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Article

Non-Contact Blood Pressure Measurement Based on IPPG

Jiancheng Zou[1], Shouyu Zhou[1,*], Bailin Ge[1] and Xin Yang[2]

[1]College of Science, North China University of Technology, Beijing, 100041, China
[2]Department of Computer Science, Middle Tennessee State University, Murfreesboro, TN 37132, USA
[*]Corresponding Author: Shouyu Zhou. Email: 1915754861@qq. com
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Abstract: Blood pressure is an important physiological parameter to reflect human vital signs. In order to achieve the non-contact dynamic blood pressure acquisition based on ordinary optical camera, a theoretical understanding of the functional relationship between blood pressure and pulse wave signal conduction time. And through imaging photoelectric plethysmography (IPPG), pulse wave signal conduction time of forehead and hand was obtained with ordinary optical camera. First, the pulse wave conduction time was obtained by recording the video with an ordinary optical camera. Second, real-time blood pressure values were collected. Finally, based on the relationship between blood pressure and pulse wave conduction time, a non-contact blood pressure measurement prediction model was obtained through neural network fitting. So that non-contact blood pressure measurement with optical camera could be completed. The method in this paper has several advantages, such as low requirements on measuring equipment, low cost, and simple operation. It can let people get rid of the discomfort caused by measuring equipment such as cuff and can measure blood pressure at any time. The predicted blood pressure results were compared with an Omron wrist electronic sphygmomanometer. The calculated error of systolic blood pressure is –9.28%~3.16%, and the error of diastolic blood pressure is –9.84~4.35%.

Keywords: Non contact; blood pressure measurement; imaging photoelectric plethysmography (IPPG); pulse wave conduction time

1 Introduction

Blood pressure (BP) refers to the pressure of blood flowing in the blood vessel on the side wall of the blood vessel. What we usually talk about is the arterial blood pressure of the systemic circulation. Blood pressure is one of the important physiological parameters of the human body and the status of cardiovascular function can be known through blood pressure [1]. In recent years, hypertension has become a common chronic disease in life and it is one of the global public health problems [2]. To prevent hypertension, you must be able to know your blood pressure at any time. However, contact measurement method will cause discomfort to human body under repeated measurement or sleep condition, which makes blood pressure monitoring have certain limitations [3]. This article proposes a blood pressure measurement: method-non-contact blood pressure measurement, which is of great significance to promote the non-contact blood pressure measurement method.

2 Non-Invasive Blood Pressure Measurement

2.1 Development of Non-Invasive Blood Pressure Measurement Technology

Blood pressure measurement is actually divided into two methods: invasive and non-invasive. Currently, non-invasive blood pressure measurement is widely used. The invasive measurement method was first carried out on animals. The invasive blood pressure measurement of the human body began in 1856 and it took about a century to be clinically accepted [4]. When using this method to measure, first insert the catheter into the aorta, and the other end of the catheter is connected to the U-shaped tube containing mercury at the beginning. However, due to the large inertia of the mercury column, a transducer was later used instead [5]. Although the results obtained by invasive measurement method are accurate, the operation is complex, which requires high technical requirements on the operator and will bring trauma to the human body, so it has certain limitations [6]. In the 1870s, research on non-invasive blood pressure measurement began to rise, and a technical prototype of the constant volume method was proposed. In the following decades, the oscillometric method still used today was proposed. The non-invasive blood pressure measurement technique is to obtain the human blood pressure value through the extraction, processing, analysis and calculation of pulse signals through the changes of arterial pulses and blood volume generated when blood flows in the blood vessels. In 1905, Korotkoff sound was discovered by Soviet doctor Korotkoff, which laid the foundation for the subsequent Korotkoff sound auscultation technique for blood pressure measurement and became the gold standard for clinical blood pressure measurement [7]. In 1963, the tension measurement method and the double-sleeve belt method were proposed successively. In 1973, the constant volume measurement technology was further developed. At the same time, an American company began to design an oscillometric blood pressure monitor, which was put on the market as a commercial product in 1976. A few years later, someone proposed to use pulse wave conduction time and electrocardiogram R wave to calculate the human blood pressure value. Later, with the development of technology, microprocessor technology was used in the oscillometric method to realize the non-invasive measurement of blood pressure. This method achieved automatic and convenient blood pressure measurement. Noninvasive measurement has gradually become the main method of blood pressure measurement because it is non-invasive, easy to operate and can be measured repeatedly.

2.2 Commonly Used Non-Invasive Blood Pressure Measurement Methods

2.2.1 Korotkoff Sound Method

The Korotkoff-Sound method, also called the auscultation method, has been used earlier in clinical practice, and has always been a common method for manual blood pressure measurement [8]. Its principle is to use the inflatable cuff to compress the artery, after completely blocking the artery, slowly bleed air, in this process to identify the sound of blocked blood flow, detected from the blood vessels to the surface of the body, is the Korotkoff sound. Based on the principle of auscultation, there is a mercury sphygmomanometer. Because the blood pressure value measured by the mercury sphygmomanometer is relatively accurate and stable, it does not need to adjust the reading, and the sphygmomanometer is used for a long time, so the mercury sphygmomanometer has become a commonly used tool in clinical blood pressure measurement at present, as well as an instrument and basis for testing the accuracy of electronic and dynamic sphygmomanometer [9]. Auscultation began with manual auscultation, as the accuracy of the measurements was affected by visual perception and the rate of air release, and was gradually replaced by electronic blood pressure monitors based on the Coriolis method.

2.2.2 Oscillographic Method

The indirect measurement method of blood pressure is represented by auscultation method and oscillometric method [10]. The oscillographic method is also called the vibration method. Use the pressure sensor in the cuff to detect the vibration wave generated when the blood flows through the blood vessel and the pressure signal applied by the cuff, and then calculate the diastolic and systolic blood pressure by fitting the relationship between the two signals. The oscillometric method is more advantageous than the auscultation method in the blood pressure measurement of newborns, children and some severely hypotensive patients because it has less interference and good repeatability. Moreover, the oscillometric method is currently the most widely used measurement technique for blood pressure monitors and ambulatory monitors [11]. When the electronic sphygmomanometer is used, due to the complexity of wearing the cuff during measurement and the long measurement time, it will bring pain to patients when inflating, so this method also has some shortcomings.

2.2.3 Photo Plethysmo Graphy

Photo Plethysmo Graphy (PPG) is a non-invasive detection method to detect blood volume changes in living tissues by photoelectric means. When light hits the skin on the surface of the human body, the contraction and relaxation caused by the beating of the heart will cause the blood volume in the blood vessels to change. When the heart contracts and ejects blood, the blood volume in the blood vessels will increase, so the absorbed visible light will increase, and the detected light will be relatively reduced; the situation during diastole is completely different from that during contraction [12]. Because the heartbeat changes periodically, the light signal detected by the photoelectric receiver also changes periodically [13]. By converting optical signals into electrical signals, volumetric pulse wave signals can be obtained, and then some important physiological parameters of the cardiovascular system can be obtained through analysis and study [14]. Blood pressure measurement based on pulse wave tracing method, getting rid of the limitation of wearing a cuff, there will be no discomfort caused by inflation, and the required equipment is not expensive, and it has the advantages of simple and stable operation, non-invasive and strong adaptability [15]. Therefore, it has received general attention from the medical community at home and abroad. In recent years, many researchers have also done a lot of research on the clinical application of PPG technology, which has been applied to human health examination and monitoring [16].

2.3 Significance of Non-Contact Blood Pressure Measurement

2.3.1 Deficiencies in Common Blood Pressure Measurement Methods

The method of auscultation is influenced by the subjective hearing or vision of the doctor due to the use of artificial auscultation, which leads to errors in judgment and affects the measurement accuracy [17]. Moreover, each person's physical condition is different, and will be interfered by the surrounding environment during measurement, which will also cause deviations in the measurement results. Existing contact blood pressure measurement methods, such as oscillometric method and auscultation method, need to wear a cuff when measuring, and the cuff inflation process will bring some discomfort to people, so it is not suitable for long-term measurement. In the case of patients with extensive skin trauma, or people like newborns who cannot use cuff, blood pressure measurement will be in trouble, and doctors cannot make corresponding and effective treatment measures quickly and accurately, thus affecting the treatment of patients. And some equipment is complicated to operate, not suitable for convenient detection in daily life [18].

2.3.2 Advantages of Non-Contact Blood Pressure Measurement Based on IPPG

Imaging photo plethysmography (IPPG) technology is a detection technology that has received wide attention from researchers in recent years [19]. This technology is very different from traditional methods of detecting physiological parameters. Without touching the human body, the desired parameters can be obtained only through the camera lens. Compared with direct measurement method, auscultation method, oscillometric method, volume compensation method and other measurement methods, continuous non-invasive blood pressure measurement method does not have the restriction of wearing equipment during traditional blood pressure detection, and can carry out long-term blood pressure monitoring. In addition, the pulse signal generated during blood flow contains a wealth of physiological parameter information of the cardiovascular system, which is of great help to blood pressure measurement [20]. Using imaging photoplethysmography technology, combined with the relationship between blood pressure and pulse wave transit time, if the non-contact measurement of blood pressure can be achieved, it is also beneficial to blood pressure measurement clinically.

The contactless IPPG measurement method is suitable for people with limited mobility, infants, or people with skin burns. Aarts verified the feasibility of non-contact IPPG to detect the heart rate of patients or infants, and the results showed that the method had good consistency with the standard method.

Others have used cross-correlation method, autocorrelation method, ICA and other methods to test whether the heart rate measurement based on IPPG is reliable. The experiment shows that the heart rate measurement based on IPPG principle has good reliability. Similarly, it is also feasible to measure blood pressure by non-contact IPPG method.

2.3.3 Research Status of Non-Contact Blood Pressure Measurement

At present, there are more and more methods to measure blood pressure at home and abroad, and the research is deepening gradually. People are not only satisfied with the existing blood pressure measurement methods, but also constantly exploring more accurate non-contact measurement methods. There are some more commonly used methods: blood pressure prediction based on a linear model, the model is BP = alnPTT + b, and blood pressure prediction is performed using pulse wave characteristic values or pulse wave transit time. Currently, more R waves and pulses through ECG signals are used Wave propagation time, train blood pressure linear model to predict blood pressure. There are linear predictions, there are nonlinear models of blood pressure prediction. Among them, the blood pressure prediction model established by PTT has better prediction accuracy; there are blood pressure prediction based on independent component analysis, blood pressure prediction based on support vector machine, based on Bayesian network, Neural network blood pressure prediction. Pulse wave signals are extracted from human skin color images and processed to obtain information needed for blood pressure prediction, which can avoid contact with human body and is also an emerging research direction of blood pressure measurement.

3 The Principle and Technology of Obtaining Non-Contact Blood Pressure

3.1 The Relationship between Blood Pressure and Pulse Wave Transit Time

There are two directions to realize blood pressure measurement by pulse wave method: pulse wave velocity (PWV) and pulse wave transit time (PTT). PTT refers to the time difference caused by the blood flow in the blood vessel to different parts of the body during the same cardiac ejection. PWV was first proposed by British physicist Thomas Young in 1808 [21]. Although PWV has a great correlation with blood pressure, the calculation process is complicated, so the direction has been turned to pulse wave transit time. In 1957, people conducted a lot of research on the relationship between blood pressure and pulse wave transit time, and concluded that there is a linear correlation between the same pulse wave transit time and blood pressure in a certain period of time [22]. Later, through continuous experimental verification, some researchers proved that there is a linear correlation between pulse wave transit time and blood pressure, and it is relatively stable [23].

At first, people derived the relationship between Young's elastic modulus of arterial wall and blood pressure based on the relationship between pulse wave conduction rate and blood pressure [24]:

$$BP = \frac{1}{\gamma}[\ln(\frac{\rho d}{K^2 h E^0}) + \ln(\frac{1}{T_{PTT}})^2] \tag{1}$$

As can be seen from the above equation, there is a good correlation between blood pressure and pulse wave conduction time. In the Eq. (1), E_0 represents the elastic modulus of the blood vessel wall when the blood pressure value is zero, h represents the thickness of the blood vessel wall, d represents the inner diameter of the blood vessel, ρ represents the blood density, l represents the distance between two points on the artery, and The constant K (for the human aorta, generally K = 0. 8), γ is the value of the blood vessel characteristic parameter [23]. Due to the large number of required parameters, it is difficult to calculate. Therefore, if the variable data such as the elastic modulus, thickness and blood density of the blood vessel wall are ignored, the relationship between blood and pulse wave transit time can be expressed as:

$$BP = a - b\ln(T_{PTT}) \tag{2}$$

It was later proposed that if the elasticity of blood vessels remains unchanged, the changes in blood and pulse wave transit time are proportional. The elasticity of human blood vessels is relatively stable in a short period of time without major changes. Therefore, blood pressure is estimated by measuring the pulse wave transit time. The value can be achieved [25]. Therefore, the blood pressure (BP) and pulse wave transit time (PTT) can be approximated as:

$$BP = a + bPTT \tag{3}$$

However, the relationship between blood pressure and pulse wave transit time is not completely linear, but linear fitting is used to approximate it. In view of the limited degree of fitting of the relationship between pulse transit time and blood pressure by the linear equation, we used the neural network to fit the relationship between blood pressure and pulse wave transit time through the prediction stage of the improved model, thereby predicting blood pressure.

3.2 Acquisition of Pulse Wave Signal Based on IPPG Technology

In 1930, some people proposed photoplethysmographic technology (PPG, photo plethysmographic), and IPPG (imaging photoplethysmographic technology) is improved on the basis of PPG technology, does not require the sensor to directly contact the patient's skin, To make up for the insufficiency of commonly used contact methods that cannot collect information on injured skin. Based on the non-contact blood pressure measurement of IPPG, the selected video capture device is an ordinary optical lens, which records the video of the human forehead and a palm at the same time, and then deducts the hand part of the forehead; after obtaining the video sequence, the two parts The pulse wave signal is extracted, some parameters required for measuring blood pressure are obtained from it, the collected data is sorted, and then fitting training is performed to obtain a blood pressure prediction model.

4 Non-Contact Blood Pressure is Obtained through Video Images

4. 1 Acquisition of Pulse Wave Signal

In this article, before getting the time interval of pulse wave signal, the pulse wave signal of the selected part should be collected at first. Because the depth of the light passing through the human tissue is limited, the capillaries in the selected part should be dense and in the shallow layer of the skin, while the capillaries in the part of the face are abundant and there are few interfering factors in the forehead area, so the forehead is selected to obtain one of the pulse signals. The other part chooses the easy recording hand as the object of pulse signal acquisition. The specific steps are as follows:

(1) The tester sat in front of the computer, looked directly at the connected USB camera or the camera built in the computer, and was about an arm's length from the camera. At the same time, the tester raised the left hand or right hand, kept still, and recorded a 10–20 second video. The video is divided into a series of pictures. The frame sequence of these pictures is the time sequence of the video.

(2) Then intercept the forehead area in each frame of the image (the interception part is a rectangle), at the same time take out the palm part, and separate the three RGB channels for each frame of the image to separate the green channel.

(3) Calculate the average pixel gray value of the two green channels for each captured forehead image and palm image.

(4) Select the average pixel gray value of the forehead and the target area of the hand as the vertical axis, and the number of picture frames as the horizontal axis, so as to obtain the PPG signal timing diagram, and then conduct normalized processing of the signal.

4.2 Acquisition of Pulse Wave Signal Transmission Time

In the relationship between pulse wave conduction time and blood pressure, the pulse wave conduction time PTT is actually the time interval generated by the blood flowing through two different parts at the same time of heart contraction. After getting the pulse wave signal of forehead and palm, we should continue to obtain the time interval between them. When the heart contracts, the ventricles eject blood, the blood volume in the blood vessels will increase, and the absorption of light will become greater, so there will be less light detected. The result reflected in each frame of the video is the decrease of gray value; when the heart is diastolic, it is just the opposite. It can be seen that in the pulse wave signal diagram, the time interval obtained by two signal peaks is related to diastolic blood pressure in the relationship between blood pressure and pulse wave transmission time [26]. Similarly, substituting the time interval obtained by the trough is the systolic blood pressure of the human body, which is usually called high pressure. After knowing these, after obtaining two pulse wave signals, we can find the peak and trough generated by the two pulse wave signals, and then calculate the difference between the peak and trough, and then record the obtained data for screening and sorting.

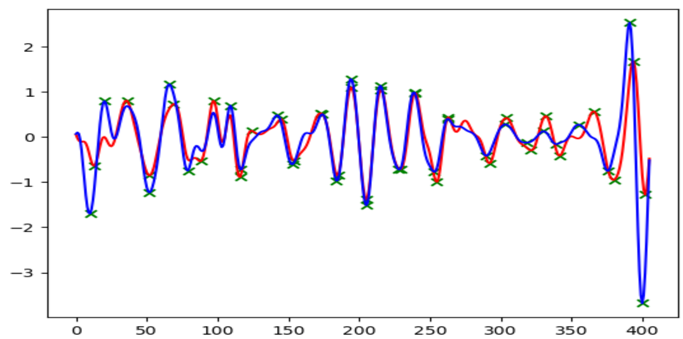

Figure 1: Acquisition of pulse wave signal of PTT (red: head, blue: hand)

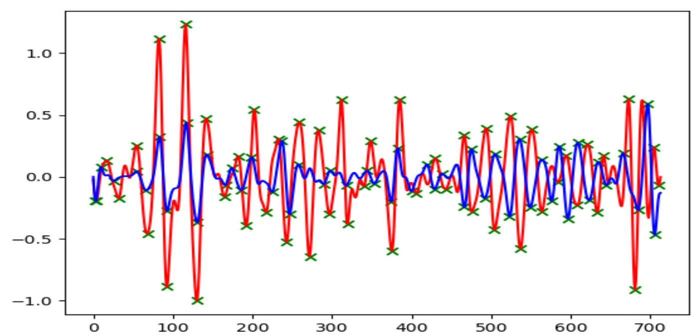

Figure 2: Pulse wave signal map of blood pressure prediction (red: head, blue: hand)

4.3 Acquisition of Non-Contact Blood Pressure Values

In order to achieve non-contact blood pressure measurement, in addition to obtaining the pulse wave signal and the time difference between the two, the blood pressure value of the measured individual when recording the video is also required. Before starting the measurement, with the help of professionals, the accurate blood pressure values of the selected individuals were measured. The systolic blood pressure was 100 mmHg and the diastolic blood pressure was 70 mmHg. During measurement, the tester sits facing the collection lens, puts an Omron wrist electronic sphygmomanometer on his left (or right) wrist, presses the sphygmomanometer switch first, then carries on the forehead and hand video collection on the computer, and stops the video recording when the sphygmomanometer measurement is completed. After that, the collected individual blood pressure value, peak difference and trough difference between two pulse wave signals were recorded.

In view of the limited fitting degree of the first-order equation to the relationship between pulse conduction time and blood pressure, we use neural network to fit the relationship between blood pressure and pulse conduction time by improving the prediction stage of the model, so as to predict blood pressure. We used a 2-layer neural network with 128 neurons in each layer. The number of neurons is usually raised to the integer power of 2, and we chose 128 rather than larger or smaller, mainly because using 128 neurons can already well represent the relationship between pulse conduction time and blood pressure. If a few neurons are selected, the relationship expression is not clear enough, and the predicted value will be inaccurate. If more neurons are selected, more data is needed to fit. In general, our data are relatively small. Training will lead to overfitting of the model, which will lead to poor generalization ability of the model. When the data with different sample distribution are predicted, the prediction error will be very large. The neuron in the first layer is connected with ReLU for nonlinear activation processing. If the nonlinear activation function is not used, the function of the two-layer neural network can be represented by using one layer in fact. Using nonlinear activation, the model can fit a stronger relationship and can fit a nonlinear relationship.

We choose Omron wrist electronic sphygmomanometer to measure blood pressure, and calculate the pulse transit time through the program, so that we have input data:pulse transit time and true label blood pressure value. The collected data is processed, 10% of the data is used as the test set, and the remaining 90% of the data is used as the training set to train and predict the neural network. The collected data is processed, 10% of the data is used as the test set, and the remaining 90% of the data is used as the training set to train and predict the neural network. In the process of training, we used the initial learning rate of 0.1, batch processing size of 32, and iterated 1000 epoches to reduce the learning rate, multiplying the learning rate by 0.1, a total of 12 times. The model is approximated by using the mean square error as the loss function. The mean square error converges faster when the error is large. The loss function of the model is trained until the model convergence is completed and the loss function of the model no longer has a large float.

The final structure of our model is as follows:

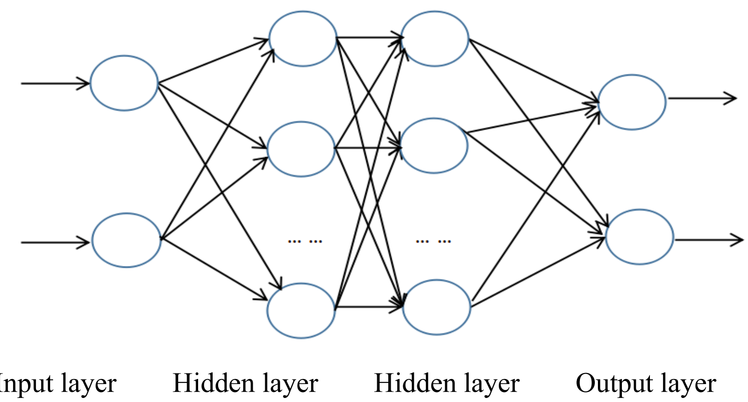

Figure 3: Three-layer fully connected neural network

Finally, the systolic and diastolic pressures were obtained based on the collected peak and trough differences of pulse waves and real-time individual blood pressure.

Table 1: Comparison of measured and predicted measurement results

Number of groups	Actual measurement P_S	Prediction P_{S1}	P_S error (%)	Actual measurement P_d	Prediction P_{d1}	P_d error (%)
1	92	95	3.1579	68	67	–1.4925
2	103	102	–0.9804	62	62	0.0000
3	106	97	–9.2784	67	61	–9.8361
4	89	87	–2.2989	68	65	–4.6154
5	108	101	–6.9307	66	69	4.3478
6	99	95	–4.2105	62	65	4.6154

7	93	92	–1.0870	69	63	–9.5238
8	93	93	0.0000	60	63	4.7619
9	90	91	1.0989	61	64	4.6875
10	102	99	–3.0303	69	68	–1.4706
11	106	100	–6.0000	66	68	2.9412
12	100	98	–2.0408	65	60	–8.3333
13	100	96	–4.1667	70	67	–4.4776
14	102	99	–3.0303	63	66	4.5455
15	98	100	2.0000	62	65	4.6154
16	103	101	–1.9802	65	63	–3.1746
17	99	97	–2.0619	67	70	4.2857
18	94	96	2.0833	60	63	4.7619
19	100	103	2.9126	64	62	–3.2258
20	93	95	2.1053	66	67	1.4925
21	91	92	1.0870	59	60	1.6667
22	93	92	–1.0870	62	65	4.6154
23	92	94	2.1277	63	60	–5.0000
24	96	99	3.0303	62	63	1.5873

5 Error Analysis of Non-Contact Blood Pressure Measurement

Different individuals were selected for the test, and 10–20 seconds of videos containing pulse wave information of human forehead and palm were collected respectively. At the same time, an Omron wrist electronic sphygmomanometer was used to measure systolic and diastolic blood pressure at the corresponding time. For each video, the pulse wave signal and the time difference between the forehead and palm video sequences were obtained based on the IPPG contactless acquisition of pulse wave conduction time. Predict the systolic blood pressure P_{S1} and diastolic blood pressure P_{d1} of the human body through the blood pressure prediction model.

Compare the systolic blood pressure P_S and diastolic blood pressure P_d measured by the electronic sphygmomanometer with the predicted systolic blood pressure P_{S1} and diastolic blood pressure P_{d1}, and calculate the error between them. The error calculation formula [26] is:

$$e_{P_S} = \frac{P_{S1} - P_S}{P_{S1}} \times 100\% \tag{4}$$

$$e_{P_d} = \frac{P_{d1} - P_d}{P_d} \times 100\% \tag{5}$$

Through the data obtained, it can be calculated that the blood pressure value predicted by using the optical lens to record the video is compared with the Omron wrist electronic blood pressure monitor. The error range of the obtained systolic blood pressure is: –9.28%~3.16%; the error range of the diastolic blood pressure is: –9.84~4.76%.

For the errors caused by these two methods, there are mainly the following reasons. First, when using the electronic sphygmomanometer to obtain the real-time blood pressure value, due to the unskilled method and improper operation, the position of the measured wrist was deviated from the level of the heart, resulting in the deviation between the actual blood pressure measurement result and the predicted blood pressure value. Second, in the process of acquiring pulse wave signal through recording video, the light will change due to the different environment in which the data is collected, which will cause the pulse wave signal to change and affect the prediction result. Third, when performing non-contact blood pressure measurement, the posture of the arm wearing the wrist electronic blood pressure meter changes midway, resulting in a large difference between the predicted result and the actual measured value, resulting in errors.

6 Conclusion

Based on the non-contact blood pressure measurement of IPPG, the blood pressure of the human body is predicted through the video image obtained by the optical lens. Compared with the method of obtaining the phase difference and heart rate of pulse wave signal with high-speed camera, the optical lens has simple equipment requirements, low cost and different selection of video acquisition area. Neural network is used for training and prediction, curve fitting is not used, and the accuracy of diastolic blood pressure predicted by this method is improved. Compared with the method of extracting the pulse wave signal by selecting the forehead and hand as the region of interest, and enhancing the skin color by Euler amplification method, it is relatively easy to obtain pulse wave signal without complexion enhancement or pulse wave characteristic parameter extraction. Also based on the relationship between pulse wave transit time and blood pressure, the non-contact blood pressure prediction method in this paper does not need to collect ECG signals in addition to the pulse wave signal to obtain the blood pressure value, which is much easier to operate.

Use a non-contact measurement method based on the IPPG principle to measure blood pressure. On the one hand, there is no need for the measuring equipment to contact with human skin, and the measured person will not feel uncomfortable during the measurement.

On the other hand, for people who cannot wear cuff, such as people who have skin damage, infants and other people, blood pressure measurement will be conducted by non-contact measurement method, which will make measurement more convenient and comfortable. Non-contact blood pressure acquisition based on optical lens and IPPG, compared with the existing contact blood pressure measurement method through video capture of the human body, it has the advantages of non-contact, non-intervention, and simple operation. On the one hand, the method used in this paper still needs to be improved in the accuracy of blood pressure prediction. More blood pressure data of different age groups should be collected for training, and the blood pressure prediction model should be improved to make the blood pressure prediction more accurate and reliable. On the other hand, it also provides a non-interventional measurement method for blood pressure detection. Making the blood pressure measurement method more comprehensive and more widely used, making daily blood pressure monitoring feasible and convenient for people to monitor blood pressure daily, which is of great significance for the popularization of blood pressure monitoring.

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