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Artificial intelligence-based blood pressure prediction using photoplethysmography signals

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[Abstract]

This paper presents a method for predicting blood pressure using the photoplethysmography signals. First, after measuring the optical blood flow signal, artifacts are removed through a preprocessing process, and a signal for learning is obtained. In addition, weight and height, which affect blood pressure, are measured as additional information. Next, a system is built to estimate systolic and diastolic blood pressure by learning the photoplethysmography signals, height, and weight as input variables through an artificial intelligence algorithm. The constructed system predicts the systolic and diastolic blood pressures using the inputs. The proposed method can continuously predict blood pressure in real time by receiving photoplethysmography signals that reflect the state of the heart and blood vessels, and the height and weight of the subject in an unconstrained method. In order to confirm the usefulness of the artificial intelligence-based blood pressure prediction system presented in this study, the usefulness of the results is verified by comparing the measured blood pressure with the predicted blood pressure.

▸ **Key words**: Blood Pressure, Artificial Intelligence, Photoplethysmography, Prediction System, Continuous Monitoring

[요 약]

본 논문은 광혈류신호를 이용하여 혈압을 예측하는 방법을 제시한다. 제시한 방법은 먼저, 광혈류신호를 측정한 후, 전처리 과정을 통해 아티펙트를 제거하고 학습을 위한 신호를 얻는다. 그리고 혈압에 영향을 주는 몸무게와 키를 부가 정보로 측정한다. 다음으로, 인공지능 알고리즘을 통해 광혈류신호, 키, 그리고 몸무게를 입력변수로 학습하여 수축기와 이완기 혈압을 추정하도록 시스템을 구축한다. 구축된 시스템은 사전에 입력된 키와, 몸무게, 그리고 측정한 광혈류신호를 가지고 수축기와 이완기 혈압을 예측한다. 제안한 방법은 무구속 방식으로 피검자의 키와 몸무게, 그리고 심장 및 혈관의 상태를 반영하는 광혈류신호를 입력받아 실시간, 연속적으로 혈압 예측이 가능하다. 본 연구에서 제시한 인공지능 기반 혈압예측시스템의 유용성을 확인하기 위해 측정한 혈압과 예측한 혈압의 비교를 통해 결과의 유용성을 확인한다.

▸ **주제어**: 협압, 인공지능, 광혈류측정, 예측 시스템, 연속모니터링

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I. Introduction

This paper presents a method for predicting blood pressure using the optical blood flow signal. In the proposed method, the need for more active management of chronic diseases has been raised from the viewpoint of optical blood flow signal measurement, pretreatment, and preventive medicine recently. Unconstrained measurement technology is being actively developed. In particular, among chronic diseases, hypertension is the biggest cause of cardiovascular disease, stroke, renal failure, and premature death and disability. In order to manage blood pressure, it is important to continuously measure and check blood pressure. In the existing electronic blood pressure measurement method, it is difficult to measure continuously because the cuff is wrapped around the arm and measured while increasing the air pressure(pressurization method) or while decreasing the increased air pressure (decompression method). is difficult. In addition, since a cuff must be used for each measurement, measurement is cumbersome. That is, it is not easy to continuously measure blood pressure in a non-invasive method using conventional methods. Recently, a method of monitoring pulse and blood pressure in real time using a biosignal such as a photoplethysmograph(PPG) and easily managing blood pressure has been studied[1~4]. It is possible to check the trend of the blood pressure while monitoring the blood pressure in real time, and when it is out of the normal range, it is possible to immediately deal with it. PPG is directly related to blood oxygen saturation(SpO2: Saturation of peripheral oxygen) and has a close relationship with heart activity. With this relevance, researches have been conducted to estimate blood pressure by measuring pulse transit time(PTT) with optical blood flow waves[5]. However, it is difficult to accurately estimate the blood pressure because the pulse wave propagation speed is affected by various factors such as the size of the blood vessel and the elasticity of the blood vessel wall. Since then, studies have been conducted to estimate blood pressure using ECG and pulse wave transit time in order to measure blood pressure more accurately[1][7].

This method is a method of indirectly estimating blood pressure, and as a step of suggesting a relationship between PTT and blood pressure, there is a limit to quantitative measurement. Recently, studies to estimate blood pressure by introducing artificial intelligence technology have been attempted[6~9]. Research has shown that it is possible to estimate blood pressure based on PPG signals with the development of deep learning algorithms and hardware technology to implement them.

In this study, we intend to develop a system using PPG signals and deep learning algorithms to continuously monitor and manage blood pressure while providing convenience to users. Also, to increase accuracy, the subject's weight and height are used as inputs.

II. Methods

Blood pressure refers to the pressure exerted on the walls of blood vessels when the heart works to supply blood containing oxygen to tissues and organs. The blood pressure that the heart pumps out is called systolic blood pressure, and the blood pressure that comes into the heart is called diastolic blood pressure. The systolic and diastolic pressures are repeated according to the heart's activity rhythm. In general, when measured using a cuff, blood pressure refers to a value measured in the brachial artery of the arm, and when it is higher than a certain level based on normal blood pressure, it is called high blood pressure, and when it is lowered, it is called hypotension. When the heart contracts, the blood that flows in through the pulmonary artery is supplied through the aorta to the peripheral blood vessels of organs and tissues that make up our body. The PPG signal is obtained by measuring the amount of light absorbed according to the blood flow rate of blood supplied from the heart to the ventricular contraction stage[2~3][5].

It is a waveform that expresses the change in blood volume as a photoelectric signal. It shows a waveform proportional to blood oxygen level and is closely related to the activity of the heart[1][3]. Figure 1 shows the relationship between ECG waveform, PPG waveform and PTT. The PPG signal shows a close relationship with the activity of the heart, and the systolic and diastolic phases can also be confirmed in the PPG. Based on the relationship between the heart activity and PPG, blood pressure information can be obtained.

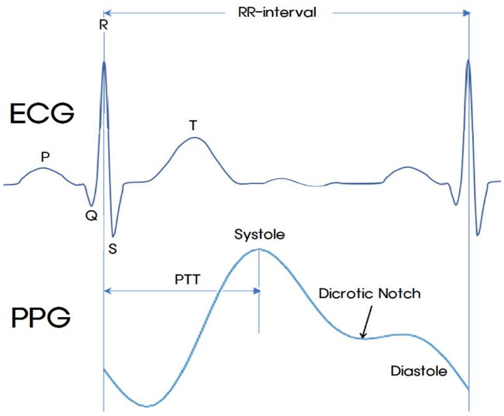


Fig. 1. Relationship between ECG and PPG signal

2.1 PPG Signal Measurements

In order to measure the PPG signal, it is measured through a sensor dedicated to PPG. Fluctuations in blood pressure are composed of the amount of blood flowing through the blood vessels and resistance components that impede the flow. The PPG signal shows similar changes in blood pressure, and shows periodic changes by repeating systole and diastole of blood vessels. Figure 2 shows an example of PPG signal measurement.

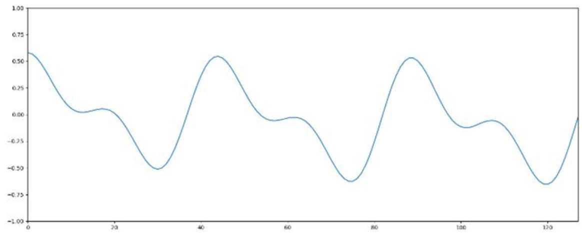


Fig. 2. PPG signal measurement example

Using the correlation between the PPG signal and blood pressure, our study uses deep learning instead of statistical and mathematical methods to analyze the PPG signal and identify significant patterns to predict blood pressure. We obtain a stable PPG signals after removing the effects of breathing and artifacts caused by body movements. In addition, the obtained signals are used as an artificial intelligence learning and verification signal. In each frame, an average value within a certain level range is obtained, artifacts such as breathing are removed, and frames showing rapid changes over a certain range are excluded from learning and recognition. This is because the statistical characteristics within the frame are not stable due to the DC component in the PPG. Figure 3 shows the DC component critical range for PPG signal pre-processing and the average value in the frame.

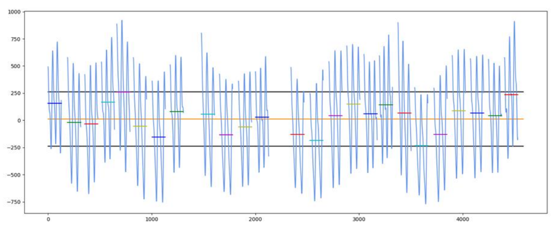


Fig. 3. PPG signal pre-processing

2.2 Atificial Intelligence Modeling

In this study, we develop an algorithm that estimates blood pressure using the PPG signals, which is closely related to the movement of the heart, and has systolic and diastolic blood pressure information, and weight and height signals. The deep learning model is configured as shown in Figure 4.

The proposed model has the premise that the movement of the heart and the condition of blood vessels, which are the sources of blood pressure, are reflected in the PPG signal. The anatomical structure of the heart, the result of contraction and diastolic activity, is the temporally varying blood oxygen level through the blood vessels, which is implicit in the PPG signal. Under this assumption, the PPG signals are directly used as an input variable in the AI model, and weight and height, which are closely related to blood pressure, are added to the input variables.

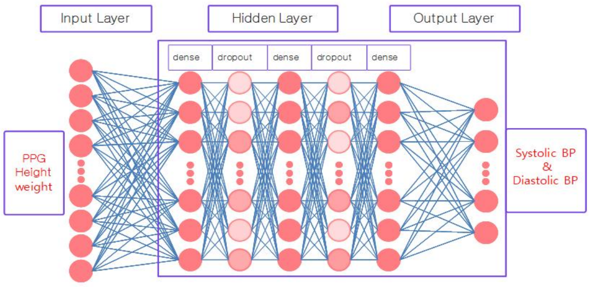


Fig. 4. Deep learning model

The pre-processed PPG signals constitute a signal of more than one period as input data. For the activation function of each node, the sigmoid function is used in the part receiving decimal information, and the ReLU (Rectified Linear Unit) function is applied in the part receiving binary information. In addition, the loss function verifies the convergence speed by applying MAE(mean absolute error) and binary cross-entropy. The output is designed to represent the systolic and diastolic blood pressures as binary outputs in 8 bits. Through this, based on the PPG signal, weight, and height information, it is applied to an artificial intelligence model to predict systolic and diastolic blood pressure.

III. Experiments and Results

3.1 System construction and modeling

Figure 5 shows the overall system configuration. The system consists of a PPG measurement module, signal processing, artificial intelligence algorithm, and a program to provide blood pressure prediction and trend. The PPG signal was measured using the MAX30102 sensor dedicated to PPG, and the entire system was designed to operate through the Raspberry Pi system. The user measures PPG by placing a finger over the sensor.

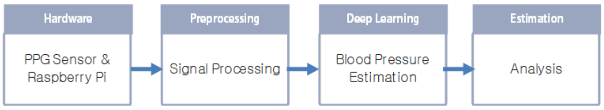


Fig. 5. AI-based blood pressure prediction system

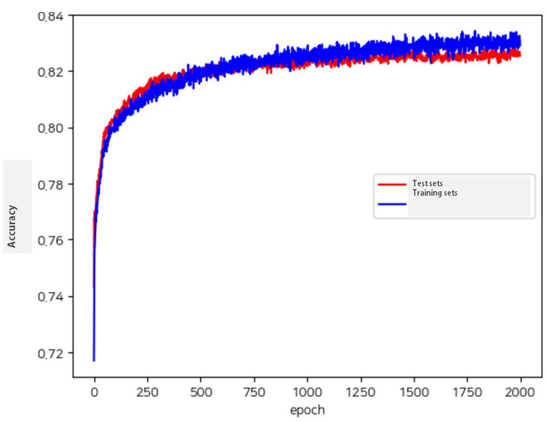
The bio-signal measurement and display were controlled by the Arduino board. During biometric information measurement, real-time measurement status can be checked through the display. The artificial intelligence model consists of one input layer and one output layer, and three hidden layers. The hidden layer is composed of three dense layers, and the activation function is set to sigmoid. The input layer has 144 nodes and is connected to 64 dense layers. The dense layer consists of three layers, each with 64 nodes. Dense layer 3 delivers data to 16 nodes of the output layer. Drop-out of 0.4 was applied to each dense layer to prevent overfitting. The output layer outputs 16 binary numbers. The output layer separates 8 units and converts them into decimal numbers in order to convert them into systolic and diastolic blood pressures. The loss function used when learning data uses binary-crossentropy of the cross entropy series, and uses ADAM(adaptive moment estimation) as an optimization function. The batch size is 5, and the epoch is repeated 2000 times to proceed with learning.

3.2 Data Processing

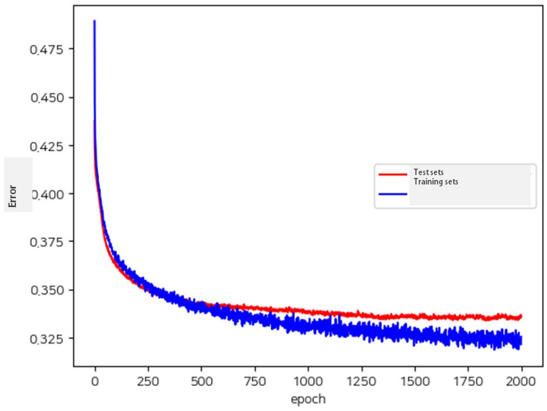
PPG signals were collected from a total of 28 measurement data from 8 users by gender and age group. In addition, PPG data were collected by classifying 40 normal conditions, 30 times of moderate exercise, and 30 times of intense exercise. Since the collected data contained noise and artifacts, preprocessing was performed to remove them. Outliers were removed through preprocessing and normalization was performed with 128 samples per window. In addition to the PPG signal, the input data were converted to binary numbers for height and weight, and then combined behind the PPG signal. The target result value is binary data of systolic and diastolic blood pressure. Converting binary to decimal gives systolic and diastolic blood pressure.

3.3 Results

As a result of training with the constructed PPG data set, results that are almost similar to the values predicted by artificial intelligence and measured systolic and diastolic blood pressure were obtained. The accuracy of this model is 0.8254 and the loss is 0.3355. Figures 6 shows the comparison graphs of accuracy and error between the test set and the training set. In both graphs, it can be seen that the gap between the test set and the training set is not large and the graphs are drawn in almost similar directions. This allows us to know that learning proceeds normally. Figure 7 shows examples of actual blood pressure and predicted blood pressure through learning data.

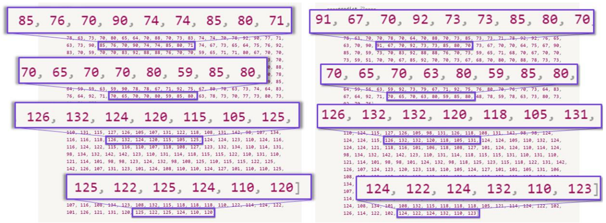


(a) Accuracy comparison graph between test set and training sets



(b) Error comparison graph between test set and training sets

Fig. 6. Results for accuracy and error



(a) actual measured blood pressure (b) predicted blood pressure

Fig. 7. Examples of actual blood pressure and predicted blood

IV. Conclusions

In this study, deep learning was used based on PPG signals to allow users to conveniently measure and manage blood pressure without restraint. Continuous measurement is possible by predicting blood pressure that can be measured by overcoming the temporal and spatial limitations of blood pressure measuring devices. The biometric information measured by the subject is recorded in the database so that the trend of change can be continuously known, which is expected to help manage hypertension or borderline hypertension. Through this, it is expected to contribute to the prevention and management of chronic diseases of the elderly and the vulnerable. In addition, this study sought solutions to improve user convenience and accessibility of the existing blood pressure measurement system through deep learning, and confirmed the usefulness of the artificial intelligence-based blood pressure prediction system during the experiment.

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