressure regularly. This would provide a lengthier and safer lifestyle. The pressure measurement using sphygmomanometer is shown in figure 1.1.

In light of effectiveness in replacing the old method of blood pressure measurement to a prediction level system is a new approach in medical science. The ideal approach is to monitor the pressure values and to predict its future variation and get rid of the downsides of traditional methods, as well as reinforce the bright sides that are functionally needed for the treatment [Agro2014]. More clearly, on one hand, to make up for the shortage of therapists which may indirectly compromise the eventual efficacy to the patients. On the other hand, to offer them individually self-usable device that is technically substantial for a blood pressure treatment. The bonus part is that, a person can self-check their health condition at home without opting for a clinical appointment. This method is also a boon to those patients who are critically paralyzed after a stroke, where continuous pressure monitoring is necessary for stroke treatment. There are other conditions besides hypertension that can be developed as part of the changes in blood pressure. There are several potential disease outcomes associated with blood pressure.

Blood pressure is generally accepted to have a role in accelerating atherosclerosis of the blood vessels and thereby influencing cardiovascular disease. More recent prospective studies have also assessed the association between blood pressure (BP) and stroke subtypes, such as haemorrhagic and ischaemic stroke. Many studies show that the role of blood pressure is a significant factor in the progression of renal failure. Blood pressure is also affected by a person's emotional state and the time of day. Since so many factors can affect blood pressure readings, the blood pressure should be taken several times in a day to get an accurate measurement. The consequences and origin of the blood pressure lead to the discovery of tools for controlling blood pressure.

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Blood pressure monitoring in now a day are a part of routine check-ups in medical analysis. Many self-monitoring devices are available in the market such as Fit-Bit charger, Apple watch and so on, which can track the heartbeat, blood pressure, etc. These devices can just monitor the values at that instant only. For patients who are at critical conditions and those who recovered from strokes have high blood pressure variations which are unpredictable. For them, continuous monitoring of blood pressure is necessary for proper diagnosis. If the future health condition of a person is known prior, then proper health measurements can be taken in order to tackle them. This work focuses on the prediction of only two parameters that is blood pressure and heart pulse variations. All the health parameters can be analyzed in this way which is an innovative feature that can be added in future.

Apart from the normal way of monitoring blood pressure, Photoplethysmography is used here [Biao2015]. Hence a non-invasive, low-cost blood pressure monitoring and prediction system can be developed. For the prediction of future blood pressure value, machine learning plays an important role. The best algorithm is also proposed based on their performance analysis. This device is very simple and can be used by any person without any assistance. Many more health indicators such as sodium, insulin, creatine, urea concentration, etc. can be predicted in this way by employing an electronic method in combination with machine learning techniques. A lot of diseases can be pre-predicted in this way. Hence personalized actions can be recommended to improve and control the health of a person in advance [Su2018].

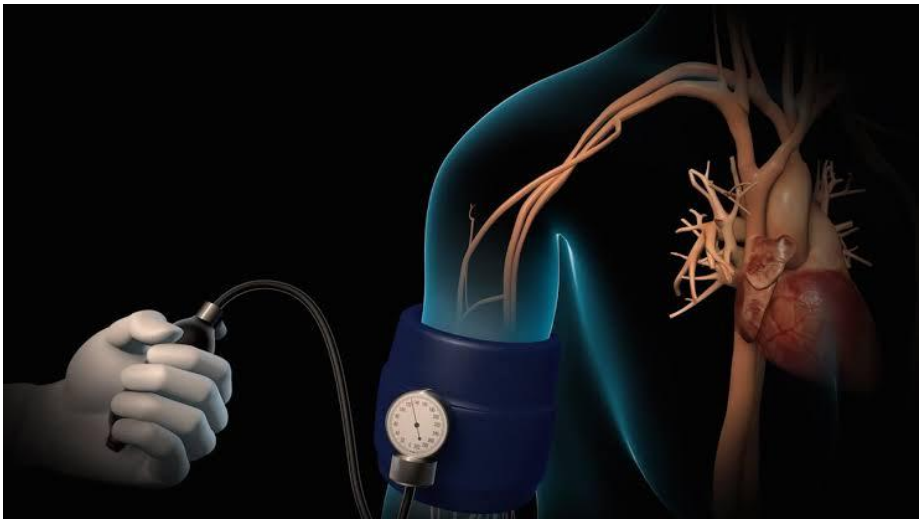

Fig1.1 Blood Pressure monitoring

2. Literature Survey

Jing Liu, et.al, [Liu2016] stated in their work that, Pulse transit time (PTT) has been extensively established as an indicator of changes in blood pressure (BP). However, multi-site sensor installation on the human body is needed in clinical practice for PTT detection, which makes it challenging to incorporate wearable devices. This research shows that the time differential between MW PPG may theoretically be used as PTT for cuffless calculation of BP with its special benefit in the easy application of sensors at just one body location.

Priyanka, et.al, [Priyanka2014] proposed a method to approximate the blood pressure from the PPG signal using the method of artificial neural networks. This research recorded the varying time intervals of PPG waveforms as properties for the implementation of artificial neural networks (ANNs) for estimating blood pressure. For the cuffless, non-invasive blood pressure (BP) calculation, a transparent photoplethysmography (PPG) sensor module is built based on PPG at the wrist on radial artery. Blood pressure refers to the length of the PPG pulse.

Nath, et.al, [Nath2018] proposed a novel blood pressure classification model using Phototplethysmogram (PPG). The proposed model uses algorithms for signal processing and machine learning to classify blood pressure into four phases: normal, elevated, phase 1 and stage 2. A total of 83 features have been derived from the PPG signal including 71 statistical features and 12 characteristics. Here random forest classifier is used to train and test the predictive model. The software includes raw PPG

data for various users and Arterial Blood Pressure (ABP) to measure the systolic and diastolic blood pressure for testing and evaluation purposes to be used as the ground truth. The results indicate that the proposed model will be ideal for integration into a non-invasive blood pressure monitoring system with significant accuracy.

Kao, et.al [Kao2017] proposed a new portable PPG-BP device designed for continuously measuring blood pressure (BP) without a cuff. This continuous and long-time BP monitoring enabled herein by the portable cuffless BP sensor. Towards the aforementioned goal, the sensor is designed capable of detecting in real-time, non-invasively and continuously the temporal intravascular blood volume change based on the principle of a photoplethysmograph (PPG) for estimating BP. A laptop is also used for a continuous view of BPs and mathematical review and test tests. 27 participants engaged in the experimental testing, in which the BPs collected was measured by OMRON's consumer blood pressure monitor and then compared.

Ghosh, Shrimanti, et al [Ghosh2016] proposed a non-invasive method for continuous blood pressure monitoring. Pulse transit time (PTT) has been documented to be highly correlated with the blood pressure but there are very limited data to investigate the impact of attitude and movement on PTT-based BP calculation. PTT has been calculated in this paper using the windowed association between the ECG and PPG signals. In systolic and diastolic blood pressure, the root-mean-squared errors (RMSE) between the reference model oscillometric cuff-based device and the approximate PTT BP were lowest when sitting or standing and maximum when walking or cycling. Therefore, the estimation of PTT-based BP was reasonably accurate while stationary but not during motion, and further improvements in estimation are required before its use for the estimation of ambulatory BP.

Wu, et.al [Wu2014] proposed a new study based on machine learning technique, specifically artificial neural network, is investigated to predict the systolic blood pressure by correlated variables (BMI, age, exercise, alcohol, smoke level etc. To construct and test the prediction method, two neural network architectures, back-propagation neural network and radial base function network, is used. An innovative form of estimating systolic blood pressure helps give early warnings to young and middle-aged people who may not be taking daily measures of blood pressure. As it is also known that an isolated measurement of blood pressure is sometimes not very accurate due to the daily fluctuation, this predictor device can provide the medical staff with another reference value. Additionally, since an independent calculation of blood pressure is sometimes not quite accurate due to the regular fluctuation, this prediction system can provide the medical staff with a further reference value. The experimental results indicate that artificial neural networks are ideal for systolic blood pressure simulation and prediction.

3. Methodology

The proposed method uses the PPG technique to monitor the blood pressure apart from other techniques. The obtained pressure values are collected and a database is created. The database is given to a machine learning algorithm which predicts the future blood pressure values. The main advantage is that it’s not a static measurement system hence provides continuous pressure values. So, anyone can accurately predict future pressure values. If the future health condition of a person can be predicted like this way, early disease prediction and prevention is possible.

Photoplethysmography

Photoplethysmography (PPG) is an uncomplicated and affordable optical measuring tool that is mostly used for blood pressure measurement and heart rate tracking. PPG is a non-invasive technique that utilizes a light source and a photodetector on the skin surface to calculate the volumetric differences in blood circulation. The aim of this work is to quickly examine some of the latest advances and challenges of wearable PPG-based tracking technologies which help to address some of the possible therapeutic applications of this technology. Photoplethysmography, most widely known as PPG, uses an infrared light to calculate the volumetric differences in the distribution of blood.

In figure 3.2, by simply shining a light on a patch of skin with an LED light source, the increased pulse pressure will cause a measurable difference in the amount of light reflected back onto or transmitted through to a light sensor. The LED light should be positioned in a region where nerves, such as a fingertip or an earlobe, are close to the skin.

The functional block diagram can be divided into two sections; hardware and software sections. The block diagram of the whole system is shown in figure 3.1. The hardware section consists of sensor based on PPG technique and a microcontroller for processing the signal to pressure values. The sensor includes LEDs and photodetector which works on the principle of photoplethysmogram. Later the signal obtained from the fingertip will be amplified since it will be in few mV.

The signal conditioning circuits will amplify and filter out the required signal to the microcontroller. Software section mainly includes the machine learning algorithms for prediction of blood pressure values. Finally, these values are given to the machine learning algorithm were future value is predicted. This will be a computer system. The software section of the system is shown in figure 3.3. Both the hardware and software sections are combined to check the correct functioning of the system.

The hardware part of the system can be divided into three sections. The finger probe section, signal conditioning and signal processing sections. All these sections are basically needed for signal generation. The software part of the section deals with database creation and machine learning prediction. After acquiring the required PPG signal and extracting the required features from them, a database is created. The machine learning algorithm is predicting the future blood pressure value from the obtained dataset.

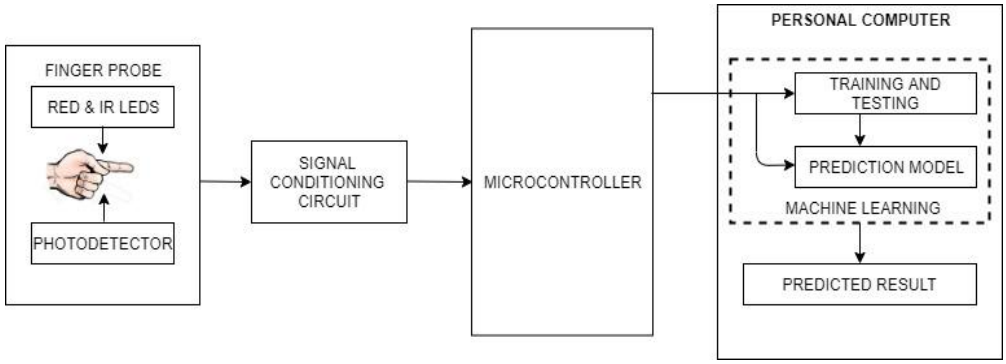

Fig 3.1: Overall System

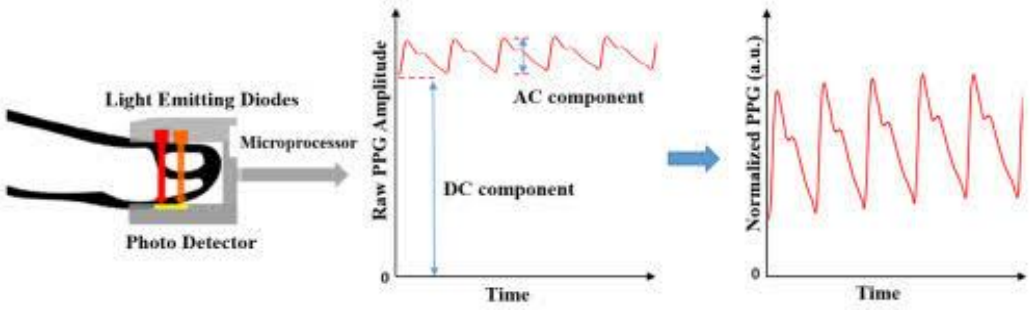

Fig 3.2: Photoplethysmography

The functions of different sections were explained below:

1. Finger probe

The sensor includes IR LED and photodetector which works on the principle of photoplethysmography. The finger can be placed in either transmittance or reflectance node. Here the finger is placed in reflectance mode. The LEDs are powered with the help of microcontroller.

2. Signal conditioning

The signal conditioning circuit will amplify and filter out the required signal to the microcontroller. The current obtained from the photodiode is converted to a voltage value by a transimpedance amplifier. Then the signal is amplified since it is in the range of millivolt. The low-frequency signals were removed by using a high pass filter.

3. Signal processing

The signal will be processed by the microcontroller and obtain the systolic pressure. The features in the PPG signal should be extracted in this phase. The Matlab software is used to analyze and extract the required parameters. Apart from blood pressure, the pulse rate of a person can be calculated from the signal.

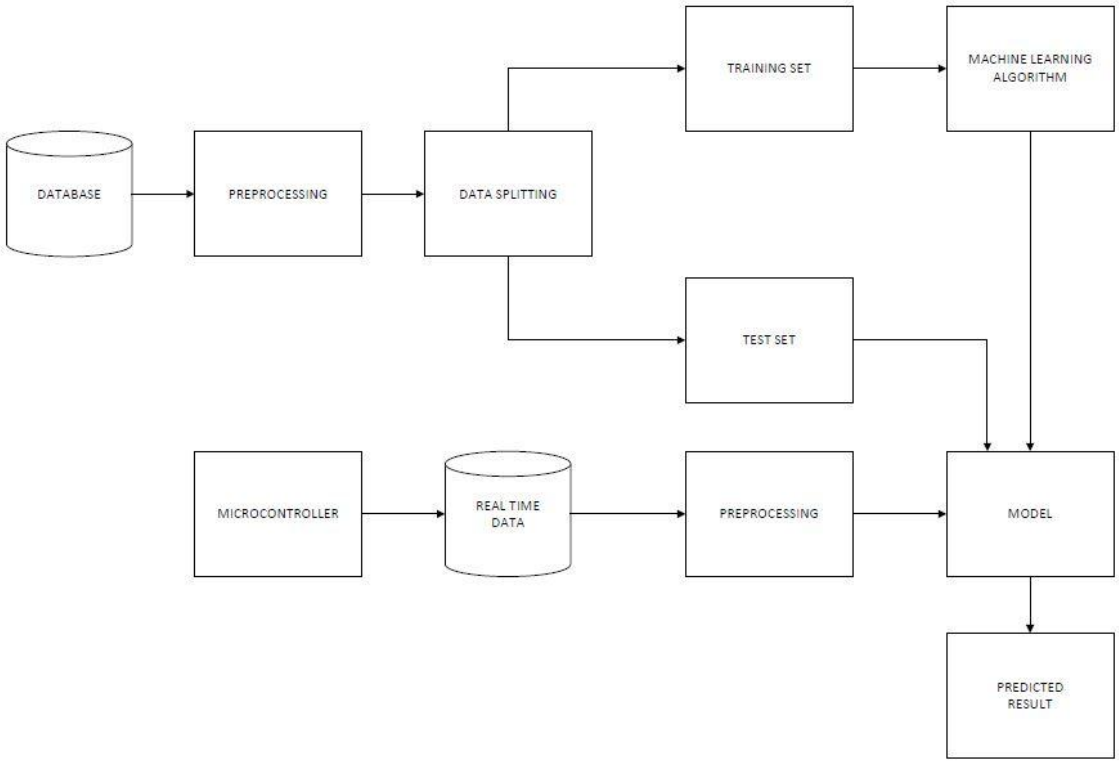

Fig 3.3: Software Block diagram

4. Database creation

The blood pressure of various subjects are collected in this phase using the proposed device. The data is stored in a computer system for creating the database. Then the data has been splitted in to two sets, test set and train set. During the training section the classifier use only 'training set', then tune the parameters using 'validation set' and finally test the performance of the classifier on unseen 'test set'.

5. Prediction using Machine Learning

In machine learning part, a database is given as the input to the model. There are string values in the database which has been converted to integer values by a process called pre-processing. Data is been cross-validated to ensure better accuracy and efficiency of the algorithm used in the training the machine. Then machine learning and classification rules are applied. Accuracy of each classification technique is calculated. Technique with highest accuracy is used for the prediction. Finally, the predicted output will be obtained.

4. Results and Discussions

The hardware includes a finger probe section, signal conditioning and processing section. The figure probe section consists of an IR Led and photodiode. The circuit wired on a bread board is shown in figure 4.1. The finger can be placed in both transmittance and reflectance mode.

The PPG signal obtained from the hardware is plotted by using serial plotter available within the Arduino IDE. This signal has to be processed to obtain systolic and diastolic pressure. The PPG signal thus obtained from the hardware is amplified and shown in figure 4.2.

Machine learning algorithms were performed on the obtained public dataset and the accuracy of various algorithms was plotted. The software IDLE (Python 3.7 64 bit) is used for running machine learning algorithms. The algorithms used here are KNN Classifier, Support Vector Machine, Random Forest, Naïve

Bayes, Linear Regression and Decision Tree. ROC curve of the above algorithms was compared and the algorithm with the best accuracy is selected.

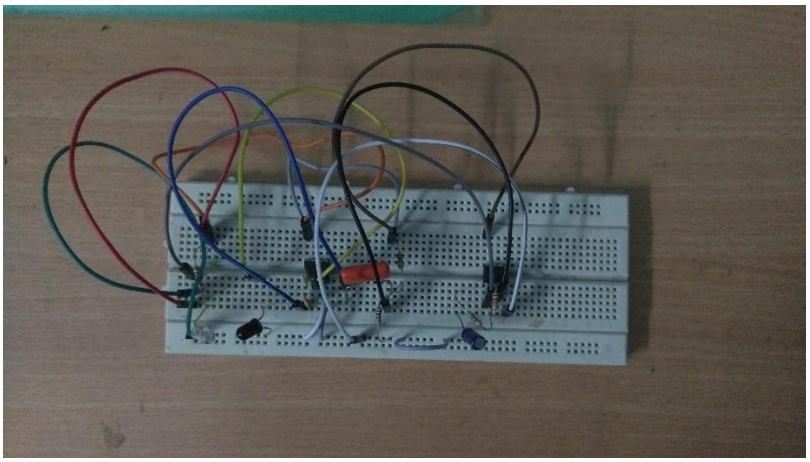

Fig 4.1: Wired circuit for PPG signal generation

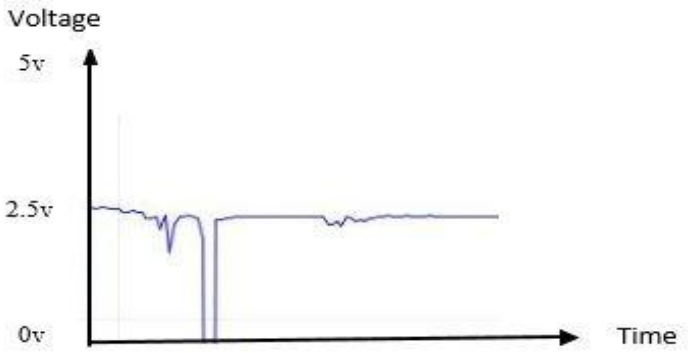

Fig 4.2: The PPG pulse waveform from the circuit

The accuracy plot of the algorithms was shown in figure 4.3. The x-axis gives various machine learning algorithms versus their corresponding accuracy on the y-axis. Python IDLE is used to run all these machine learning algorithms and the graphs were plotted by using matplot.lib function. It is necessary to do a comparison among different machine learning algorithms to check their consistently. A method to do this is to calculate average variance, accuracy and accuracies of distribution models. The comparison among machine learning is said to be fair if each algorithm evaluates on the same data on the same way. The table showing percentage of accuracy is shown in table 4.1.

Even though the decision tree provides 100 percent accuracy it can't be selected as the best one since it predicts the result based on the branching technique. It might be true or false depending upon the splitting threshold. Hence Random Forest is selected as the best prediction algorithm. Receiver Operating Curve is a graphical representation which visualizes the ability of a classifier system at various values of threshold. The ROC curve is made by plotting the actual or true positive rate (TPR) against the false positive rate (FPR) at different levels of thresholds. The figure of the plotted ROC curve is shown in figure 4.4.

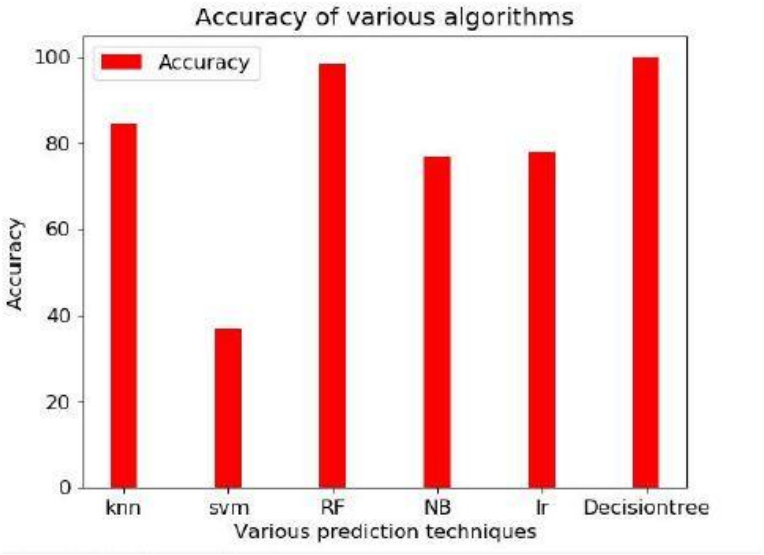

Fig 4.3: Accuracy plot of various algorithms

Table 4.1: Accuracy of various algorithms

No.	**Learning Algorithms**	**Accuracy**
1	Knn classifier	84.35 %
2	Support Vector Machine	37.25 %
3	Decision Tree	100 %
4	Random Forest	98.45 %
5	Linear regression	78.56 %
6	Naive Bayes	76.72 %

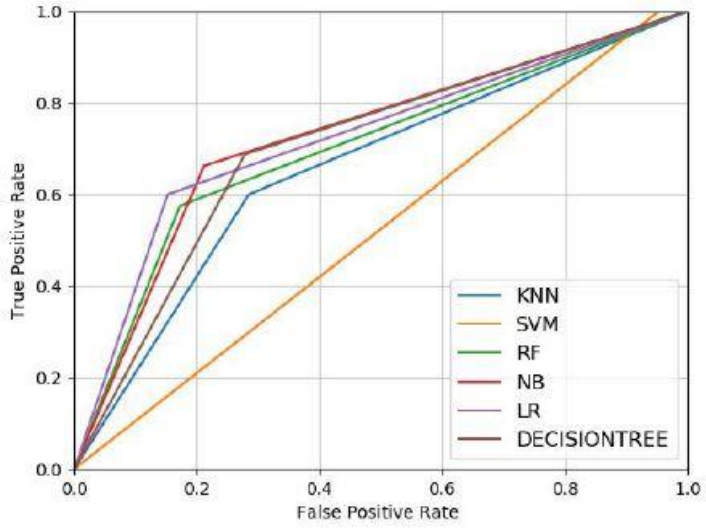

Fig 4.4: ROC plot of various algorithms

5. Conclusion

A PPG based blood pressure monitoring and prediction method are proposed here. This work helps to reduce the difficulty that a patient experience while calculating blood pressure. The key aim of this work is to reduce the need for any doctor or specialized staff in the process of calculating blood pressure with a fairly inexpensive and user-friendly tool. Data that can be used by doctors is easy to store for further study. PPG based blood pressure monitoring system has been successfully developed and tested using a micro-controller at a lower cost. From the developed hardware, PPG signals were obtained and thereby created a private database. This simply enhanced the prediction of future blood pressure values using machine learning. Various machine learning algorithms were compared and plotted the accuracy, ROC curves. Random Forest Classifier is found to be the most accurate one, which is used for the purpose of prediction. Hence this work makes use of the continuous PPG measurement to produce accurate estimates of BPs based on a prediction mechanism that provides future value.

6. Future Scope

Nowadays this dynamic world is running after technologies which are far beyond for human to imagine. As a result of this hectic environment, people are supposed to suffer from stress, anxiety and many more health problems. Even though we cannot stop these consequences but can prevent them by taking successive measures. Data science has emerged as a new technology that became an inevitable part of everyone's life. The world has been changing and much more predictive for human by data analysis. From the stock market to weather forecasting, the prediction plays an important role. Hence this same mechanism can be also adopted in medical science. If the changing nature of vital parameters in the body can be predicted in advance, it will be boon to those patients who are suffering from severe health issues. In future, this concept can be expanded to predicting many more health indicators such as sodium, insulin, creatine, urea concentration, etc. Using electronic method in combination with the machine learning technique, a lot of diseases can be pre-predicted. Hence personalized actions can be recommended to improve and control the health of a person in advance.

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