Project Title: **Vital Aid**

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Problem Definition

Our modern civilization is very fragile. Whenever there is a large scale of natural disaster or in war areas, medical systems can easily get saturated and lose part of their functions. A small group of medical service might have to take care of tens of to hundreds of patients or wounds. Similar situation also happened during an epidemic outbreak. Under such conditions, physicians generally do not have enough electronic medical devices to help themselves and the patients. Obviously, it is not cost effective for medical institutes to keep more full function medical devices than they need in the daily routine life. However, it will be nice to have a vital sign monitor that can provide useful information to judge which patient is in a critical condition and require immediate care. If there were a lot of patients rushed into a hospital, a large quantity of monitoring devices would be needed. Therefore, such monitoring devices should be very low in price, small in size and easy to use and stored. The most import thing is that they have to be always ready to work in the case of an emergency need. To fulfill such a need, a simple vital sign monitor, Vital Aid, is proposed in this project.

Vital Aid is a tiny device that detect heart rate from near-infrared skin reflectance. It is to stick on the forehead of a patient to monitor the heart pulse. A green LED flashes synchronously with heart beat to tell people beside the patient that he is in a stable condition. When the pace of heart beat becomes too fast or too slow, the color of flashing LED turns into yellow or red. This is a warning sign to have physician come over to inspect the condition of the patient. Just one untrained person can easily learn to help to look after the condition of many patients around. This device will allow the physicians to have more time to concentrate on the most important works during an emergency or release their work burden.

Vital Aid also can be used in developing countries because its designation is under the assumption that a developed region might suddenly become an undeveloped area. Such conditions did happen during hurricane Katrina, South Pacific tsunami, massive earthquakes and war.

Impact in developing world

Heart rate is the most important vital sign that can be used to judge the condition of a patient. In most cases, heart rate is the major parameter that electrocardiograph (ECG) and pulse oximeter are used to monitor patients. A simple heart rate monitoring device will be important to the remote areas or in developing world, just as the importance of expensive and advanced monitoring devices to the physicians in developed regions. Even in a developed region, there are many circumstances that a large quantity of heart rate monitoring devices is needed. For instance, many patients might be isolated in small cabinets during an epidemic outbreak. A cheap and disposable device will be helpful to monitor the isolated patient from a distance. This is also true for an outbreak in developing world.

The main purpose of using monitors in modern hospitals is to automatically remind the physicians about the condition of patients. This is especially true to the places where medical staff and resources are not enough. Vital Aid can have great helpful to these places because non-physicians can now help to monitor the conditions of many patients.

Required performance specifications

Vital Aid is a heart rate monitoring device taped the forehead with the size similar to a band aid. It detects heart rate by analyzing the photoplethysmograph signal of skin reflective. A near-infrared (NIR) light emitting diode (LED) is used as light source to illuminate the skin. The brightness of the reflected light detected by a photodiode changes along with skin tissue perfusion of blood. A near-infrared LED is used as the light source because melanin for skin color has relatively low absorption of near-infrared. This greatly reduces the affection of signal amplitude by skin pigment.

According to the American Heart Association(AHA), the normal range of heart rate for adults over 18 years old is between 60 to 100 per minute, and the normal range of heart rate for children and teenagers under 18 years old is between 70 to 100 per minute. When the heart rate is in the range between 60 and 100 bpm, the flash of LED is shown in color of green. The LED turns into yellow when heart rate falls in the fast (between 100 and 110 bpm) or the slow (between 50 and 60 bpm) warning ranges. This yellow light is a color mix of green and red LEDs lighting at the same time. If heart rhythm is in a dangerous pace (below 50 or above 110 bpm) or no heart beating, the color of flash turns into red. The color changing with heat rate is a visual alarm sign to show the condition of a patient.

In case no electricity is available, the electronic monitoring device is basically powered by batteries. Different types of batteries can be used so long as their voltage and current specs meet the minimum requirement. Also, the power requirement should be very low that electricity from different energy harvest methods can be used to drive the Vital Aid.

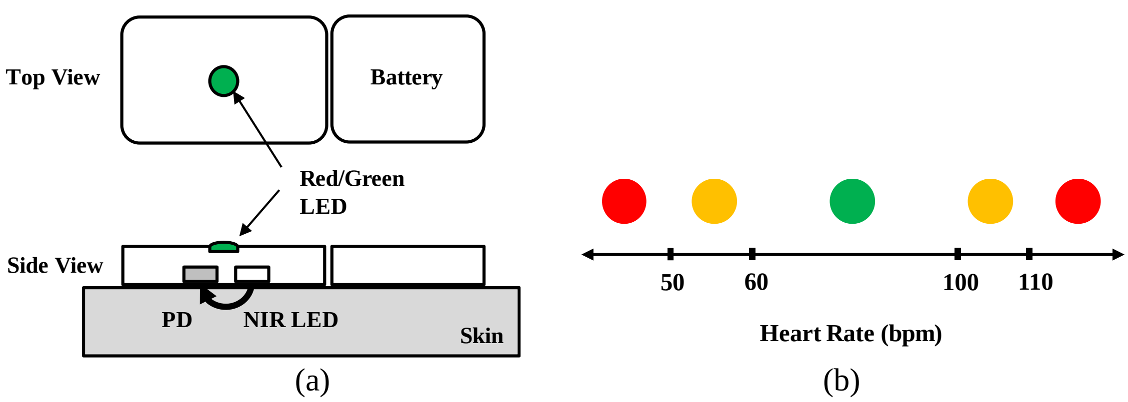
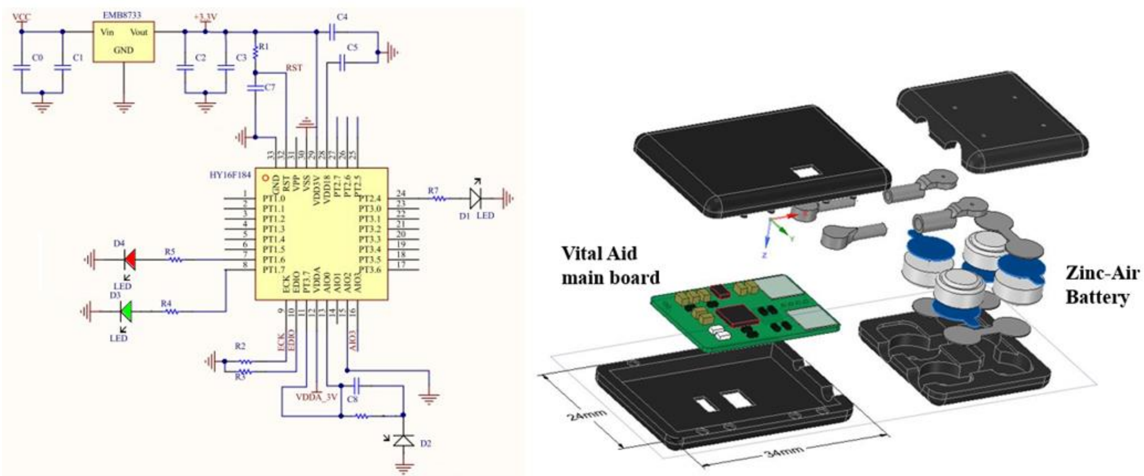


Figure 1. (a) The top and side view of Vital Aid, (b) The color definition of different heart rate ranges.

Implementation of prototype

The circuit scheme of Vital Aid and its mechanical structure are shown in Figure 2. A 3.3V low-drop-output regulator is used for stabilizing the power voltage. A low cost 32-bits mixed signal microcontroller (Hycon Tech.) with a built-in operational amplifier convert the photo current into electrical signal.. The microcontroller has a high resolution 24-bits sigma-delta analog-to-digital converter that provides an ultra large dynamic range. Besides the current-to-voltage conversion, no further amplification is needed and signal will not be saturated. The detection and calculation of heart rate is carried out by a real time digital signal processing program.



(a) (b)

Figure 2. (a) Schematic diagram of the circuit and (b) exploded drawing of Vital Aid.

By filtering the high frequency noise and the low frequency baseline drifting, a dynamic threshold is set to detect the crossing point. The maximal value between two cross points is determined as the peak of photoplethysmograph waveform. When a signal peak is detected, a short pulse signal is sent out to light up an LED. The time duration of pulse is only 1 millisecond in order to save power consumption. The ultra bright LED flashes synchronously with heart beat helps people around the patients to identify the vital condition. Then, the heart rate is calculated from the time interval between two continuous peaks. The color of flash is determined by the time interval to show whether the patient's condition is critical or not.

Figure 3 show the size of a Vital Aid prototype in a 3D printed case. To make sure Vital Aid is working properly, a Vital Aid with a Bluetooth transmitterwas also built, as show in Figure 3(c). The 24-bits digitized photoplethysmograph signal can be continuously transmitted to a notebook computer for recording. Software program for digital signal processing was developed and tested using this raw data.

(a) (b) (c)

Figure 3. (a) and (b) The size of Vital Aid. Each background grid is 5mm by 5mm. (c) A Bluetooth version of Vital Aid for transmitting PPG signal.

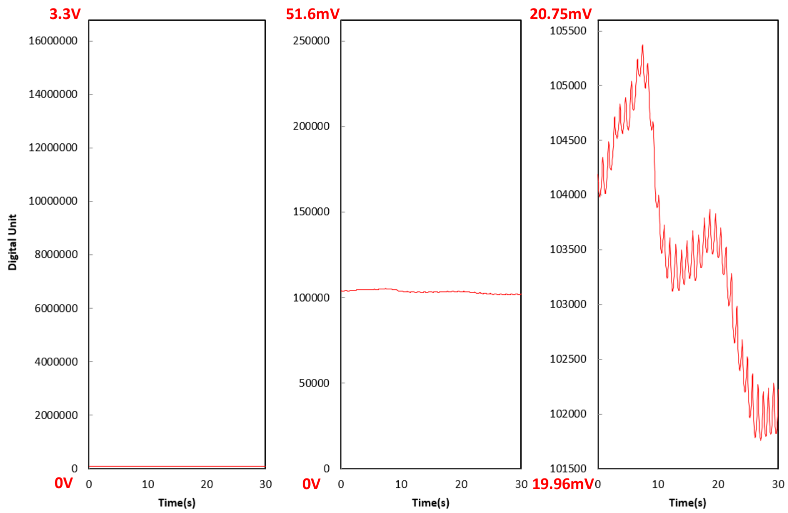


Figure 4. The same signal viewed at different zoom levels: (a) 24 bits, (b) 18 bits, and (c) 12 bits. The y-axis ranges in red show the real analog signal amplitude, respectively.

The curves in figure 4 shows that only the lower 18 bits are really needing for this signal. The baseline drifting of signal is caused by the change in chest pressure with breathing and posture movement.

Proof of performance

The detected peaks of each pulse in Figure 5 are marked in red of verifying the algorithm. The calculated heart rates are also shown in Figure 5(b). A larger variation range of heart rate was tested by measuring the heart rate recovery after riding an exercise bike. When the subject stopped riding, the heart rate started to drop from nearly 150 bpm and gradually recovered to normal range within three minutes. The heart rate was marked according to the range and color defined in Figure 1(b).

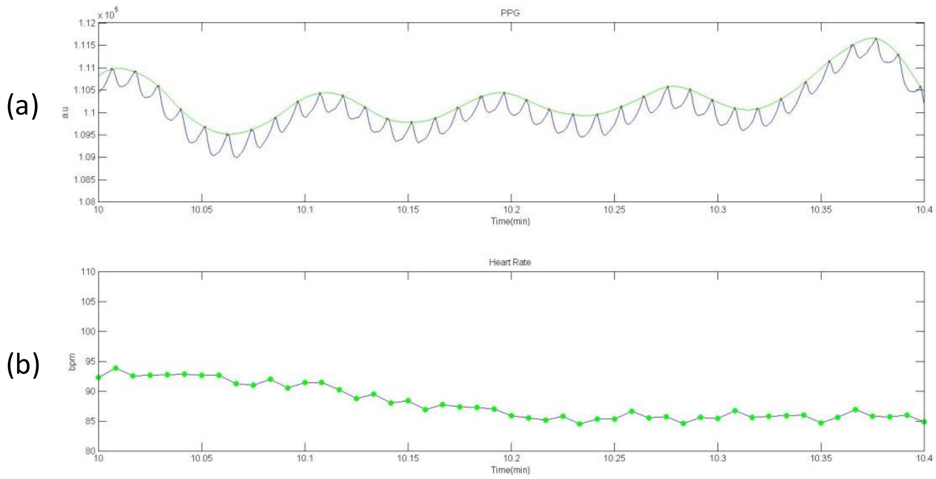


Figure 5. (a) Peaks detected on the original photoplethymograph signal from Vital Aid. (b) Heart rate calculated from the time intervals between the peaks.

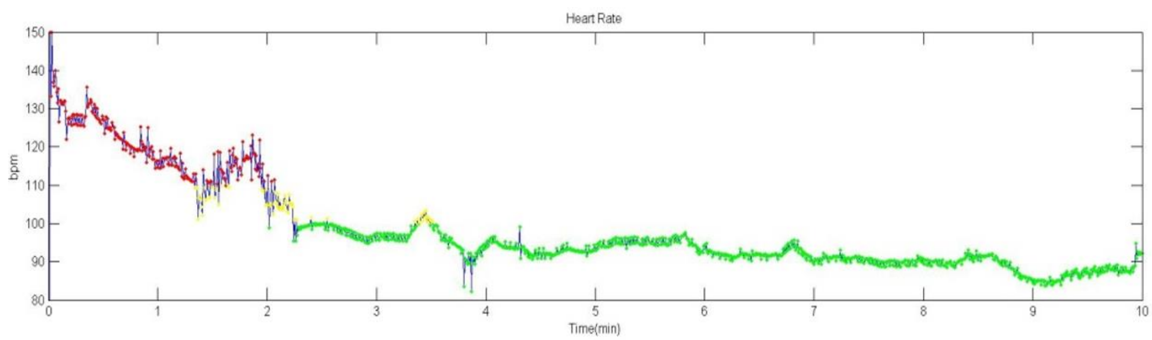
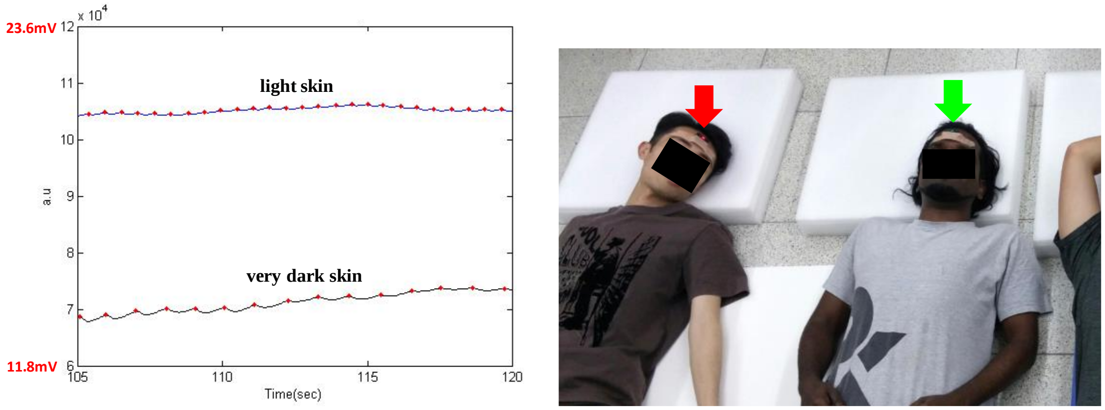


Figure 6. The recovery of heart rate after riding an exercise bike. The color of markers indicates the ranges of heart rate.

Figure 7 shows the reflectance intensity of light from two volunteers, one with light skin color and one with very dark skin color. These signals show that there is still a very large dynamic range, and no saturation of signal need be worried about.



(a) (b)

Figure 7. (a) The near-infrared photoplethysmograph signals from a light skin subject and a very dark skin subject. (b) The visibility of LED viewing at a distance in a very bright environment is demonstrated.

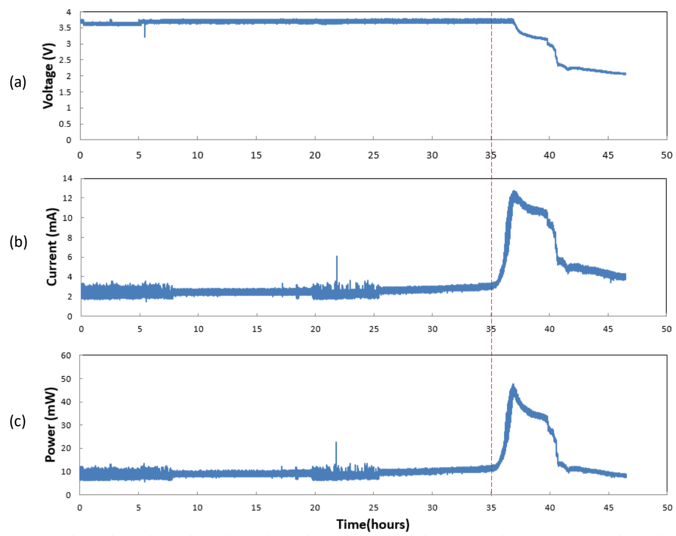


Figure 8. A long-run test of Vital Aid using four Zinc-Air batteries. The (a) voltage, (b) current and (c) power consumption were all very stable during the first 35 hours.

A long term test of Vital Aid using Zinc-Air 312 batteries are shown in Figure 8. Although the unloaded open voltage of batteries was 5.2V, it dropped down to 3.6V when connected to a Vital Aid. For over 35 hours, the voltage held pretty constant and the source current slightly drift from 2.2mA up to 3mA after 35 hours of operation. The average of power consumption of Vital Aid was about 10mW. The variation of these curves in the first 35 hours is mainly caused by the on and off of flashing LED.

Business plan for manufacture and distribution of the technology

Nowadays most sport bands and smartwatches come with an optical heart rate sensor. Most of these devices are not targeted to work on emergency need [1][2][3]. A heartbeat flash earring also has been proposed early in 2001, but not with a color changing display.

Vital Aid is designed to be a low cost and small heart rate monitoring device that can continuously works for a long period of time. Its main purpose is to reduce the working burden of nurses or physicians in remote areas or when a large number of patients rush into hospital. According to Table 1, the component cost estimated for one thousand units of quantity is less than $2.5.-/each. With such a low price, the Vital Aid can even be disposable when cross infection is a big concern. Otherwise, it is possible to reuse Vital Aid simply by replacing the batteries and do some basic cleaning and sterilization. This will also make Vital Aid more cost-effective.

Table 1. The cost of Vital Aid in one thousand units

Component	Quantity(each)	Quantity(1k)	Price(1k)
Microcontroller (Hycon FY188)	1	1000	$1000.-
Capacitance	8	8000	$40.-
Resistance	7	7000	$38.-
Photodiode	1	1000	$150.-
LED	3	3000	$50.-
Circuit board	1	1000	$200.-
Zinc-air battery	4	4000	$900.-
Total cost/1k			$2378.-
Total cost/each			$2.378.-

Besides its low cost, Vital Aid is actually based on several sophisticated components. These include high efficient LEDs, a photodiode, a mix mode microcontroller, and Zinc-air battery. However, the whole structure is very simple and easy to assemble. Its small in size makes it easy to ship or carry around when it is not in use. Therefore, the usage of Vital Aid should not be limited to the occasion of emergency. This vital signs detector can be promoted as an item in the first aid kit, so that it can be used by everyone even without the professional training. Zinc-air battery has the advantages of long shelf time and high energy density. Even after being stored for years, the battery is still ready to be used. With more general applications, it will be possible to keep it under a daily production. This is more efficient than to start a production line only in time of need.

Powered by different kinds of battery is another key feature that make Vital Aid be able to adapt to different occasions of need. Powered by batteries also make it safer to patients and easier to pass the regulation of electric safety. We also have succeeded in powering this device with home-made Magnesium-air batteries for about an hour. Since the manufacturing technology of Magnesium-air battery is not as mature as Zinc-air battery, it is still hard to shrink the size for now. However, it is possible to build batteries from widely available materials to drive Vital Aid when it is necessary.

[1] US7164938 B2, “Optical noninvasive vital sign monitor,” 2007.
[2] US20140107493 A1, “Portable Biometric Monitoring Devices and Methods of Operating Same.” 2012.
[3] US 20140213863 A1, “Low-Complexity Sensor Displacement Tolerant Pulse Oximetry Based Heart Rate Measurement,” 2013.
[4] US 6277079 B1, “Flashing earring heartbeat monitor,” 2001.