Device to Detect Acupuncture Points in the Feet Soles for Massage Treatment

Quyen Manh Nguyen, Tuan Hoang Nguyen, Lam Van Tran, Tin Thanh Dang, and Anh Dinh

Abstract This paper presents a massage-treatment prototype on acupuncture points whose method of detecting is based on differences of blood oxygen saturation ratio. Sensor MAX30100 is used to measure blood oxygen saturation (SpO2) of more than 20 people in bright room conditions with an intensity of 115 lx and an ideal dark room condition. Then based on Beer's law of absorbance and experiment, we determined that the points with SPO2 concentration over 99.2% are the locations of the acupuncture ones in order to perform biological massaging pulse. The main scientific principle is the diffuse remittances of diverse red led from meridian and acupuncture point that make blood oxygen saturation levels higher than other areas. In the experiment, we also consider prudently the results of tissues surrounding acupuncture points with the distance of 5, 10 and 20 mm and the influence of that to the final outcome. In general, the final result is reliable with moderate accuracy. However, there are some drawbacks in this system such as errors for people who have inappropriate skin surface for optical detection.

Keywords Oxygen saturation · Acupuncture points · Beer's law · SpO2

1 Introduction

Acupressure, especially foot massage, also known as "foot reflexology" is a popular oriental medical treatment and described as a magical therapy. This therapy has been known to indigenous people in Africa, also been practiced by ancient Chinese and Egyptians a long time ago. There are also numerous studies that verify foot

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reflexology not only promotes circulation of local blood, improves the metabolism of nutrients, makes the muscles, bones, joints soft, supple, but also enhances resistance and immune system. Acupressure is considered as a proper remedy in hospitals performed by professional acupuncturists in order to impact a distinguish acupuncture point for desired health recovery. However, it is not easy to detect and influence precisely the appropriate points due to the complexity of the human body and the Chinese acupuncture map. Therefore, most of the acupuncturists follow their instinct and experience. The unclear proofs of acupuncture points and *qi* make this therapy seem suspicious to a group of people although having great beneficial health impacts. As a result, many scientists urge to find proof that people need to specify the unique characteristic of the acupuncture points. Throughout various experiments and hypotheses, there are two methods that are considered to be reliable: electrical properties and the optical absorption features of the acupuncture points.

In this paper, based on the optical absorption features of the acupuncture points, we measured the concentration of saturated oxygen in the feet soles and tried to find the different characteristics between the acupuncture points and the other nits. We also investigated the tissue properties around that location for the best overview. As a result, we have created a product that can both detect acupuncture points and massage with a biological pulse at that point. The structure of this paper consists of the following main parts: Sect. 2 lists several previous research works and experimental results. Section 3 details the hardware structure of our model system. Section 4 explains the algorithm to calculate oxygen saturation of a specific point in foot soles and determine a threshold for an acupuncture point via a descriptive statistics method. Section 5 provides empirical results in two experimental conditions with comparisons of results evaluation. Finally, the last part will summarize the assessment of the pros and cons and the prototype applicability in practice.

2 Related Works

In the past, there were many methods to study the optical absorption features of the acupuncture points in the soles of feet. Langevin et al. [1] carried out physiological studies and show the dissecting relationships of acupuncture points and meridians with connective tissue planes. By physical aroma John et al. [2] showed that meridians have lower resistance or impedance than others. Han et al. [3] presented a fiber-optic diagnostic method to identify acupuncture points under the thin cuticles. A fiber with a diameter of 600 μm is used in connecting with the cuticles to get information from the scattered light of the tissue layer. The light is emitted from halogen-halogen lamps (FOK-100W, Optical fiber, Korea) to single fiber with a diameter of 600 mm and then to the sample. Backlight scattering from samples is recovered by a spectrophotometer (HR4000G, Ocean Optics, USA). The analysis results show that the reflexion of the meridian point of Wai Guan is measured larger than the neighboring tissue in almost the entire wavelength. However, these methods have the disadvantage of limiting the ability to reproduce on the same subject because they have to contact the skin tissue.

Some of the following methods use a non-invasive sensor system that has the advantage of not causing any discomfort or irritation. Baik et al. [4] proposed a new procedure to observe the long-standing floating fiber structure inside biological photon engineering vessels. The main technique is to inject acridine-orange into the femoral vein and dye the nucleus of the intravascular fibers inside the blood vessel, then observe it under a fluorescence microscope. Lo [5] used infrared imaging to describe the effect of acupuncture on a patient's acupuncture points. He used a Meditherm2000 with the degree Celsius resolution of 0.01 °C, and a detector kept at 13 K measuring all infrared radiation from points on the body. The patient is acupuncture needles used by a doctor at a point located a certain distance from the area of pain, while the infrared camera constantly observes hot spots. Observation results showed that the temperature in the pain zone continuously decreases in the range of 0.5–2 °C.

Han et al. [6] have presented a new way to detect non-invasive human meridians. The main technique is to use three laser beams of He–Ne 633 nm (Melles Griot), 658 and 785 nm laser diodes (LQC, Newport) that have been modulated in 10 Hz by an optical cutting machine (SR540, Research System Stanford). The collected fibers are a double fiber investigation containing two strands with a main diameter of 600 mm (Ocean Optics) connected to PMT (Oriel, USA). The signals can be recorded and analyzed later. Research shows that light attenuation is less transmitted along pericardial meridians than along non-meridional directions.

3 Hardware Platform

See Fig. 1.

3.1 Sensor Max30100

I^2C address of the MAX30100 sensor is 0×57. Data is stored in a FIFO buffer up to 16 measurements, where each sample is a size of 4 bytes [7]. In the project, the sensor is set up to operate in Heart Rate and Oxygen Saturation mode with 100 Hz sampling rate, 1600 μs LED pulse width, 50 mA infrared led current and 27.1 mA red led current.

3.2 Vibration Motor

The speed of the motor is 6000 rpm at the voltage of 3 V, which is powerful enough to be a massage probe. This small-sized vibration motor is attached to a probe for massage purposes. PWM port 10 control on–off BJT C1815 in order to create a pulse

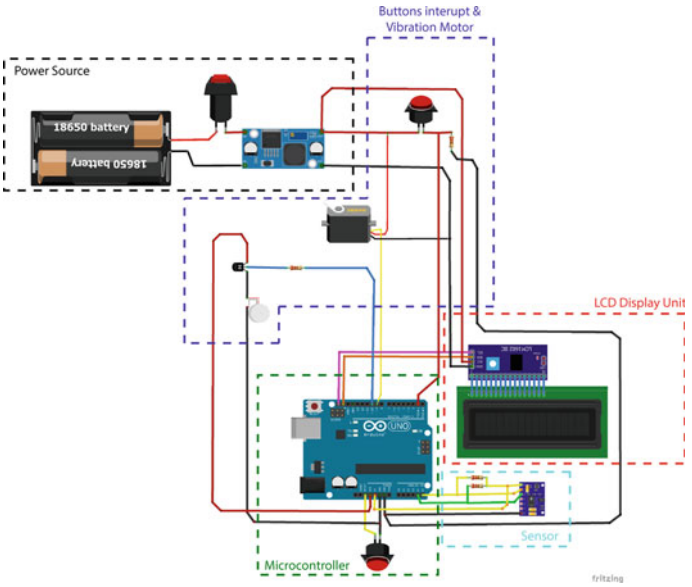

Fig. 1 The detailed wiring diagram for the system

Ultra Reiz (frequency of 143 Hz) with positive biological impact on the human body. The voltage source V_{CE} is 3.3 V from the Arduino Uno R3.

4 Acupressure Detection Method

4.1 Principle of Measuring SpO2

Oxygen saturation is the ratio of the hemoglobin component that contains oxygen to the total hemoglobin in the blood. Normal oxygen saturation ranges from 94 to 100%. Chromatographic measurements work based on the light absorption of Hemoglobin (Hb) and Oxyhemoglobin (HbO2) is different for 2 different wavelengths of Red light (660 nm) and Infrared light (905 nm). HbO2 absorbs more Infrared light than Red light [8]. According to BEER's law, the total amount of light absorbed will be proportional to the concentration of that light absorber. The oxygen saturation can be determined by Beer-Lambert Law:

$$SpO2 = \frac{R.\text{Ext}(Hb, \lambda_2) - \text{Ext}(Hb, \lambda_1)}{R.(\text{Ext}(Hb, \lambda_2) - \text{Ext}(HbO_2, \lambda_2)) + (\text{Ext}(HbO_2, \lambda_2) - \text{Ext}(Hb, \lambda_2))} \quad (1)$$

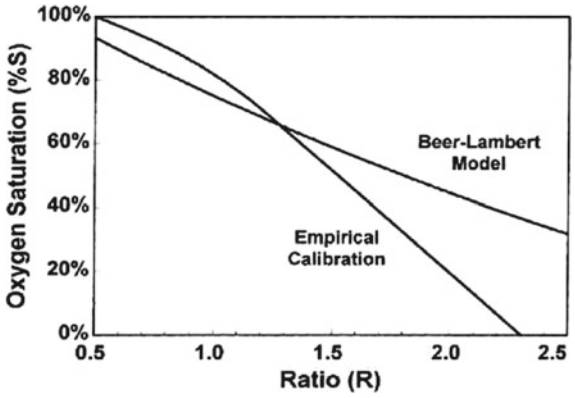

Fig. 2 Relationship between R and Oxygen Saturation [9]

where R is the ratio of Red light to Infrared light received from the sensor:

$$R = \frac{\log(AC_{red})}{\log(AC_{Infrared})} \tag{2}$$

In the prototype, the above Beer-Lambert Law can be simplified by this equation:

$$SpO2 = A + B.R \tag{3}$$

where A and B are two crucial constants required to calculate in order to find precisely the SpO2 ratio. Therefore, we use a medical device Accuro II (Charmcare) to calibrate. Following the Beer-Lambert model, we assume that there is a linear relationship between the SpO2 ratio that is larger than 80% and R. The calibrating procedure of the sensor Max30100 is experimented in an ideal environment (darkroom) to reduce the light noise that interferes final result of the sensor (Fig. 2).

4.2 Algorithms for Acupuncture Points

There are two operating modes in our device: mode 1 for detecting acupuncture point and mode 2 for triggering a massaging pulse to determinate one. The change of 2 operating modes can be easily implemented by the interrupt mechanism when the button is pressed.

Mode 2 is for massage purpose; the PWM will be created at port 10 to control the vibration motor at a desired frequency and duty cycle. The massage pulse is a modified pulse Ultra Reiz (frequency of 1.43 Hz). That means the condition of port 10 will be HIGH for 0.2 s and LOW for 0.5 s.

Mode 1 is for detecting acupuncture point, which is the starting mode of the loop. When activating mode 1 for the first time, all the results of the sensor are updated.

We will check if the pulse is detected, the procedure for stabilizing sensor (delay 5 s) is implemented due to the value of the index is 0. After that, SpO2 results will be re-updated and the average of ten Oxygen Saturation results from sensor Max30100 overtime starts computing (Average-value Procedure). The crucial condition for this procedure is that the value of Oxygen Saturation cannot be null: $Result.SaO2! = \text{'\0'}$.

To be more detailed, the SpO2 result after each loop is added to a sum following the index increase of one unit. When the sum is an addition of ten SpO2 results which means the index reaches value 10, the condition statement begins. In this, the final Oxygen Saturation ratio that would be displayed on LCD is the average of sum, the index and sum are reset and the procedure will start again.

$$sum+ = result.SaO2;$$

$$SpO2 = sum/10;$$

Furthermore, in order to ensure precisely the location of an acupuncture point, we propose a solution using the oxygen-saturation threshold and continuous data stability. The principle of continuous data stability is quite simple: the detecting point in the foot sole would be considered as an acupuncture point if after every average-value procedure, continuously numerous return values of SpO2 were always greater than a threshold. In our algorithm, by using a global variable: times, at least three consecutive values responded to the condition would be believed to determine whether the point is an acupuncture one or not. That means after every average-value procedure, SpO2 will be compared with the threshold, the times would increase if SpO2 satisfied the condition. Any value that is smaller than the threshold will change the determination by setting the times back to 0. LCD will display the notification of the founded acupuncture point when times reaches 3. Finally, times are reset for the beginning of the new loop.

We believe that our algorithm would build up a reliable method to detect and study the acupuncture point. However, the problem of this is the figure of the proposed threshold. It is required the various number of reference data to do the statistic and result in a trustworthy outcome. The process of finding the threshold will be presented in the experimental result section (Fig. 3).

5 Experimental Setup and Results

5.1 Experimental Setup

The experiment was performed in 20 people with the ages from 13 to 50 and the gender was random. Pulse Oximeter and Heart-Rate Sensor IC (Max30100) were used to find the difference between normal points and acupuncture points. An assumption is made that the acupuncture points have higher SpO2 than normal points and

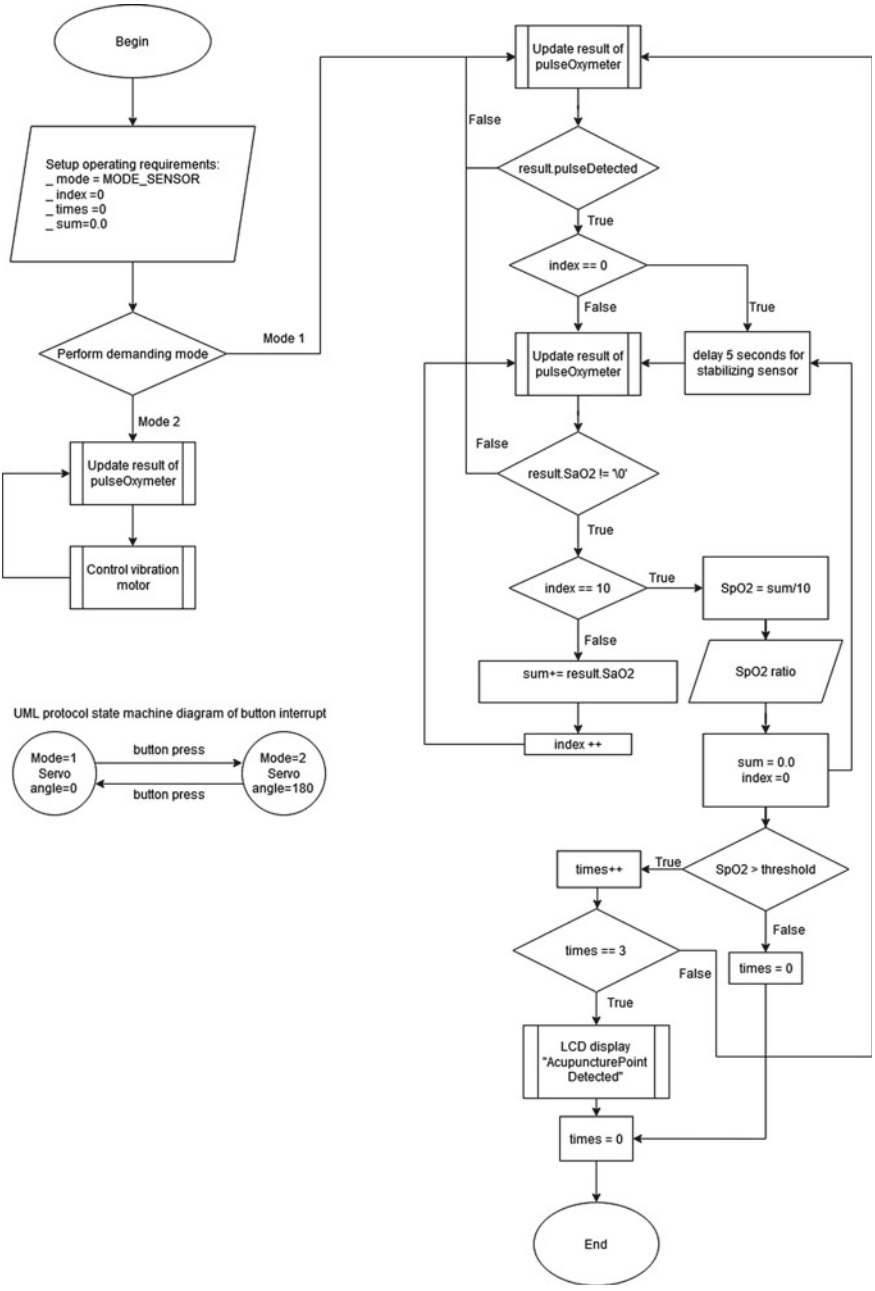

Fig. 3 Flowchart showing the operation sequence of the system

acupuncture Kidney points [11] was chosen to make this experiment. This experiment was performed in light condition (115 lx) and dark condition to compare the result of both cases. Firstly, the sensor was put on the Acupuncture Kidney Points to get the SpO2. Secondly, move the sensor to the normal points 5 mm, 10 mm, 20 mm and random normal point away from the Kidney point. The parameters are SpO2 will be monitored and save 10 times then output the average value in the sensor. This experiment was made 5 times and has been statistics; the total sensor calculated 50 values per point. It takes a minimum of 6.33 s to display the result of SpO2 on the LCD screen in such a way (Fig. 4).

Value of SpO2 in a 21-year-old man to test subjects given in Table 1.

Average Value of SpO2 test subjects given in Tables 2 and 3.

These are all people with normal and stable health and the acupuncture point in the foot of each person is equal. Basing on these tables, the differences of the normal point and the acupuncture points are clear and it takes minimum of 34 s to display the result of the acupuncture point on the LCD screen. From the above results, the thresholds of SpO2 to distinguish the normal point and the acupuncture point are determined to be about 99.1%.

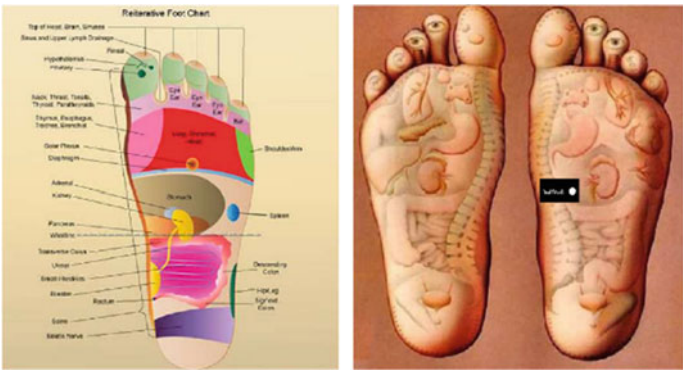

Fig. 4 Experimental setup [10]

Table 1 SpO2 concentration of a 21-year-old man in the standard room (115 lx)

Time	Acupuncture points	Normal points			
		5 mm away	10 mm away	20 mm away	Random normal point (heel)
1	99.44	98.73	98.61	98.25	98.17
2	99.47	98.64	97.73	98.37	98.74
3	99.48	98.76	98.42	98.5	98.69
4	99.39	98.67	98.16	98.59	98.79
5	99.31	98.89	98.52	98.45	99.01
Average	99.418	98.738	98.288	98.432	98.68

Table 2 SpO2 concentration in the standard room (115 lx)

Gender	Age	Acupuncture points	Normal points			
			5 mm away	10 mm away	20 mm away	Random normal point (heel)
Female	21	99.2	98.76	98.25	98.94	98.32
Male	21	99.42	98.74	98.29	98.43	98.68
Male	23	99.46	98.93	98.97	98.93	99.01
Female	13	99.29	98.60	99.18	98.72	98.35
Male	50	99.59	98.03	99.14	98.86	99.05

Table 3 SpO2 concentration in the darkroom

Gender	Age	Acupuncture points	Normal points			
			5 mm away	10 mm away	20 mm away	Random normal point (heel)
Female	21	99.29	98.65	98.76	98.91	98.59
Male	21	99.54	98.79	98.53	98.82	98.92
Male	23	99.36	98.8	98.97	98.71	99.04
Female	13	99.62	99.12	98.87	99.07	98.53
Male	50	99.56	98.76	98.93	98.45	98.73

5.2 Accuracy Verification Methods

In this part, the sensor was put on the different acupunctures to compare the variance between acupuncture points. Basing on the acupuncture map, we chose five acupuncture points to compare with the results of the sensor in the standard condition because this is the best condition for measurement. Noise parameters may occur when the external condition affects such as the humidity of skin, dust, malformed skin surface, etc. Besides, the sensor needs to be kept fixed to minimize the diffraction phenomenon. From that result, we can evaluate the accuracy of the threshold and algorithm. We conducted experiments on five different points including Kidney, Lung, Eye, Head, and Small Intestine. The results were shown in the table below.

Average Value of SpO2 in five acupuncture points test subjects given in Table 4.

The maximum variance of a person is 0.71% to give us an overview about the accuracy of the threshold. Basing on that results we can choose the threshold as the smallest SpO2 value at all points. However, this approach can be risky because depending on the host factor, the minimum of SpO2 in the acupuncture can vary. The accuracy of the algorithm can be improved when the number of samples is very big and the algorithm needs a filter of noise values. Otherwise, we can set up a system

Table 4 SpO2 concentration of five acupuncture points in the standard room

Gender	Age	Acupuncture points				
		Kidney	Lung	Eye	Head	Small intestine
Female	21	99.2	99.24	99.42	99.91	99.57
Male	21	99.41	99.84	99.36	99.82	99.93
Male	23	99.46	99.73	99.51	99.74	99.41
Female	13	99.29	99.66	99.43	99.59	99.75
Male	50	99.59	99.64	99.87	99.83	99.67

to consist of many sensors that work at the same time to measure SpO2 in the foot. By that way, the system can find the situation of acupuncture on each person.

Because the MAX30100 sensor is unprofessional in the medical equipment field, the accuracy of it has to be adjusted by more typical devices. For more details, we used a device which names "ACCURO II™". This device can enhance SPO2 measuring by the latest RT-SAT™ patented technology which belonged Charmcare. The SPO2 values of it are used as a standard model so that we adjusted the MAX30100 sensor and the algorithm. As a result, the accuracy of Max30100 sensor equals approximately to ACCURO II™.

6 Conclusion

To sum up, we presented a feasible non-contact approach for measuring the concentration of oxygen saturation in the soles of the feet with the MAX30100 sensor. The purpose of the method is to find and massage the acupressure points there. The system was tested on 20 objects with the device at distances of 5 mm, 10 mm and 20 mm from the point of pressure on the soles of their feet. The accuracy of the results is relatively high at about 80% and can be developed to detect blood circulation disorders. Moreover, it is feasible to bring this product to the market thanks to its affordable cost. However, this device only works correctly under mandatory conditions and cannot collect enough relevant data to give the most accurate SpO2 threshold for determining acupuncture points.

With further research and improvements in noise correction such as light, temperature and humidity to enhance detection accuracy in all cases. We hope that this method can be used in the early diagnosis of disorders of blood circulation. We are confident that this system will help the physician's better cure than pure reflexology. This device can add some new features like heating acupuncture points.

Conflict of Interest The authors have no conflict of interest to declare.

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