Design an IoT wrist-device for SpO2 measurement

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***Abstract*— IoT technology with the 4.0 revolution in industrial technology promises to change drastically in every aspect of human life. The elderly health care industry is forecasted to grow fastly, providing a more economic and effective method for health monitoring through the utilization of IoT technology. Blood oxygen saturation (SpO_2), one of the vital survival parameters, is potentially used in health monitoring on patients, elders and newborns, etc. This study focused on developing a SpO_2 wearable measurement device, which allows the real-time monitoring and prediction of human health via the Internet. In addition to building a complete, low-cost and low-power assumption prototype, the study also focused on introducing different open-source solutions for data collection and display.**

Keywords*— *Pulse Oximeter; Wearable device; SpO_2; Light Reflection; Remote Monitoring System; jQuery; Web service.

I. Introduction

Industrial revolution 4.0 is an indispensable technology trend that countries must look forward to. At the same time, the applications of Internet of Things (IoT) in production, living and life are considered as the key technological solution for the success of this revolution. This technology leads to many positive changes in the human life, including the monitoring and care of human health.

Many companies have provided the smart compact mobile and wearable medical devices for human health care. To name a few, clothes with integrated sensors to measure the parameters of temperature and heart rate [1], wrist-watches for pulse and body temperature measuring and fall detection [2], contact-lenses glasses with zoom function of up to 2.8 times [3], and so on. Many commercial products also support wireless data transfer to smartphones or to a database on internet so that users can monitor their health easily and quickly, such as Fitbit Charge of Fitbit Co. [4]. Thus, the area of health monitoring wearable devices has really boomed more than ever. These devices indirectly advise users for their health improvement without frequent hospital visits for check-ups. This helps reduce the load at hospitals and reduce the cost of pesonal health care.

One of the most important health parameters, the blood oxygen saturation level - SpO_2 (measured on arterial blood), can be used to monitor and to predict the health of people. Unfortunately, in the traditional SpO_2 systems, the measuring and monitoring positions such as fingers, toes, earlobes, nose, etc., with light transmission measurement causes inconvenience for users in daily activities, such as handling, movement or communication [5,6]. This feature has just been integrated into a few of wearable devices.

Fig. 1. Some common locations of oxygen saturation measurement in arterial blood according to heart beats (SpO_2) [5]

This article presents a development of a new wrist SpO_2 monitoring device that makes SpO_2 measurement more user-friendly, with low-cost and low power consumption. This device integrates the wireless feature to be able to transfer data to a database in the Internet. A web server for monitoring and surveillance was developed base on studying in several open source solutions to select the best tool which allows the rapid development of a website interface with highly interactive charts for users.

II. The Measurement System Developement

A. *The light reflection SpO_2 measurement method*

Pulse Oximeter is a general name of the devices which can measure the oxygen saturation in arterial blood. Because some Pulse Oximeters with transmission probe can not work well on some special of human body (e.g., wrist), Pulse Oximeter with reflectance probe is used to monitor the arterial oxygen saturation (SpO_2) by receiving reflected light intensity. This section presents the principle of reflected light intensity SpO_2 measurement method in order to allow us developing a complete system.

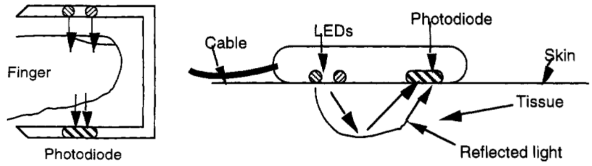

Fig. 2. Probe using transmittance (left) or reflectance (right) principle [9]

The idea of using light reflection instead of light transmission in clinical oximetry was the first described by Brinkman and Zijlstra in 1949. They realized that when beaming a single source of light to a physical environment as the cells of the body tissue, some rays of light will go through the physical environment and some sources of light will be absorbed and cause the scattering. This scattering tends to go to reach the other end, or tends to bend under the "banana" effect and then back to the original environment [10].

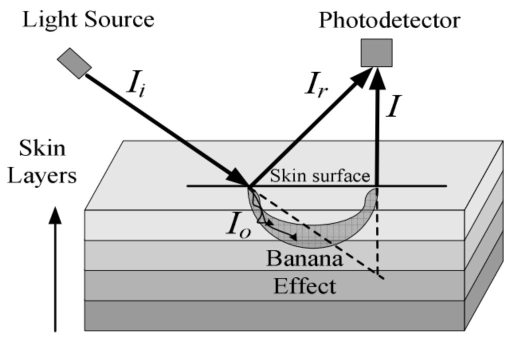

Fig. 3. The "banana" effect of light scattering [10]

In principle, both forms of reflection and transmission measurement principles are based on the current in the photodetector output to determine the absorbance of HbO_2 and Hb. In the method of using transmitted light, posittion of transmitting LED (Light Emitting Diode) and receiving LED are always sandwiched on thin skin. Hence, the light easily passes through some special of human body (e.g., earlobe, fingertip). The light transmission is described as follows: the light from red LED and infrared LED is emitted through the tissue, the first ones is absorbed, second ones is scattered, and remaining ones is transmitted to the head rest receiver photodetector. With light reflection method, because the photodetector receiver and transmitting LED are placed on the same side, there is only the reflected light is collected after being scattered and come back comply with the effect "banana". Therefore, the signal received from light less than the light transimission method. Consider the following specific cases: When the tissue is illuminated by a light source, 93–97% of the light is either absorbed by various structures (a) or undergoes scattering (b). The remaining 3–7% is reflected by moving red blood cells (c, d) and returns to photodetector.

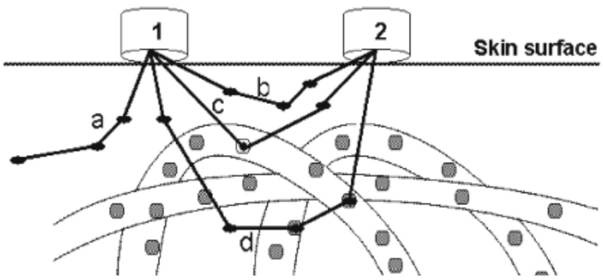

Fig. 4. Simplified representation of light distribution [11]

Based on previous study by the same authors of the best measuring SpO_2 area on the wrist [7], the best measure is defined as the B3 area as described in Figure 5.

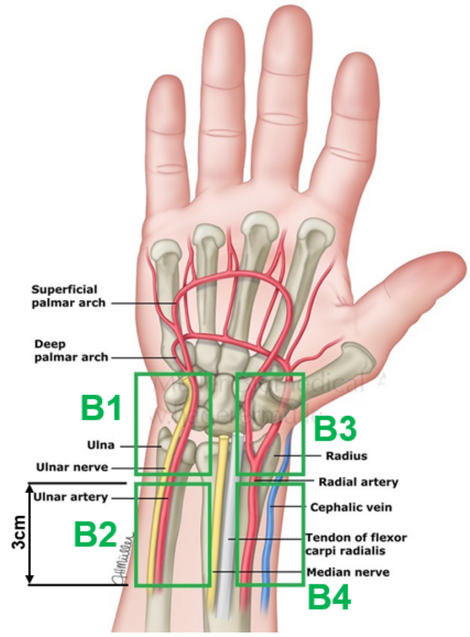

Fig. 5. Description of the measuring blocks based on the arterial line (red) on the wrist [7]

In the previous study, the magnitude of measured signal at the wrist is 1.7mV, just only less than at fingers (6.1mV) and earlobes (1.85mV) [7]. It is only approximately 29.7% of the measurements at the fingertips. Nevertheless, thanks to combining the design of amplification circuit block with a 12-bit analog-to-digital conversion (ADC) circuit block, sampling with 2.5V internal reference voltage and 0.3mV quantum error (2.5 / 4096/2 = 0.3mV), the received signal samples measured at the wrist is relatively accurate.

TABLE I. RATED THE BEST MEASURING AREA BASE ON COMPARING RECIVED SIGNAL AT OUTPUT SENSOR ON DIFFERENT AREAS [7]

Measured area	Average magnitude of red LED (mV)	Average magnitude of IR LED (mV)	Average magnitude (mV)	Rate
Wrist	1,1	2,3	1,7	3
Fingertip	5,3	6,9	6,1	1
Foot	0,5	0,8	0,65	6
Nose	0,8	2,2	1,5	5
Earlobes	1,7	2	1,85	2
Forehead	0,9	2,2	1,55	4

The development of SpO_2 measurement wearable device will be presented in the next section.

B. The developement of the SpO_2 measurement wearable device

Figure 6 describes the functional block diagram of SpO_2 measurement module. The basis of assessment of blood oxygen saturation in relation between Hb and HbO_2 based on measurement of amplitude of absorbance of these components with light. So 660nm (red) and 940nm (IR) wavelength is used. Because in these two wavelengths, differences of light absorption ability of HbO_2 and Hb is the most obvious. Therefore, the red LED and infrared LED is selected in this study. Two LEDs are turned on or off alternately by “LED Driver Circuit". This circuit block receives feedback signals and controls (increase or decrease) the intensity of the two LED of the DC level signal from "Photodiode" sensor, so that the DC gain is approximately equal. Photodiode sensor receive the reflected photons from two LEDs and produce free electrons to generate an electric current in the output of photodiode. This electric current is converted into voltage by "I / V converter" circuit block, and then the analog digital converter (ADC) of the microcontroller can read. However, the voltage signal at the output of "I / V convert" it is too small and is affected by noise, that difficult give directly to the microcontroller (MCU) to sample. It must need pass through the filters and amplifiers before going to the MCU. The low pass filter block (LPF) and high pass filter block (HPF) will work to filter the output signal at the block "I / V convert" at frequency from 0.5Hz to 5Hz. This correspond with heart rate ranges from 30 to 300 beats a minute. This time, thanks to ADC0 and ADC1 modules of MCU, the signal was eliminated much noise and can be sampled. The value of received samples were used for adjusting the DC balance of the two LED at two wavelengths and calculating the SpO_2 level. The result of the calculation will be fully shown on screen display.

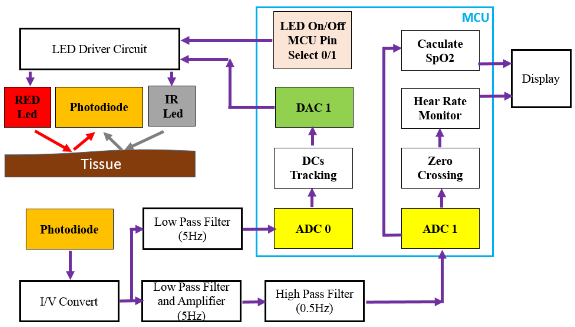

Fig. 6. Function block diagram of SpO_2 module [12]

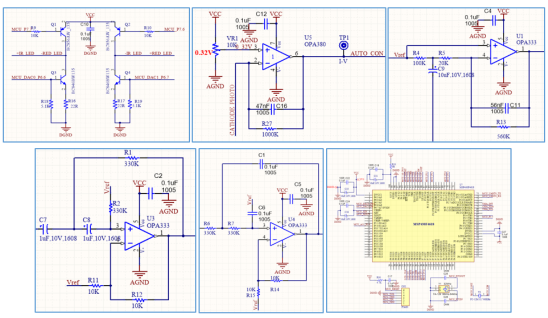

Fig. 7. The schematic diagram for SpO_2 module [12]

To consist with the size of a small wearable device, printed circuit board (PCB) is designed with 55mm x 35mm in size, ultra-small component of resistor and capacitor is selected with 10x05 mm (04x02 inch) in size, and using high quality multilayer PCB technology (4 layers).

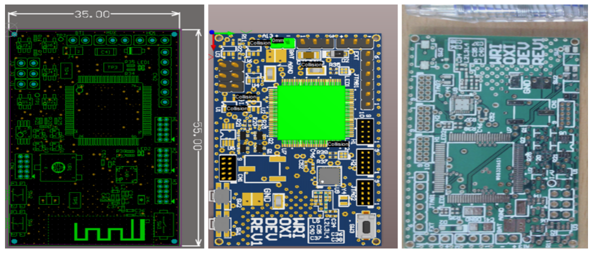

Fig. 8. 3D PCB layout and real PCB [12]

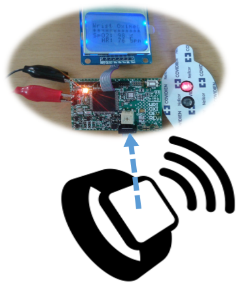

Fig. 9. Circuit board of device base on wristable device with integrated sensor [12]

C. Experimental results

We have tested the designed electronic board in measuring signal at wrist area with a commercial reflex oximetry module of Nellcor. After going through the I/V converter, the output signal is less than 10 mV and includes white noise. Therefore, in the device, we used some filters and amplifiers to enhance the quality of the signal. In figure 10, the output signal measured from oscilloscope shows that our device removed most of the noises and the final signal is very clear. The magnitude of signal is about hundreds mV which is enough for the ADC12 of MCU to convert signal into DC value in a good resolution (2,5/4096)/2 = 0.3mV.

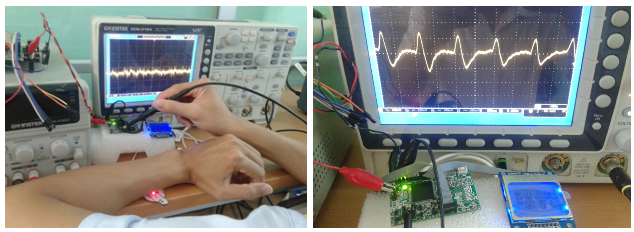

Fig. 10. Exprimental result in measuring SpO_2 in real environment: signal after SpO_2 sensor (left) and signal after going through filters and amplifiers (right) [12]

Measured SpO_2 signals responding to Red LED and Infrared LED have different amplitude. In the test with only red LED, the signal after going from oximetry sensor through all filters and amplifiers gives the results:

- The DC voltage level varies lightly at 1.65V

- The max peak to peak signal approximates 220mV
- Frequency of signal is 0.8Hz
- Signal is smooth and few noises.

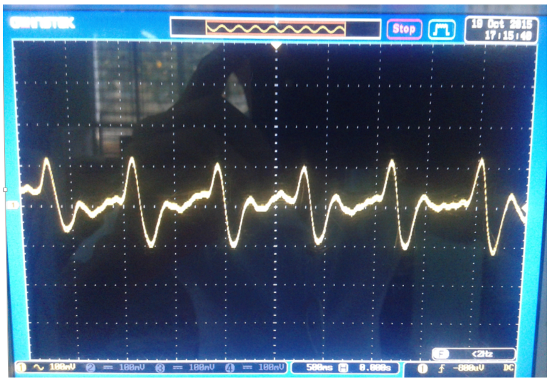

Fig. 11. Received signal after going from oximetry sensor through all filters and amplifiers in red LED test [12]

In the test with only Infrared LED, the signal after going from oximetry sensor through all filters and amplifiers gives the results:

- The DC voltage level varies lightly at 1.65V
- The max peak to peak signal approximates 250mV
- Frequency of signal is 0.8Hz
- Signal has small noises.

Fig. 12. Received signal after going from oximetry sensor through all filters and amplifiers in infrared LED test [12]

This result show that the average peak to peak signal after the 5Hz low filter is 220mV in Red LED test and 250mV in Infrared LED test. The output signal is very clear which can be sampled well in the ADC 12 bit. From [13,14,15,16], the approximate linear equation of the Pulse Oximetry method can be defined as:

$$SpO_2 = 110 - 25\ (R/IR)\ (\%) \qquad (1)$$

Where, R/IR is the signal ratio between singal measured at red LED and signal measured at infrared LED. This ratio can be defined by equation:

$$\frac{R}{IR} = \frac{AC_R}{AC_{IR}} \qquad (2)$$

Where AC_R is the AC part of measured signal when LED red is ON, AC_{IR} is the AC part when infrared LED is ON. Data from the signal after sampling is used to calculate the value of SpO_2 according to the equation (1) reloaded on the screen of the device every 25s.

The average result which was measured by our device, was rounded and compared with Pulse Oximeter development board (SpO_2 AFE44x0 EVM) of TI, the percentage deviation is calculated by the following formula:

$$\text{Deviation} = \frac{|(our\ device - TI\prime\ deivce)|}{TI\ device} \times 100\% \qquad (3)$$

TABLE II. COMPARING MEASURED RESULTS BETWEEN THIS STUDY DEVICE WITH DEVELOPMENT KITS FROM TI

	Volunteer	This study device		AFE44x0 SpO_2 EVM		Deviation (%)	
		HR	***SpO_2***	***HR***	***SpO_2***	***HR***	***SpO_2***
1	V1	64	90	60	89	6,7	1,1
2	V2	72	94	68	90	5,9	4,4
3	V3	96	97	100	99	4	2
4	V4	70	84	67	85	4,5	1,2
5	V5	75	95	79	99	5,1	4

In results table above, the measured results of our device have the highest deviation of 6.7% when measured heart rate and 4.4% when measured SpO_2. These deviations are acceptable, while ensuring the operational goal of the tracking device that the system can detect the cases of abnormal heart rate and SpO_2.

III. THE DEVELOPMENT OF THE MONITOR SYSTEM SERVICE

A. Developing visual charts with open-source libraries

Remote monitoring via the website requires accurate representation of health parameters and user-friendliness through the efficient use of visual charts and graphs. This article will introduce some of the open source libraries that meet the above requirements. Thanks for these libraries, we can easy create lots of charts, graphs with beautiful visualizations.

Most of the library are written in jQuery language, a new type of JavaScript library that simplifies the way Javascript is written and speeds up the processing of web events using AJAX technology, saving more time for data processing than traditional methods. Combined with jQuery and CSS, programmers can quickly create websites with more eye-catching, more convenient interfaces. Besides, jQuery is also compatible with most popular browsers today, so that programmers do not need to rewrite the Javascript commands for each browser. Because it is based on Javascript, file extensions of libraries written in jQuery are also in *.js format. Some popular libraries for quickly creating charts, graphs can be listed as Google Chart, Morris, ChartKit, Flot, NVD3, Rickshaw, Xcharts, Elycharts, etc.

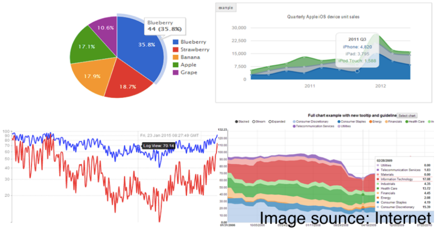

Fig. 13. Some chart patterns use ChartKit, Morris, Rickshaw, NVD3 libraries

The important contribution to building these libraries are jQuery files such as jquery.min.js, prettify.min.js, raphael-min.js, etc. These files contain the code that creates Graph details such as column or line graphs, color properties, axis, symbol shapes, event points on a graph, etc. All of these files are open source. In this paper, the authors use the Morris library to create graphs.

```
<script src="../jquery.min.js"></script>
<script src="../raphael-min.js"></script>
<script src="../morris.js"></script>
<script src="../prettify.min.js"></script>
<script src="lib/example.js"></script>
<link rel="stylesheet" href="lib/example.css">
<link rel="stylesheet" href="../prettify.min.css">
<link rel="stylesheet" href="../morris.css">
```

Fig. 14. The code demonstrates how to use the Morris library

The following table compares the evaluation for each category based on criteria such as whether fees are charged, whether internet is needed, whether the use is simple, whether the library has a variety of graphs to choose from, etc. Form there, select the right kind of library to use for each specific case.

TABLE III. *COMPARING PERFORMANCE, COMPLEXITY AND PRICE BETWEEN THIS STUDY DEVICE WITH OTHER COMMERCIAL PRODUCTS*

Library	Cost	Internet	Use	Diversity	Reliability
Google Chart	Free for commercial	Yes	Easy	Many	High
Morris	Free	No	Very easy	Some (line, area, bar and donnut)	High
Chartkit	-	Yes	Easy	Some	developing
Flot	Free	No	Easy	Some	developing
NVD3	Free	No	Normal	Many	developing
Rickshaw	MIT license (Nonprofit)	No	Normal	Some	
Xcharts	Free	No	Normal	Little	
Elycharts	Free	No	Normal	Little	

"-" : Only free for non-commercial purposes.

B. Develope the web interface for SpO_2 wearable measurement system

Tracking the remote health parameters of the device is necessary. So, the authors also built a website service that allows the user as well as user's family can remotely monitor the health status of the person who is wearing the device through the Web interface. Remote monitoring via website request must show exactly the health parameters and user-friendly interface design thank for the effective use of visual charts, graphs and statistics. The Morris library was chosen in creating graphs for the website system because of the simplest of the proposed libraries, high user interaction, and it's free.

After data is collected, processed, and calculated from the device, it will be sent to the database server via an internet-connected device. This measurement device will communicate wirelessly with devices that have an internet connection. The data is sent to server is used for the creation of charts on the website. Figure 15 shows a version of Website that displays a complete health information of patient such as heart rate, oxygen saturation level in the blood, systolic pressure, diastolic pressure, body temperature, blood sugar level. A heart rate chart is created on the measured data from the device is also shown to be very intuitive, so that we can know the depth and regularity of breathing.

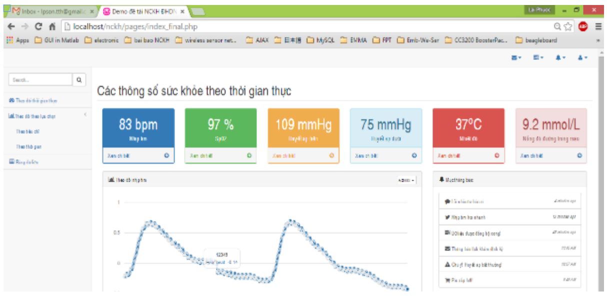

Fig. 15. Using open libraries to build web interface for remote monitoring with beautiful, highly interactive and graphical user interface

IV. CONCLUSIONS

To have an objective recognition of the commercial possibilities of the device and to have accidenceis for improvements for future versions, the authors have investigated and made a comparison of the performance, the complexity and the cost of our device to other commercial products.

TABLE IV. *COMPARING PERFORMANCE, COMPLEXITY AND PRICE BETWEEN THIS STUDY DEVICE WITH OTHER COMMERCIAL PRODUCTS*

	Performance	Complexity	Price
Our Device	Using rechargeable battery, continuous measurements in a few days	Heart rate (HR) and SpO_2 measurement, SpO_2 sensor measure at wrist, remote monitoring support via website	99 USD (price proposal)
Pulse Oximeter - Activ8rlives (2016) [17]	Using two 1.5V batteries, non-continuous measurement	Heart rate (HR) and SpO_2 measurement, SpO_2 sensor measure at	55.82 USD http://www.activ8rlives.com/devices/pulse-

		fingertip, remote monitoring support via website and smartphone	oximeter.html
Withings Pulse O2 (2015) [8]	Using rechargeable battery, continuous measurements in two weeks	Heart rate (HR), calories and SpO_2 measurement, SpO_2 sensor measure at fingertip, remote monitoring support via smartphone	99.95 USD http://www.withings.com/us/en/products/pulse
Fingertip Pulse Oximeter – ChoiceMMed (2015) [18]	Using a signle 1.5V battery, non-continuous measurement, need to 40mA for each measurement	Heart rate (HR) and SpO_2 measurement, SpO_2 sensor measure at fingertip	19.99 USD www.amazon.com
MightysatRx - Masimo 2015) [19]	Using two 1.5V batteries, non-continuous measurement, about 1800 times	Heart rate (HR), and SpO_2 measurement, SpO_2 sensor measure at fingertip, remote monitoring support via smartphone	399 USD www.amazon.com

Table 4 gives a comparison of performance, complexity and cost of the studied device with other commercial products which SpO_2 can be measured, such as: Activ8rlives (started selling in 2016), Withings Pulse O_2 (2015), Fingertip Pulse Oximeter - ChoiceMMed (2015), MightysatRx - Masimo (2015). From the table above, we see that the studied device has the advantage of wearing and measuring at the wrist without removing to measure at the fingertip like as other commercial products. However, our device is inferior in performance and price. Therefore, to put the device into the consumer market, two limted problems must be solved.

The article has studied a wearable device to measure oxygen levels in the blood using light reflection method. This device has small size, convenient measurement location, and integrated hardware support for wireless data transfer with the internet-connected devices. Experimental results show that the output signals are very clear. The peak to peak amplitude is approximately 220mV when red LED turns on and approximately 250mV when IR LED turns on. The value of maximum deviation compared with standard SpO_2 measurement board is 6.7% (in HR measurement) and 4.4% (in SpO_2 measurement). Placing the sensor in the wrist helps users avoid the inconvenience of daily living such as wearing in the first-place fingers, toes, nose, etc. At the same time, the paper also suggested a service website template associated with the studied device. This website which shows the remote monitoring health parameters is easily designed thanks to the open source libraries. This studied device offer measuring solutions and measuring position is more convenient than other commercial devices, however price and performance is still not equal.

The next task of this study is to continue to study improvements to the energy problems for the time to use the device is longer.

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