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AUTOMATIC BLOOD PRESSURE FOR WEARABLE HEALTH MONITORING USING IOT TECHNOLOGY

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Abstract. *The number of patients at high risk of developing hypertension has been increasing over the years. They need to be checked up by medical staff which requires a complicated process. In order to make it more effective, this article presents a remote blood pressure monitoring system through the IoT system. The system will use a new blood pressure calculation using oscillometric method and digital image processing technique. The result will be sent from the IoT to an application on a smartphone of a user which allows the user to see the blood pressure continuously. Besides, the blood pressure and heart rate results were shown to be more accurate compared with commercial digital B.P. Monitor at rates of 98.29%, 96.95% and 97.61% on average for systolic pressure, diastolic pressure and the heart rate values, respectively.*
Keywords: Blood pressure, Auscultatory technique, Oscillometry, IoT for health care

1. **Introduction.** Nowadays smart electronics technology has been used in biomedical engineering in order to improve healthcare quality. Most of the systems are improved in the form of remote medical and at home, which can be performed at home effectively [1-4]. This improves quality of life and reduces the uncomfortable feeling of getting medical treatment at a hospital. High blood pressure is supposed to be checked continuously. High blood pressure means someone who has more than 140 mmHg systolic and 90 mmHg diastolic [5]. It is a chronic disease which was predicted to affect one fourth of the adult population globally, as well as a risk factor for other chronic and non-chronic patients [6]. Therefore, the system is crucial for high-risk patients, that is imperative to continually monitor their blood pressure using a system that does not interfere with the patient's normal daily activities. Based on the data collected during ongoing monitoring, doctors can track the daily evolution of blood pressure values. In addition, these devices can also alert a remote alarm to the doctor. The most commonly used method for measuring blood pressure is the auscultatory method. This method is based on the contemporary use of a sphygmomanometer and a stethoscope. The method is based on listening to the arterial sounds in accordance with the principle of Korotkoff sounds. This method is difficult to analyze because of the physiological variation in Korotkoff sound patterns. Moreover, small signals will be disturbed by ambient noise and misleading information can occur [7,8]. Instead of the auscultatory method, there are other important indirect methods such as the oscillometric method, which is one of the best approaches to evaluating the systolic and diastolic blood pressure [9,10]. The oscillometric method is one of the methods used in electrical BP measurement instruments [11,12]. Therefore, the oscillometric method is suitable for daily health monitoring [13] and long-term measurements [14]. Practically,

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the user may place a sphygmomanometer cuff around the upper arm. The oscillations caused by heart pumping are changed with the altered pressure in the cuff. The observed pressure oscillations are measured with an electronic pressure sensor. When the cuff pressure is close to the mean blood pressure (MBP), the peak of oscillometric curve will occur. In general, the systolic blood pressure (SBP) and diastolic blood pressure (DBP) are corresponding to the pressure of 0.5 times and 0.8 times of oscillometric peak, as shown in Figure 1. The estimation of SBP and DBP from oscillometric waveform is important. Lim et al. [15] proposed an improved measurement of blood pressure in terms of extracting the characteristic features from the cuff oscillometric waveform. Their study employed the multiple linear regression (MLR) and the support vector regression (SVR) for the relationship discovery. Moreover, Koohi et al. [16] presented a dynamic threshold algorithm to evaluate trustworthiness of the estimated blood pressure in oscillometry. Arakawa et al. [17] presented the development of non-invasive steering-type blood pressure sensor for driver state detection. From the above research, it has been found that digital signal processing techniques in conjunction with oscillometric principles have not yet been applied for the real-time measurement of blood pressure. This technique allows for highly accurate blood pressure measurements because it can measure and distinguish signal elements effectively. This paper presents the electronic unit to perform a non-invasive measurement of the blood pressure based on the oscillometric method that calculates the blood pressure using digital signal processing techniques, where the proposed system provides accurate measurement of blood pressure. It also sends data via the IoT system, which will make it convenient for users and can monitor the blood pressure continuously remotely and alert when an emergency occurs to the patient via SMS on the smart phone of doctors and caregiver to be able to provide timely assistance.

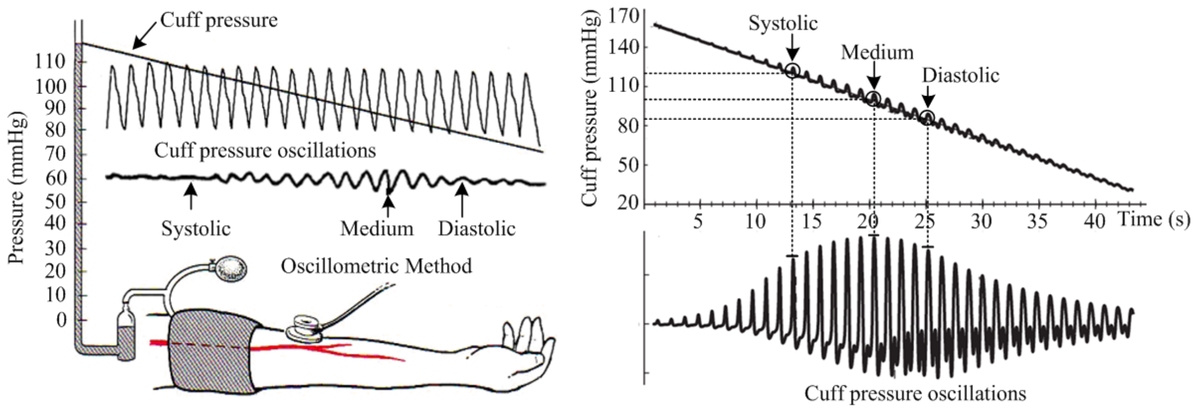

FIGURE 1. Oscillometric measurement of blood pressure

2. Principles and Methods.

2.1. Oscillometric measurement of blood pressure. Today one of the most common automatic blood pressure devices relies on oscillometric processes [8]. In this method, the cuff placed on the arm of the patient is inflated with air until the blood flow in the arm artery is stopped. After that, the blood in the arteries begins to flow again while the pressure of the cuff placed on the arm decreases; meanwhile, the small oscillations occurring in the cuff pressure because of the heartbeat are observed. The amplitude of the oscillation is increased while the cuff is being deflated. Subsequently these oscillations slow down and disappear.

Systolic blood pressure can be determined by measuring the cuff pressure at the moment when the oscillations start, while diastolic blood pressure can be determined by measuring the cuff pressure at the moment when the oscillations begin to disappear. The mean arterial pressure (mean blood pressure) is determined by means of the cuff pressure observed at the moment when the oscillations with the highest amplitude occur while the cuff is deflated. Thereafter, systolic and diastolic blood pressure is estimated using mathematical formulas. There is no clear information on the matter, as these formulas are trade secrets of the manufacturer. Different systolic and diastolic ratios are used for each device. The oscillation amplitude produced by the oscillometric method is shown in Figure 1 [9,10]. For example, research on automatic noninvasive measurement of arterial blood pressure [7], study of the measurement of systolic blood pressure by means of the detection of the blood pressure pulses' reappearance during cuff deflation has the potential to provide accurate automatic measurement of systolic blood pressure. In Figure 1, the criterion for systolic and diastolic blood pressure was an oscillometric wave with amplitudes of 0.6 and 0.8 of the maximal amplitude of the oscillometric wave derived from blood pressure measurement, respectively.

2.2. **Proposed measurement of blood pressure.** The proposed new method of calculating the blood pressure is based on the calculation using oscillometric method in conjunction with digital signal processing. The process presented is shown in Figure 2. This will store data with the ESP32 microcontroller, and it will start to store data when the ESP32 receives the clock (x_0), in which the data is stored as an array variable by storing the output of pressure sensor ($V[N]$) and oscillometric signal ($a[N]$) as equation

$$V[N] = [V_0, V_1, V_2, \ldots, V_N] \tag{1}$$

$$a[N] = [a_0, a_1, a_2, \ldots, a_N] \tag{2}$$

Then the output of pressure sensor will be converted to the blood pressure value using the equation

$$BP[N] = [0.0844 \times V[N] - 35.215] \tag{3}$$

When all the data is collected, the system will calculate the result by finding the maximal amplitude ($A_{\max}$) and index of $A_{\max}$ in the variable $a[N]$. When the value $A_{\max}$ is obtained, the system will calculate the value $A_S = 0.6A_{\max}$ and $A_D = 0.8A_{\max}$ to determine the index that yields the systolic and the diastolic blood pressure.

The determination of the systolic blood pressure was initiated by the determination of the variable $a[N]_S$ whose conditional value $A_S = 0.6A_{\max}$ is but in actual operation, variable $a[N]$ may not have a value that matches A_S. Therefore, the value must be met as follows:

$$0.5A_{\max} \le a[N]_S \le 0.7A_{\max} \tag{4}$$

where $a[N]_S$ must have an index that is less than the index of $A_{\max}$, when $a[N]_S$ is obtained, the system will use the index of $a[N]_S$ to determine the index of the $BP[N]$ variable to bring the corresponding $BP[N]$ value to show the value as the systolic blood pressure.

The determination of diastolic blood pressure was initiated by the determination of the variable $a[N]_D$ whose conditional value $A_D = 0.8A_{\max}$ is but in actual operation, variable $a[N]$ may not have a value that matches A_D. Therefore, the value must be met as follows:

$$0.7A_{\max} \le a[N]_D \le 0.9A_{\max} \tag{5}$$

where $a[N]_D$ must have an index that is over the index of $A_{\max}$, when $a[N]_D$ is obtained, the system will use the index of $a[N]_D$ to determine the index of the $BP[N]$ variable to bring the corresponding $BP[N]$ value to show the value as the systolic blood pressure. In addition, the system uses the value $x[N]$ to calculate the heart rate. The equation can be written as

$$HR = \frac{1}{x[N]/N} \times 60 \text{ bpm} \tag{6}$$

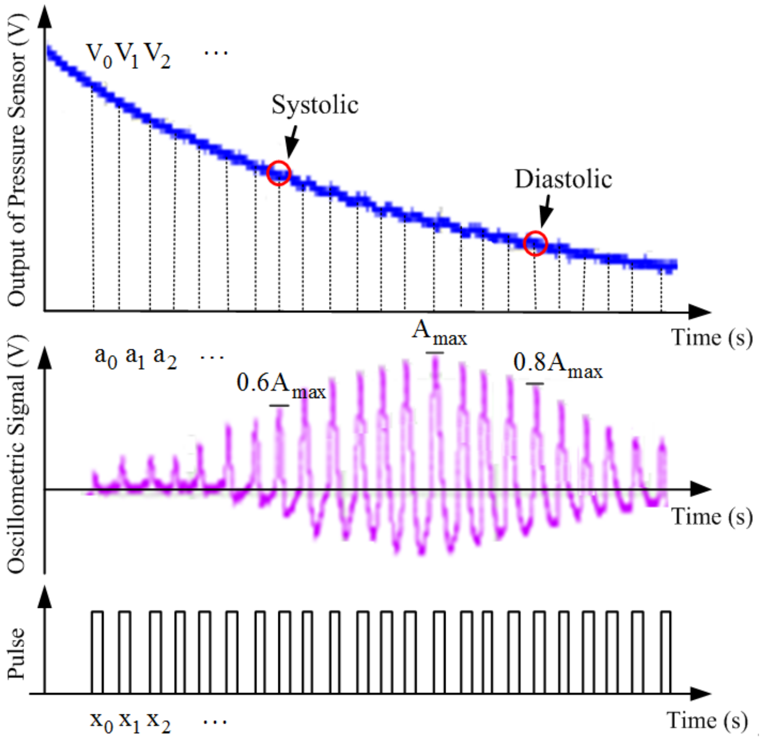

FIGURE 2. Proposed measurement of blood pressure

2.3. **Circuit design.** Based on the principle of calculating blood pressure according to the proposed principle, a circuit for measuring blood pressure can be designed as shown in Figure 3. The circuit consists of instrument amplifier circuit, band pass filter circuit, inverting amplifier circuit, low pass filter circuit and comparator circuit respectively. From Figure 3, the working principle is to obtain blood pressure from the cuff placed on the arm by using a pressure sensor. The sensor output is then amplified so that it can be used for signal processing. These values are used to generate three signal patterns: the voltage dependent on the cuff placed on the arm (V_{PC}) pressure value, the value of the oscillometric wave signal (V_{OSC}) and the value of the clock signal (V_P), respectively.

The three output signals are used as inputs to the microcontroller for the calculation of systolic and diastolic blood pressure and heart rate.

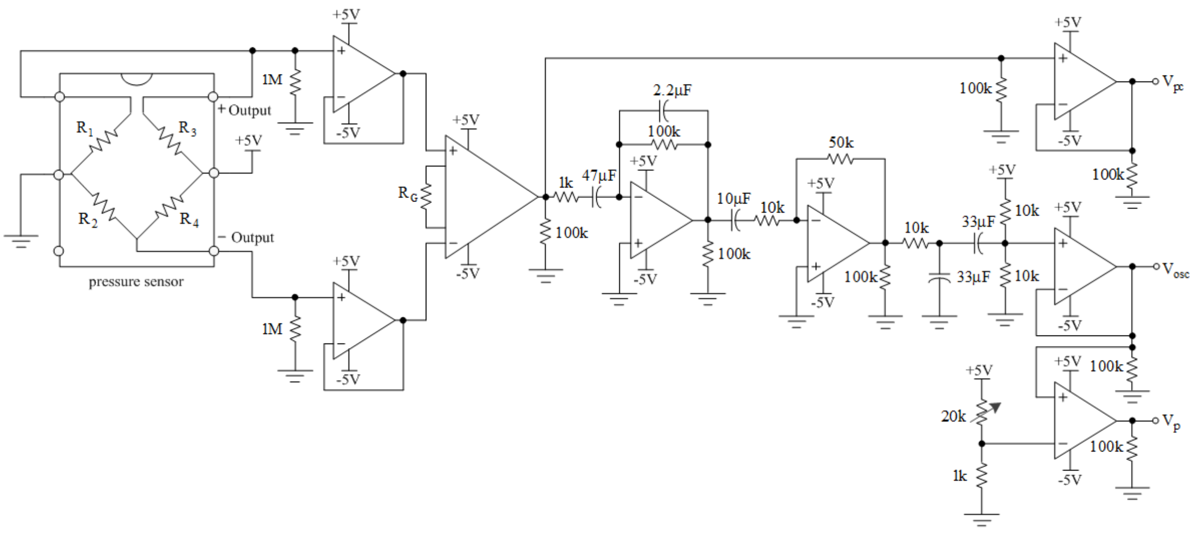

FIGURE 3. Circuit design for the proposed measurement of blood pressure

2.4. **IoT based B.P. Monitor.** The IoT system is used in this article to make the blood pressure monitoring system more intelligent, so that the system can continuously monitor the patient's blood pressure, remotely, and can alert to physicians for patients and their relatives. This will result in immediate assistance to patients. The proposed IoT system is shown in Figure 4. The system will work on the basis of Blink Server.

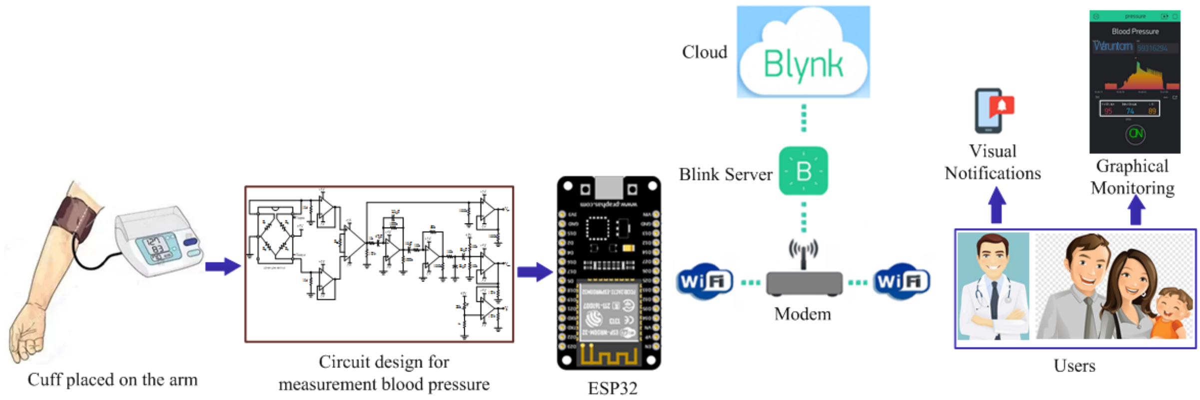

FIGURE 4. IoT based B.P. Monitor

3. **Experimental Results and Discussion.** The proposed system tests are divided into 3 parts: Part 1, the circuit proposed system testing, Part 2, calibration of the proposed blood pressure monitor with standard machines, and Part 3, blood pressure and heart rate monitors presented testing via IoT system with 10 healthy subjects compared with Commercial Digital B.P. Monitor. The test results are shown in Figure 5, which is the output of the proposed circuit. It consists of output of the pressure sensor, oscillometric waveform and clock waveform respectively. Figure 6 shows the results of the calibration presented with the sphygmomanometer which gives a similar pressure value with a coefficient of determination of $r^2 = 0.999$.

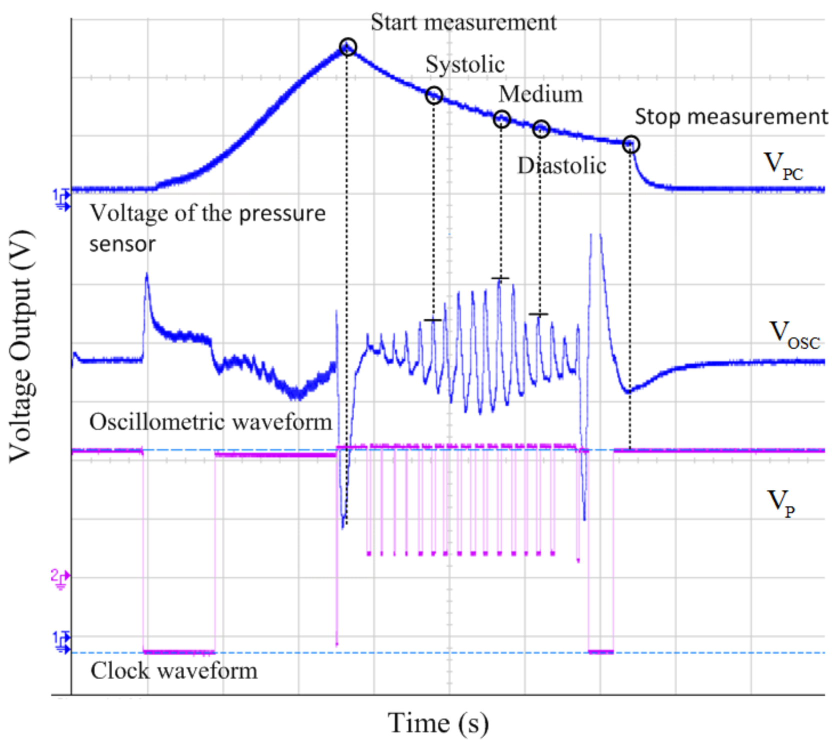

FIGURE 5. Output of circuit design for the proposed measurement of blood pressure

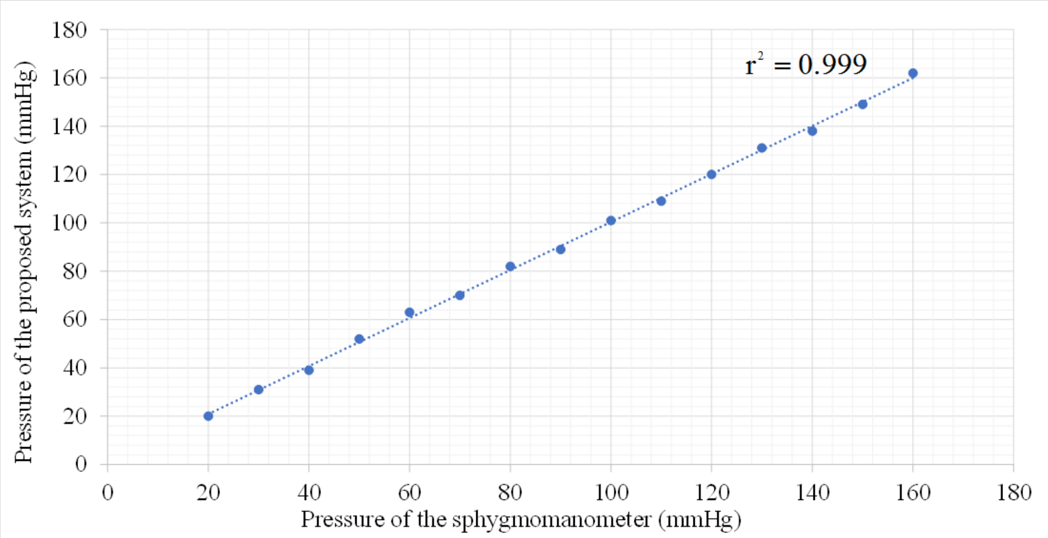

FIGURE 6. Comparison of our monitor with the sphygmomanometer

TABLE 1. Comparison of our monitor with a digital B.P. Monitor available on the market

Subject	Commercial Digital B.P. Monitor			IoT Based B.P. Monitor			Accuracy (%)		
	Systolic (mmHg)	Diastolic (mmHg)	Heart rate (bpm)	Systolic (mmHg)	Diastolic (mmHg)	Heart rate (bpm)	Systolic (mmHg)	Diastolic (mmHg)	Heart rate (bpm)
1	122	83	79	120	88	80	98.3	94.2	98.7
2	117	75	76	116	78	74	99.1	96.1	97.3
3	112	68	80	113	67	79	99.1	98.5	98.7
4	114	69	79	111	71	82	97.3	97.1	96.3
5	123	70	80	121	72	78	98.4	97.2	97.5
6	97	76	87	95	74	89	97.9	97.3	97.7
7	98	75	76	97	72	75	99.0	95.9	98.7
8	116	76	85	112	74	82	96.5	97.3	96.4
9	114	70	78	115	72	75	99.1	97.2	96.1
10	111	75	76	109	74	75	98.2	98.7	98.7
						Average	**98.29**	**96.95**	**97.61**

As for the test with 10 healthy subjects, the test results will be shown in Table 1. The results of the measurements show that the developed prototype made measurements with accuracy rates of 98.29%, 96.95% and 97.61% on average for systolic pressure, diastolic pressure and the heart rate values, respectively.

When testing by paired samples test, the results were found that the systolic pressure, diastolic pressure and the heart rate values obtained from commercial digital B.P. Monitor and IoT based B.P. Monitor were not statistically different at p value < 0.05, shown as in Table 2.

TABLE 2. The results of paired samples test

	Paired differences					t	df	Sig. (2-tailed)
	Mean	Std. deviation	Std. error mean	95% confidence interval of the differences				
				Lower	Upper			
Pair 1 test1 – test2	0.57333	7.91197	0.91360	−1.24705	2.39371	0.628	74	0.532

IoT users can display blood pressure and heart rate measurements through smart phone applications via Blink platform. The user interface is shown in Figure 7. In addition, emergency information is sent to SMS on the user's smart phone when blood pressure anomalies occur.

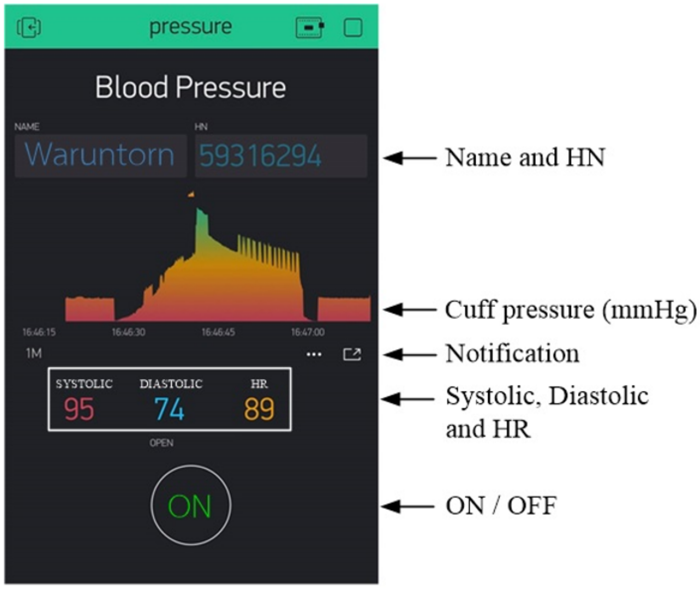

Figure 7. IoT blood pressure monitor user interface

4. **Conclusions.** This study proposed the wireless blood pressure device with IoT technology based on the principles of oscillometric method in conjunction with digital signal processing. The system was developed for an interface with a smart phone to display and control the operation of blood pressure monitors. A new algorithm used for estimating blood pressure and heart rate is also being developed. The developed wireless blood pressure monitor was tested by 10 healthy subjects at different ages. Besides, the blood pressure and heart rate results were shown to be more accurate compared with commercial digital B.P. Monitor at rates of 98.29%, 96.95% and 97.61% on average for systolic pressure, diastolic pressure and the heart rate values, respectively. From the study, that the system provides accurate and real-time blood pressure measurements. Therefore, the approach to developing the system will use AI to analyze data and predict events that indicate patient anomalies in advance of the dangers that will occur to patients so that they can receive treatment in a timely manner.

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