Vital Sensor Kit for Use with Telemedicine in Developing Countries

Natalie Arrizon, Jose Hernandez, Tokunbo Ogunfunmi
Department of Electrical Engineering
Santa Clara University
Santa Clara, USA

Antonio Maldonado-Liu, Alejandra Pacheco, Unyoung Kim*
Department of Bioengineering
Santa Clara, USA
*ukim@scu.edu

***Abstract*—In many developing countries, a large percentage of the population lacks access to adequate healthcare. This is especially true in India where close to 70% of the population lives in rural areas and has little to no access to hospitals or clinics. People living in rural India often times cannot afford to pay to see a doctor should they need to make their visits to a hospital. Telemedicine, a breakthrough in the past couple decades, has broken down the barrier between the patient and the physician. It has slowly been implemented in India to make doctors more available to patients through the use of video conferences and other forms of communication. To improve the outcome of virtual visits via telemedicine, we have developed a compact and affordable kit that will be used to take a patient's blood pressure, heart rate, blood glucose concentration and oxygen saturation. In addition to our sensor development, by wirelessly sending data results from the vital sign kit, the first essential part of a treatment can be carried out via wireless communication, saving the doctor and patient time and money.**

Keywords— vital signs, blood pressure, heart rate, oxygen saturation, telemedicine, IOT

I. INTRODUCTION

Many people in the developing world go without health care from which they could benefit greatly. The poor in developing countries are even less likely than the better off to receive effective health care. This is especially true in India where close to 70% of the population lives in rural areas and has little to no access to hospitals or clinics. In addition, the doctor to patient ratio is 0.7 to 1000 [1], meaning a large percentage of the population in India has no access to a doctor or clinic [2]. This means that people living in rural India are left without access to a nearby hospital and often times cannot afford to pay to see a doctor if they do make the journey to a hospital [3]. Telemedicine, a breakthrough in the past couple decades, has broken down the barrier between the patient and the physician. Telemedicine has slowly been implemented in India to make doctors more available to patients through the use of video conferences and other forms of communication. According to Amrita Pal, telemedicine is highly needed for India's rural population. Currently, patients usually have a late diagnosis of their illness, cannot get to their care provider in time, and do not get the treatment they need from the right providers [4]. However, a shortcoming of this is that the doctor still has no direct access to a patient's information, other than descriptions and x-rays.

Our objective is to develop a kit equipped with sensors that will be used to take a patient's vital signs, such as blood pressure, heart rate, and blood oxygen saturation. It will be inexpensive and accessible to people in rural areas of developing countries. In such scenarios, this device would replace the first steps of any standard medical checkup. Instead of traveling all the way to a hospital to have baseline vitals measured, you would measure them with this device, and send them to a physician for review to help determine whether an in-person appointment is necessary. This frugal device gives under-resourced families the opportunity to take care of their health and live a better life. Although our device could be applicable in almost any region with lack of access to healthcare, we believe India would be the region that would benefit the most from our device, which is why most of our research and project will focus with India in mind.

By having a medical kit that takes many important vital signs, even people who do not have insurance or easy access to a hospital will be able to monitor their own vital signs and those of their family members. This solution is better than others currently available because it is much smaller, cheaper, and more intuitive in design and use. Current devices include carts that are used in most hospitals here in the US, that are about three feet tall, and cost in the range of hundreds to one thousand dollars. An example of this commercial monitor is the Welch Allyn Vital Sign Monitor that is commonly used in hospitals, at the price of $300 [4]. There are a number of other available devices, but they are expensive, and generally only have one or two types of sensors. FDA approved pulse oximeters only have one function of measuring oxygen saturation, yet they cost up to $100. The proposed device is targeted to cost no more than $150, will contain at least three sensor types, and be connectable to a mobile device such that data can be sent wirelessly to a physician via Wi-Fi or SMS. Communities can share multiple vital sensor kits and split costs accordingly to make the device even more affordable. We strongly believe that by making this device low-cost and simple to use for developing countries, communities and families will be much happier and healthier because they will be able to get the medical attention they need from doctors without having to have the financial burden of paying for multiple hospital visits and transportation costs.

II. MATERIALS AND METHODS

A. *Requirements for an Affordable Vital Sensor Kit*

In order to make a well-rounded product, there were various concerns that needed to be addressed in the creation of our device. Table 1 addresses the three main factors that are important in the design process. In addition, the accuracy, portability, simplicity and possibility for smartphone compatibility are also significant factors that stem from the economic, ethical, and manufacturing considerations.

TABLE I. ECONOMIC, ETHICAL AND MANUFACTURING CONSIDERATIONS

Considerations, Reasoning, and Requirements		
Cost	Should be affordable so communities are able to buy it in developing countries.	- Maximize accuracy per cost of components. - Total cost of device should not exceed $200.
Ethical	Use of the medical device should not cause negative side effects or hurt patient.	- Add in acrylic plastic between LED and skin to eliminate skin-electronics contact. - LED wires of device are insulated so that patient does not touch them.
Manu-facturing	Materials should be environmentally sound and affordable.	- Material chosen should be affordable, non-toxic, and recyclable to eliminate waste. - Device should be able to be intuitively put together to optimize manufacturing process.

B. *Sensor Designs*

The final prototype of the Multi-Vital Sign Kit was a PCB with an Arduino Uno connected underneath (not pictured) connected to an ear clamp [Figure 1]. The ear clamp housed the pulse oximeter sensors. The ear clamp and housing for the PCB was made out of Acrylonitrile-Butadiene-Styrene (ABS) and 3D-printed in the Santa Clara University Maker Lab. The final circuit designs for the blood pressure and pulse oximeter sensor on the PCB is in [Figure 2] and [Figure 3]. The LED drivers design on the PCB is shown in [Figure 4]. The microcontroller PCB design is shown in [Figure 5]. Finally, the ear clamp, which houses the three sensors consists of two pieces. On one side houses the two LEDs for the pulse oximeter and one LED for the glucose sensor [Figure 6]. On the other side is where the two photodiodes for the pulse oximeter and glucose LEDs are housed [Figure 7].

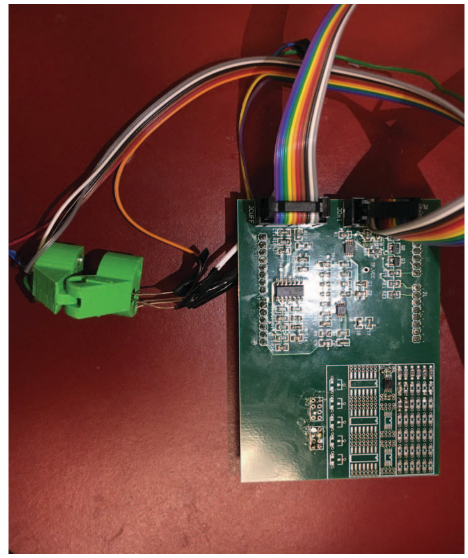

Figure 1: Final Printed Circuit Board Design with External Components

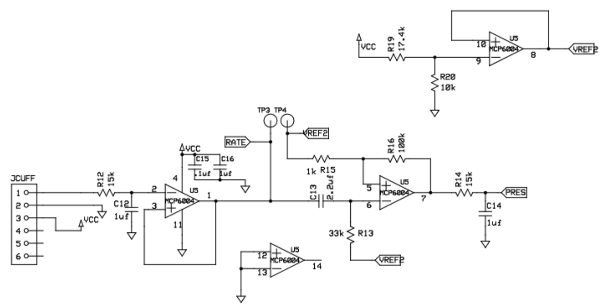

Figure 2: ExpressPCB Blood Pressure Circuit Design. This is the circuit design for the blood pressure sensor that is printed on the PCB in Figure 1.

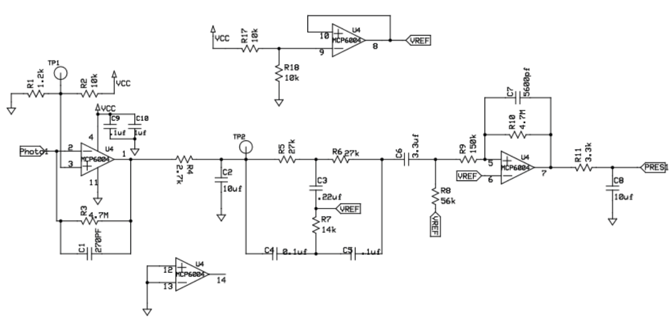

Figure 3: ExpressPCB Pulse Oximeter Circuit Design

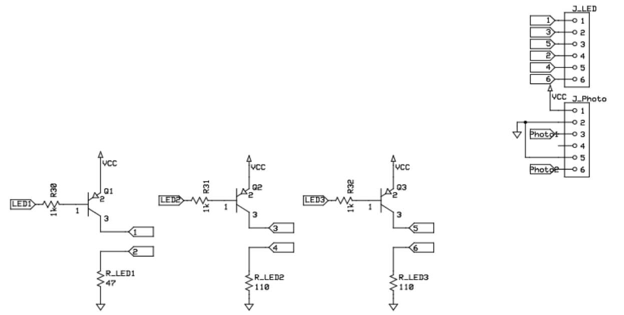

Figure 4: ExpressPCB LED Drivers Circuit Design

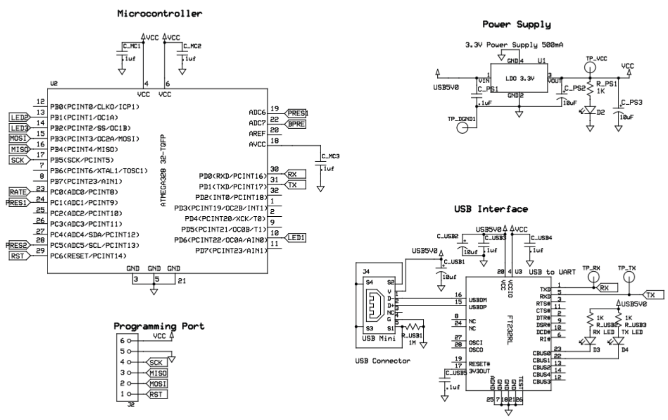

Figure 5: ExpressPCB Microcontroller Circuit Design

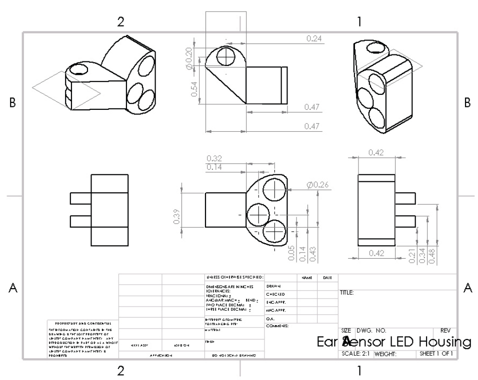

Figure 6: Ear Sensor LED Housing Design

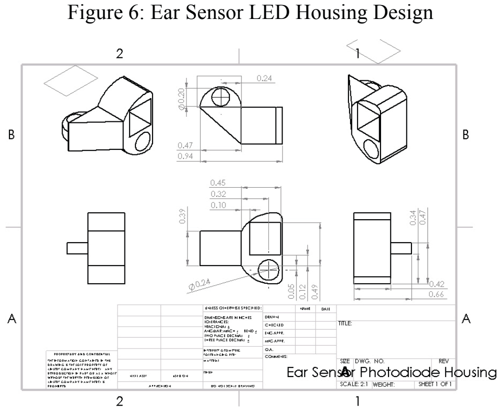

Figure 7: Ear Sensor Photodiode Housing Design

C. *Testing Procedures*

1) Blood Pressure Sensor:

The testing procedures for the blood pressure followed the testing procedure that would be encompassed in all of our sensors. Our patient would first take their blood pressure from our commercialized blood pressure sensor, so that we would have a baseline to compare their results against our prototype. Once this was done, our patient would use our blood pressure cuff so that we could measure our own data through our device. As a group member would manually pump the blood pressure pump, corresponding data would appear through our Arduino code.

2) Pulse Oximeter:

The pulse oximeter testing was conducted in two states, with a resting and elevated heart rate. Testing oxygen saturation and heart rate both when a patient is at rest and then after doing moderate exercises further broadens the ability of the sensor to be able to accurately detect oxygen saturation and heart rate.

The final testing setup was used with the ear clamp to house the LEDs, and shield them from outside light as best as possible, with the photodiode on the other half of the ear clamp. In addition, the LED's were directly connected to the PCB.

III. RESULTS

TABLE II. PULSE OXIMETER AND HEART RATE DATA

HR	1	2	3	4	5	6
Our Sensor	72	72	52	52	76	52
Commercial	66	82	57	55	81	56
% Error	8%	14%	10%	6%	6%	7%
Avg. Error	8%					

O2 Levels	1	2	3	4	5	6
Our Sensor	98%	98%	97%	97%	100%	96%
Commercial	98%	98%	98%	98%	99%	99%
% Error	0%	0%	1%	1%	1%	3%
Avg. Error	1%					

A. Oxygen Saturation and Heart Rate Data

The data shown in Table II are the results gathered using our oximeter to test patients as well as the data from the commercial oximeter. The error for our heart rate data was below 10% for four out of six patients on the first trial. The heart rate was calculated in MATLAB from the Infrared LED readings used for the oxygen saturation measurements. The Infrared LED data set was used instead of the Red LED because Infrared light best absorbs arterial blood and would represent the heart rate best.

Our oxygen saturation data showed a error margin of 1% on average. The measurements were calculated using MATLAB from the data gathered using our blood pressure sensor.

For the pulse oximeter data, the error is likely due in part to the physical design and positioning of the detecting components themselves. The early design stage had many of the components loosely aligned, and required some effort to set up the measurement in the first place. Refining the design of the ear sensor housing would allow for faster and easier alignment of the photodiode with the LED light beam, and has potential for producing an error rate lower than the 10% achieved.

TABLE III. BLOOD PRESSURE DATA

Trial 1	Person 1	Person 2	Person 2	Person 4
Commercial BP:	119/77	102/70	107/72	103/65
Sensor:	110/65	98/72	100/67	98/67
% Diff (Systolic)	8%	4%	7%	5%
% Diff (Diastolic)	16%	3%	7%	3%
Trial 2	Person 1	Person 2	Person 2	
Commercial BP:	116/72	98/73	100/60	
Sensor:	92/63	100/67	93/61	
% Diff (Systolic)	21%	2%	7%	
% Diff (Diastolic)	13%	8%	2%	
Avg. Error Systolic		8%		
Avg. Error Diastolic		7%		

C. Blood Pressure Data

The data sets in Table III show how our blood pressure sensor compared to the commercial one used for benchmark testing. For Person 1 in Trial 2, there was more than 10 percent error for both the systolic and diastolic pressures. This data set is observed to be an outlier because both Person 2 and Person 3 percent errors were under 10%. The commercial sensor could have possibly been giving faulty readings, since at times, test subjects would get blood pressure readings from the commercial sensor that were not consistent with values measured in hospitals, nor consistent with their health conditions (abnormally high blood pressure readings measured from the commercial sensor at times). Since the results were quantified manually through excel, this could have also led to more error since it was not clear when the heart rate started (for systolic pressure) or ended (for diastolic pressure).

E. Cost Analysis of Device

As summarized in Table IV, the overall price of the device is $133.58. As previously mentioned, the proposed device was targeted to cost no more than $150, while containing at least three sensor types, and be connectable to a mobile device such that data can be sent wirelessly to a physician via Wi-Fi or SMS.

TABLE IV. COST ANALYSIS OF DEVICE

Item	**Cost**
Blood Pressure • 3Way Dump Valve • Hand Pump & Pressure Cuff • ASDX015PDAA5 Transducer	**Total = $ 47.53** $2 $14.95 + $18.89 = $33.84 $11.69
Oximeter • TI OPT101P Photodiode • 5mm Red LED (660nm) • 5mm IR LED (940nm)	**Total = $ 8.43** $7.46 $0.29 $0.68
PCB	$25
Arduino Uno	$40
Surface Mount Component (Res, Caps)	$4.49
Surface Mount Components (Op-Amps, Mosfets)	$8.13
Acrylonitrile-Butadiene-Styrene (ABS)	Free*
Total Cost	**$133.58**

* Donated by the Frugal Lab

IV. CONCLUSIONS

The objective of this project was to develop an affordable kit equipped with sensors that will be used to take a patient's vital signs, such as blood pressure, heart rate, and blood oxygen saturation. This kit is intended for developing countries such as India in order to help alleviate the health care issues of people not being able to check on how their overall health performs. In conjunction with telemedicine, this device would replace the first steps of any standard medical checkup. Instead of traveling all the way to a hospital to have baseline vitals measured, the patients would measure their vital signs with our proposed device, and send them to a physician for review to determine whether an in-person appointment is necessary. Our vital sign kit is compact and also easy to use. We found that on average, the pulse oximeter and heart rate sensor had less than 10% error compared to commercial products. In addition to our sensor development, by wirelessly sending data results from the vital sign kit, the first essential part of a treatment can be carried out via wireless communication, saving the doctor and patient time and money.

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