Health Walker - Six Minute Walk Testing Unit

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Abstract

'Health walker-Six minute walk testing unit' is a device that determines various health factor like heart rate, body mass index, oxygen saturation, which play a vital role in deciding pulmonary or cardiovascular fitness. The conclusions inferred by our device- "Health Walker" are of good help to the doctors for analysing person's health status.

Health Walker consists of three segments: pulseoximeter (to calculate the heart rate and oxygen saturation), pedometer (to calculate the distance walked in six minutes) and graphical user interface (to make a medical sheet).

Keywords—MSP430, pulseoximeter, six minute walk and distance (6MWD), heart rate, oxygen saturation.

I. INTRODUCTION

The ability to walk is a quick and inexpensive measure of physical function, since it reflects the capacity to undertake day-to-day activities. The 6-min walking distance (6MWD) test is used in clinical practice and research into patients with chronic obstructive pulmonary disease (COPD).It provides useful information as the severity of chronic obstructive pulmonary disease increases. It is proved to be safe, easy to perform, and valid for all age groups [1].

Six minute walk test being popular and feasible, is difficult to conduct as it requires different devices to successfully carry out the test. First, a pulseoximeter is used to measure heart rate and oxygen saturation in blood.And to measure distance walked, participants are asked to walk back and forth on a 500m indoor track[2].
This walking in short distances and turning back and forth reduces the maximum efficiency with which the person can walk in 6 minutes.[3] So, we decided to make a device which is capable of conducting the test in one go without any need of multiple devices. There is no existing project as per our knowledge that implements the procedure of six minute walk test in such a user friendly way. Although, pulseoximeter and pedometer (separately) based on other microcontrollers do exist in market, but our device provides the following features:-

1)It is a complete tool to perform the Six minute walk test that automatically measures distance walked in six minutes, heart rate and SpO2 before and after the test (As expected in Six minute Walk Test).

2)It creates a health sheet on your computer. Once the device is connected to the PC, A python Based Graphical User Interface (GUI) interacts with the microcontroller and a heath sheet is created using various medical algorithms. This sheet may prove to be a great help to the doctors for further assessment of the patients.

3)It can serve as a full-fledged device for the doctors to perform the 6MWT (Six Minute Walk Test).

4)Cheap

5)less power consumption and rechargeable device

A. Technical Background

SIX MINUTE WALK TEST

The 12-min walking test was introduced in 1968 as a guide to physical fitness, and was later applied to patients with chronic obstructive pulmonary disease (COPD).[1]. It was then found that decreasing the time of the walk to 6 min did not significantly reduce the utility of the test. Henceforth, Six minute walk test came into existence.

- The distance walked in 6 min (6MWD) is reduced by several types of diseases, including obstructive lung disease, heart failure, arthritis, and neuromuscular disease.The results allowed determination of the predictors (based on height, weight, body mass index (BMI), age, and gender) of the 6MWD in the healthy subset of study participants

The distance walked in six minutes depends on the factors like Age, Height, Weight and gender[4].The reference equations derived for ideal six minute walking distance are:

For men
6MWD = (7.57 × height in cm) − (5.02 × age) − (1.76 × weight in kg) − 309 m, and
(Subtract 153m to obtain lower limit of reference distance walked)

For women
6MWD = (2.11 × height in cm) − (2.29 × weight in kg) − (5.78 × age) + 667 m.
(Subtract 139m to obtain lower limit of reference distance walked)

- Body Mass Index(BMI)
Mathematically, BMI = Mass in kgs / (height in meters^2). According to database available online, the BMIs have been categorised as[5]:

CATEGORY	BMI RANGE
Very severely underweight	<15.0
Severely underweight	15.0-16.0
Underweight	16.0-18.5
Normal	18.5-25.0
Overweight	25.0-30.0
Moderately obese	30.0-35.0
Severely obese	35.0-40.0
Very severely obese	>40.0

Figure 1: BMI for various age groups

- Resting Heart Rate- The figure 2 has been taken from [6]..Normal heart rate of various age groups is as follows:

Age Group	Age	Heart Rate
Child	7-12	75-110
Adult	18+	60-100
Athletes	------	40-60

Figure 2: Resting Heart Rate of different age groups

Heart Rate Recovery(HRR) is defined as the difference between heart rate at peak exercise and 1 min following test termination.
A low HRR value is observed to be a marker of increased mortality. A HRR <= 12 beats at 1 min post exercise is proposed as a threshold to define an abnormal response[7].

- SpO2 (Oxygen Saturation in Blood)

Normal (range)	97 (95-100)
Hypoxemia	< 95
Mild Hypoxemia	90 – 94
Moderate Hypoxemia	75 – 89
Severe Hypoxemia	< 75

Figure 3: Different levels of SpO2[8]

B. Proposed Solution

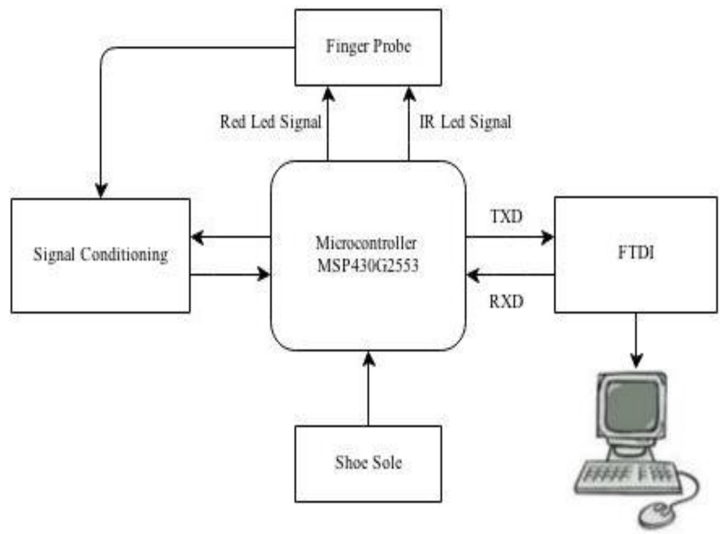

Figure 4: Block Diagram of Health Walker

The microcontroller is the central part of the project that is controlling all the devices.The MSP430 sends timing signals to red LED and infrared LED so that they glow alternatively. The photodiode signal from the finger probe goes to the signal conditioning circuit that filters and separates the output from the probe into two signals- one for red other for infrared.The filtered and separated signals then goes to the ADC pin of microcontroller for the calculation of heart rate and oxygen saturation in the blood before and after walking.There is also a connection between shoe sole and microcontroller that calculates the maximum distance walked by the person in 6 minutes. Then, all the parameters necessary in 6MWT are sent to the computer via a USB(universal serial bus) cable which displays the data in a Python based Graphical based Interface (GUI) and gives some suggestions regarding the health of the person.Thus, our device eliminates the need for various equipments like stethoscope, stopwatch, measuring tape. The use of python based GUI help us to store the health record of the person. Hence,combining the use of microcontroller, sensors, amplifiers and analog to digital converters make the device user-friendly, mobile and cost effective.

C. Organization of the Paper:

Section II explains the designs of analog subsystems of our device – "Health Walker". It includes the detailed explanation of finger probe , signal conditioning circuit.Signal Conditioning block includes sample and hold demultiplexing and bandpass filtering.

II. PROPOSED SOLUTION

Our device consists of three main segments: Pulseoximeter, Pedometer and GUI.

PULSEOXIMETER (combination of finger probe and signal conditioning circuit) as shown in Figure 5:

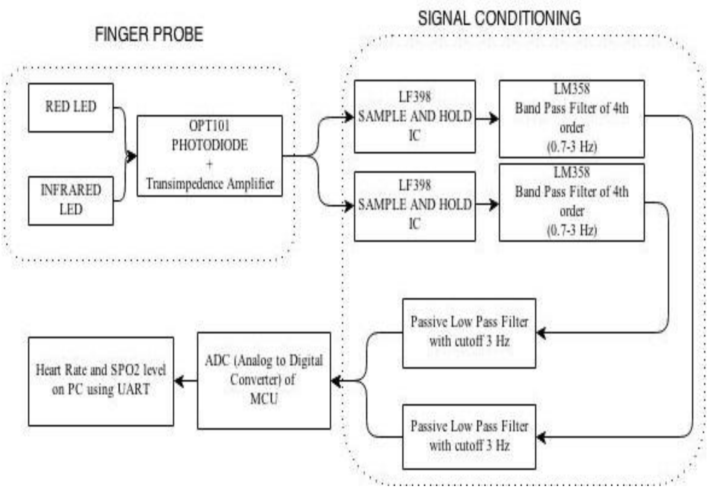

Figure 5: Pulseoximeter Segment

The basic optical sensor of a non-invasive pulseoximeter consists of both red and infrared LED's with peak emission wavelengths of 660 nm and 940 nm respectively, and photodiode. The light intensity detected by the photodetector depends, not only on the intensity of the incident light, but mainly on the opacity of the skin, reflection by bones and tissue scattering. Microcontroller MSP430 will generate a digital switching pulse to drive the red and infrared LED's in the sensor alternately at a converter repetition rate of approximately 1KHz. The transmitted light is detected, amplified and converted to a voltage using OPT101. At this point in the circuit the signal is fed to two identical sections, one for each of the transmitted wavelengths. Since the light is pulsed, we need to use a sample-and-hold circuit to reconstitute the waveforms at each of the two wavelengths[9]The outputs from these circuits are then filtered with a band-pass filter (with 0.7 Hz and 3 Hz cut-off frequencies) in order to remove primarily the dc component but also high frequency noise. The resulting signals thus represent the cardiac-synchronous information in the waveforms and these are further amplified before they are converted to digital format for subsequent analysis by the microcontroller.

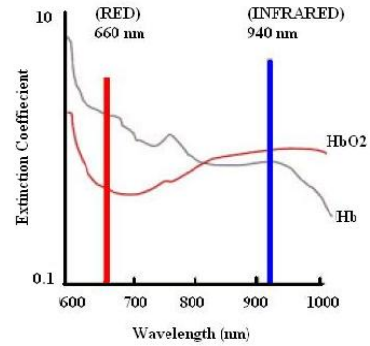

Figure 6: Absorption of oxygenated and non-oxygenated hemoglobin at different wavelength

Oxygenated haemoglobin absorbs more infrared light and allows more red light to pass through. Deoxygenated haemoglobin absorbs more red light and allows more infrared light to pass through as shown in Figure 6. This effect can be seen with the unaided eye because haemoglobin in arterial blood is mostly saturated and appears red while venous blood, where it is mostly deoxygenated , appears darker because it absorbs more red light. The ratio of absorption at the two wavelengths is used to determine the fraction of saturated haemoglobin.

MAIN HARDWARE COMPONENTS

1)FINGER PROBE:

Light coming from two leds passes through the finger and the remaining transmitted light falls on OPT101(Photo diode).The output Voltage is a function of both wavelength and intensity of light falling on it. The signals from the MCU are sent as shown in figure 8.

50us pulses were supplied to red and IR led at a repetition rate of 1 kHz.[10] A frequency of 1 kHz is suitable because such a frequency is well above the maximum frequency present in the arterial pulse. The verified signals are shown on oscilloscope as shown in Figure 9.

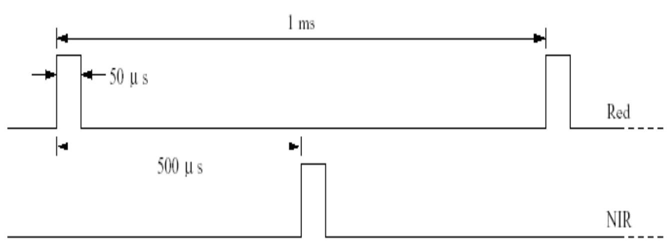

Figure 8: Timing signal sent from MCU to drive LEDs

2) SIGNAL CONDITIONING CIRCUIT

(A combination of sample and hold circuit and bandpass filter):

Sample and Hold circuit:

Here the sample and hold circuit is being used to separate the output of photodiode into two signals: one for red and one for infrared. The logic signal sent to the Sample and Hold IC for both red and infrared signal is same as the timing signal sent to the red led and infrared led respectively.
When logic signal is high, the Sample and Hold IC samples the signal from the photodiode and when the logic signal is low, it holds the value it sampled last as shown in Figure 11.

Bandpass Filter(4th order)
The first part was to design a band pass filter with frequency range of 0.7 to 3 Hz. The filter was designed by the combination of passive highpass filter and active lowpass filter[11]. The practical frequency range for filter came out to be 0.6 to 4 Hz.
(The deviation from practical results was probably a result of component drift).[11]

low pass filter after band pass filter:
When we put low pass filter after band pass filter we observed further improvement in signal quality as shown in Figure 14.The low pass passive filter was designed with cut-off frequency of 3 Hz.

MAIN SOFTWARE COMPONENTS
TINA, PSPICE is used to simulate the filters. CCS code compose studio is used to code the microcontroller.
PYTHON is used to create GUI (Graphical User Interface)

III IMPLEMENTATION

A. Hardware implementation

The hardware includes majorly these parts: Pedometer, Pulse oximeter, Microcontroller and FTDI for the processing of signals.
First all three parts were made separately and tested for best accuracy. Afterwards, a final board comprising of all was made.
PEDOMETER is implemented using a simple membrane switch along with a pull up resistance placed under shoe sole as shown in Figure 15. The switch detects every step as is undergoes pressure. Since the stride length of every individual is different, first the device has to be calibrated by walking up to ten meters.

Figure 15: The membrane switch place inside shoe sole.

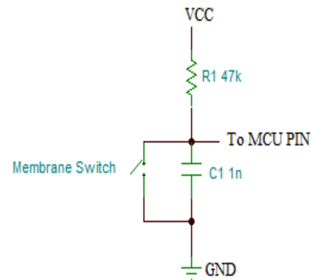

Figure 16: Schematic of shoe sole

The device measures the distance with help of a membrane switch attached to the shoe sole. Every time a step is taken, heel puts pressure on the switch and it generates a pulse which it further sent to the micro-controller.
Since we get the step length (by calibration) and number of steps taken by the person in six minutes, the distance walked by him can be calculated using simple mathematics.

step lap= 10 meters/ number of steps in 10meters
After calibration, the person is asked to walk as he wants. Henceforth,
distance travelled = (number of steps) x (step lap)
So, it can measure your speed of walking or running as it depends on how fast you place your foot on the group. No specific IC is being used in pedometer part.

PULSEOXIMETER

1. FINGER PROBE

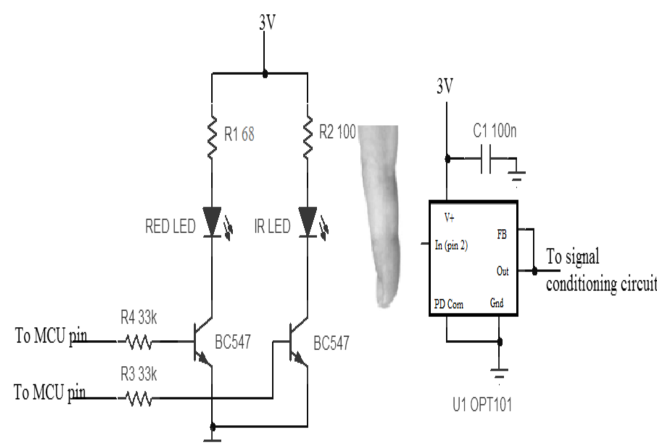

Figure 7: Schematic of Finger Probe

Construction of finger probe:

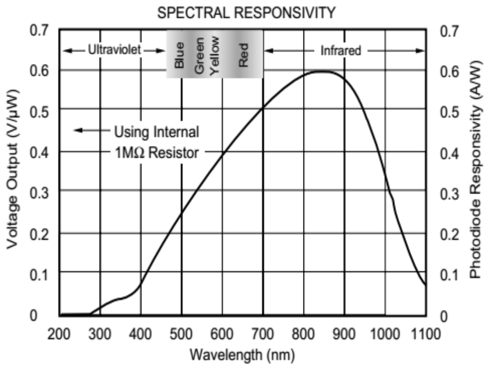

Figure 17: Spectral responsitivity of OPT101 v/s wavelength of Incident light (from datasheet of OPT101)

The wavelength of Infrared light varies from 700nm to 1100 nm.And generally, infrared leds are available with 880nm. But we need infrared led of 940nm because of following reasons:

1) Photodiode OPT101 gives very good spectral responsitivity for infrared led from 800 nm to 950 nm from Figure 17.

2) The difference in the extinction coefficient of pulseoximeter increases after 800nm and is maximum at 1100 nm as shown in Figure 6.Therefore , considering both the factors, IR led should be of 940nm.Wavelength of red light is 610nm to 740nm .Since the difference is maximum at 660nm , therefore red led with 660 nm was chosen. and we determined the wavelength of led in the following way:

E= hc/wavelength

E = q*V

where

h= planck constant= 6.62 x 10^(-34) Joule sec

c= speed of light = 3 x 10^8 m/s

E= energy

q= charge of a electron= 1.6 x 10^(-19) Coloumb

V= voltage drop

After putting all values , V =1.31 Volts

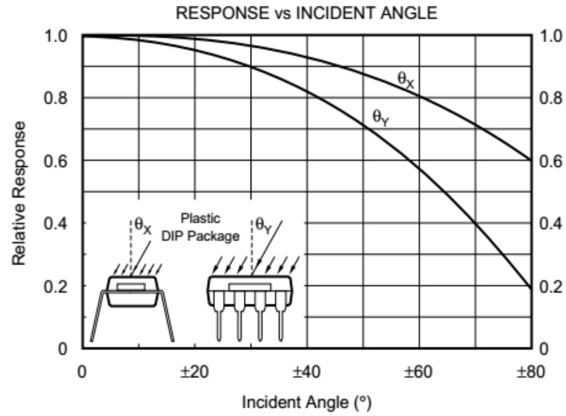

Figure 18: Relation between relative output response and angle of incident light on photodiode(from datasheet of OPT101)

Moreover, from the figure 18 , we came to the conclusion that SMD LEDs cannot be used in the construction of finger probe as SMD led have 120 degree viewing angle. So, If light from the red and infrared led is incident on OPT101 at an angle of 180 degree , then relative response of OPT101 will less than 0.2.Henceforth, normal (3mm package) LEDs are used having viewing angle not more than 20 degree.

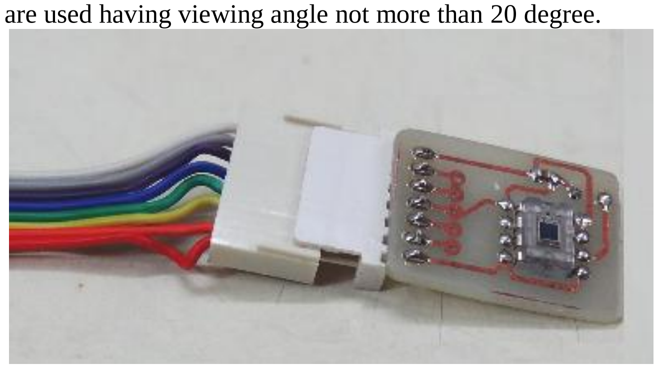

Figure 31: OPT101 (Light sensor) placed inside finger probe.

2. SIGNAL CONDITIONING

2.1 SAMPLE AND HOLD

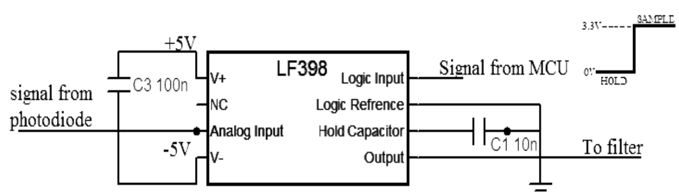

Figure 10: Sample and hold circuit

2.2 FILTER

The filter was first simulated using TINA software and PSPICE. Then the circuit was made on breadboard and checked using oscilloscope.

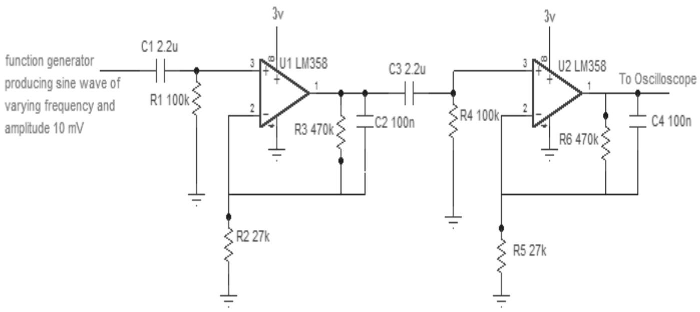

Figure 12: Combination of two 2nd order Band Pass Filters

After theoretical designing of the bandpass filter the circuit was first simulated with PSPICE, TINA for accurate values of bandpass region.

5th order filtering: Only Two bandpass filters , each consisting of passive high pass filter and an active low pass filter have been used till now in existing pulseoximeter. But we have used an extra passive low pass filter after the bandpass filtering to clean the output of 4th order filters.

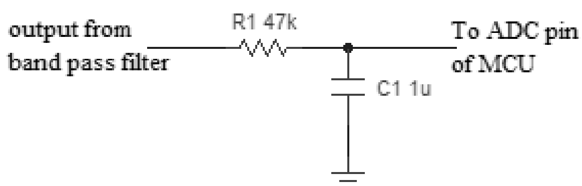

Figure 13: Schematic of low pass filter

B. Software Implementation

Two major softwares used in making of Health Walker are: Code composer studio (for microcontroller's signal coding) and Python (For Graphical User Interface and communication between PC and microcontroller).

1.Code composer studio

CCS codes the microcontroller for input and output signals. Here the MSP outputs high signals to Red and IR LED (placed on finger probe), logic signals to Sample and hold IC, it receives signals from the two filters at its ADC input. The controller also sends and receive RXD and TXD signals from FTDI chip. The flow of code is shown in figure number 19.

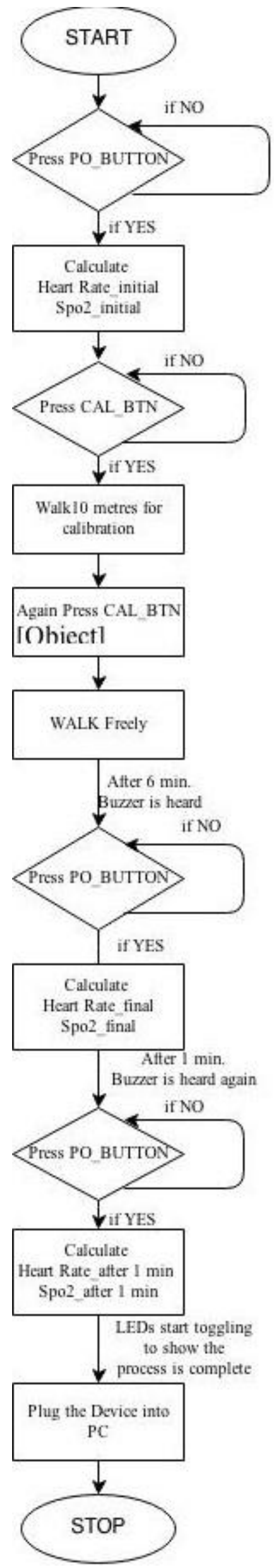

Figure 19: Software Flowchart of Health Walker

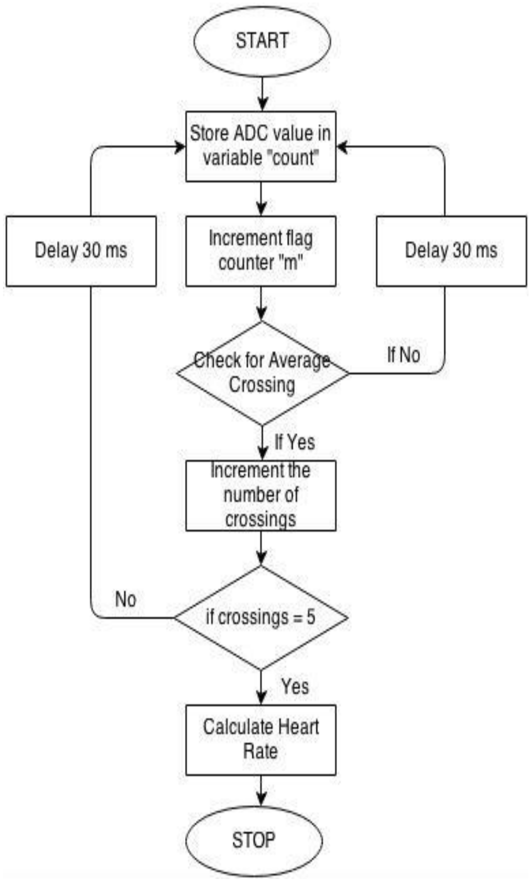

Figure 20: Flowchart showing heart rate calculations

The pseudocode for the calculation of oxygen saturation (SpO2) is shown below.

```
while(1)
{
        Avg=70;
        adc_convert();
        if(count>max)
                max=count;
        else if(count<min)
        min=count;
m++;
if((lastcount>avg)&&(count<avg))//average crossing detected
   {
        If(no_of_beats==5)
        c=m;
        Min_value=min;
        Max_value=max;
        min=1023;
        max=0;
   }
break;}
```

The ratio of voltage due to red signal to the voltage due to infrared signal (R) is calculated as [11]

R=((Vmax(Red)-Vmin(Red))/Vmin(Red))/(Vmax(Infrared)-Vmin(Infrared))/Vmin(Infrared)

and oxygen saturation of blood can be formulated as: SpO2=HbO2/(HbO2+Hb)

On the basis of **Beer Lambert law**:

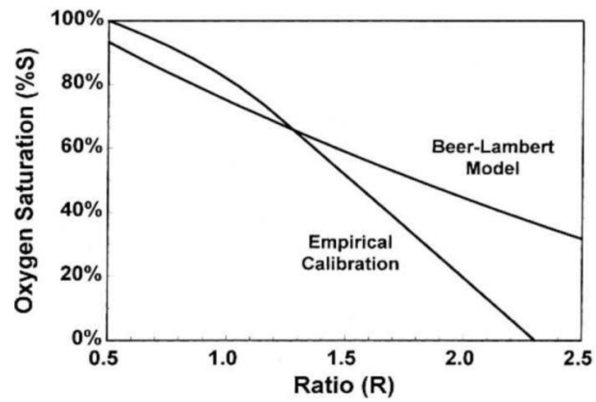

Figure 21: Relation between R and SpO2 from beer-lambert law [12]

According to the Beer Lambert Model, the relation between SpO2 and R is:

SpO2 = 110 – 25* R

Practical results deviate from the theoretical relation. So, we Modified the formula according to our device by comparing the results with an existing pulseoximeter.
The empirical calibration according to our device:

SpO2 = 110 – 20* R

2.Python

The programming language python has been used for the designing of Graphical User Interface as well as for communication between the PC and the Microcontroller. It makes use of serial library for efficient communication.

User need to enter some information about himself (e.g. name age weight, height, problem caused and disease suffered in past) and the rest will automatically be retrieved from the microcontroller.

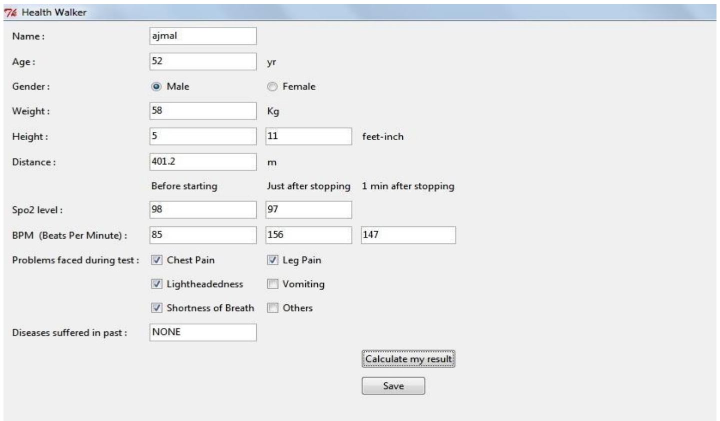

Figure 22: Screenshot of Health Walker application (using python)

Upon clicking the "calculate my result" button, the software uses various algorithms (mentioned in Technical background) and displays the result as shown in figure 22.

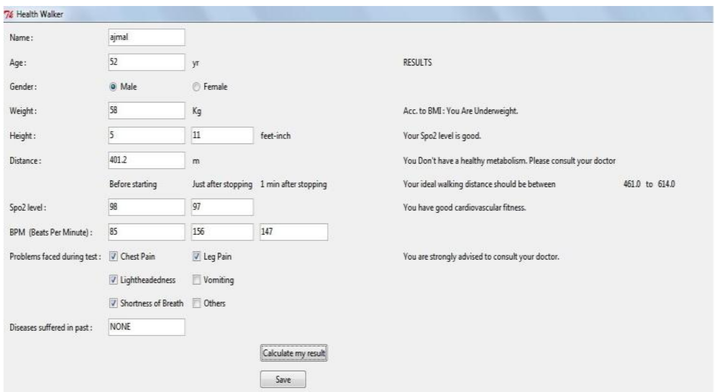

Figure 23: Results in Health Walker application

The results shown in figure 23 can be saved in any format for further analysis by the doctor.

IV. RESULTS

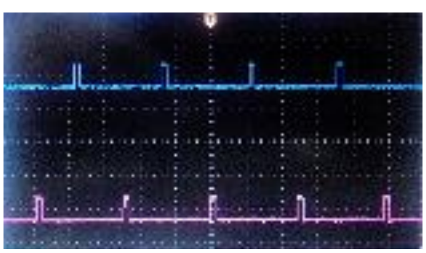

Figure 9: LED Driving Signal coded using MCU and tested on oscilloscope.

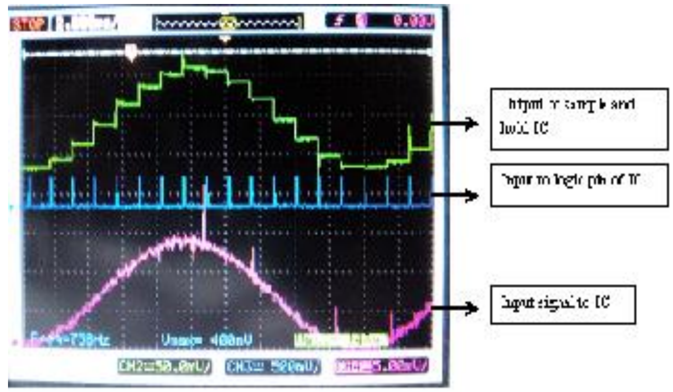

Figure 11: Sample and Hold screenshot (Test Signal)

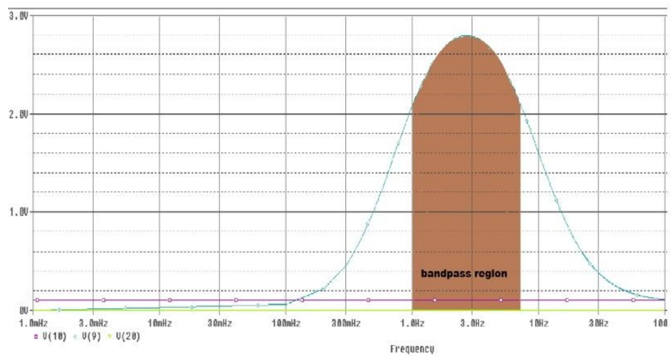

Figure 24: Simulation of Bandpass filter (PSPICE)

Input frequency from function generator (Hz)	Output voltage on oscilloscope (V)
0.450	0.600
0.500	0.840
0.550	1.04
0.600	1.24
0.700	1.4
0.800	1.56
0.900	1.64
1	1.68
1.5	1.80
1.75	1.80
2	1.76

2.5	1.64
3	1.56
3.5	1.40
4	1.28
4.5	1.04

Figure 25: Observation table for Bandpass filter

Upon satisfactory results from simulation softwares the circuit was made on a breadboard and the filter response was taken on the oscilloscope.
Lissajous pattern of the cutoff frequency came as under. The pattern was observed in X-Y mode of oscilloscope, negative half of wave being clipped off due to unipolar bias voltage given to LM358 IC.

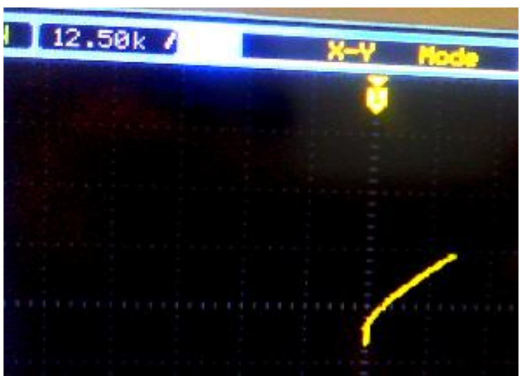

Figure 26: Lissajous patten at mid-frequency (1.5 Hz)

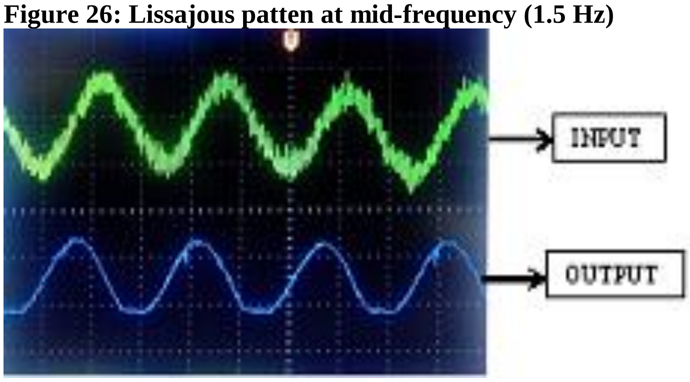

Figure14: Testing of Low pass filter

The green signal is the signal before putting low pass filter (output of band pass filter). The blue signal is the output of low pass filter.

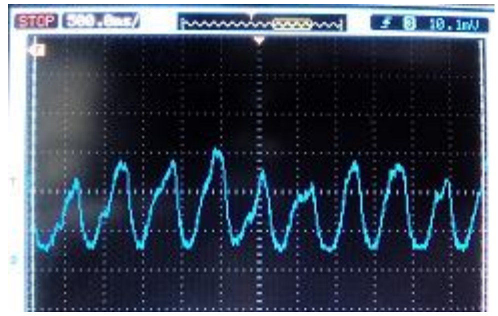

Figure 27: Cardiac Signal on Oscilloscope

The cardiac signal (after analog processing) sent to the ADC pin of microcontroller is shown in figure 27.

V. CONCLUSIONS

Our "Health Walker – Six Minute Walk Testing Unit" is able to successfully perform 6 minute walk test. It is able to automatically calculate distance walked in 6 minutes, heart rate, oxygen saturation with the help of audio and visual indicators on PCB. It even creates a health sheet on PC. This sheet may prove to be a great help to the doctors for further assessment of the patients. It is cheap and power saving.

<u>Limitations:</u>

1) The finger probe is very sensitive to motion artifact.
2) Brightness of the LEDs is currently constant, irrespective of finger sizes.
3) There are chances that photodiode may get saturated and damaged. Therefore, the device should be powered only after inserting the finger.

<u>Future Scope:</u>

1) Complex algorithm can be incorporated in which the brightness of the LEDs will be determined by the thickness of the skin.
2) The weight measurement can be incorporated to measure the weight of the person necessary for BMI.
3) Wireless communication between microcontroller and PC can be incorporated.

ACKNOWLEDGMENTS

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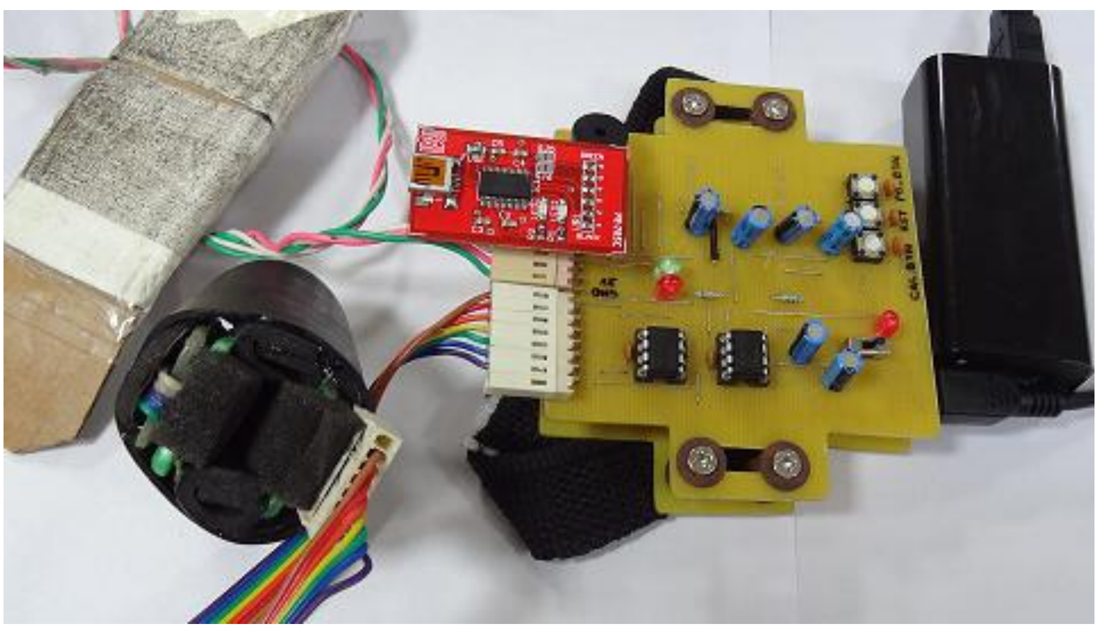

Figure 28: Final demonstration board of "HEALTH WALKER"

APPENDIX A

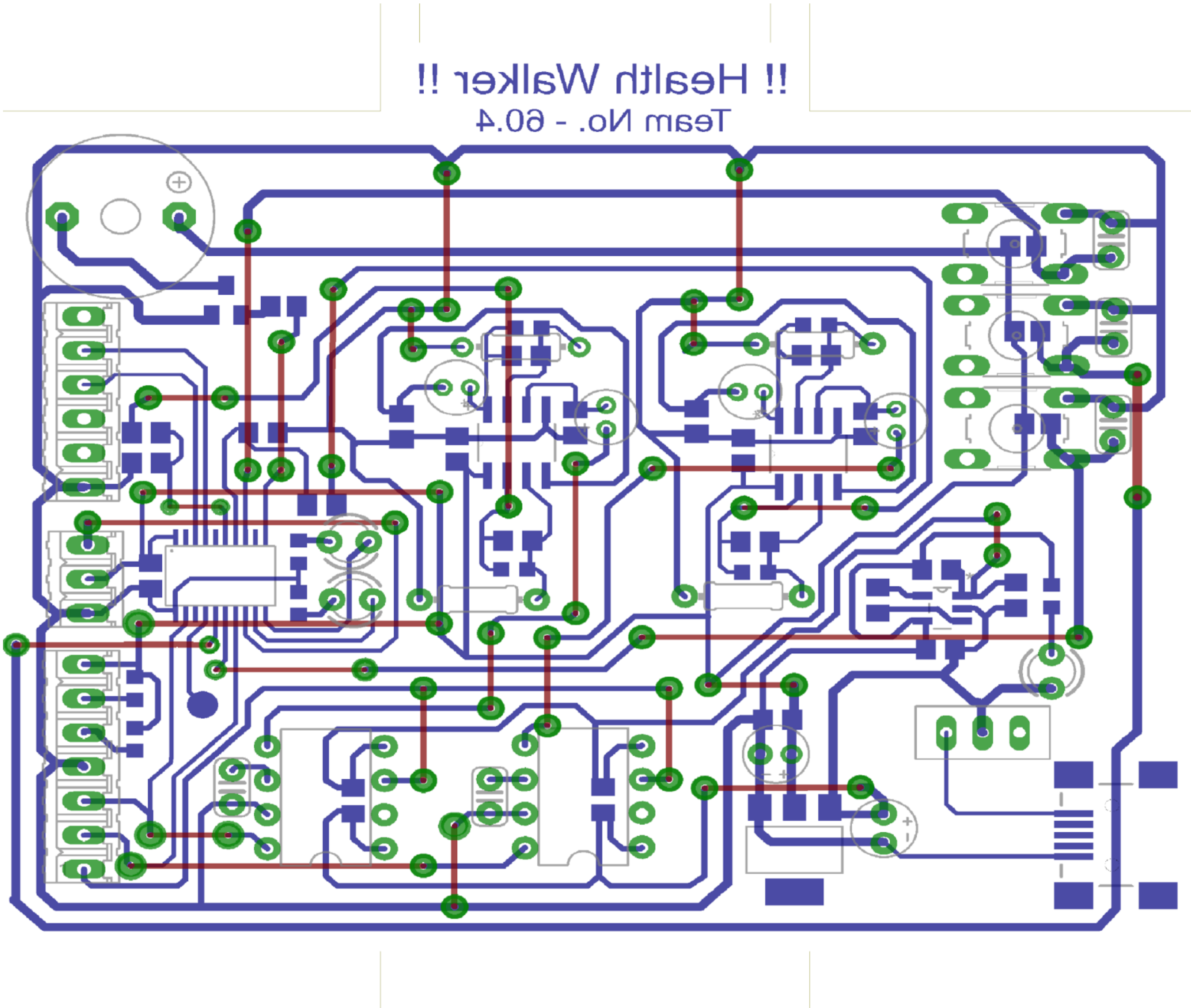

Figure 29: Board file of the final board.

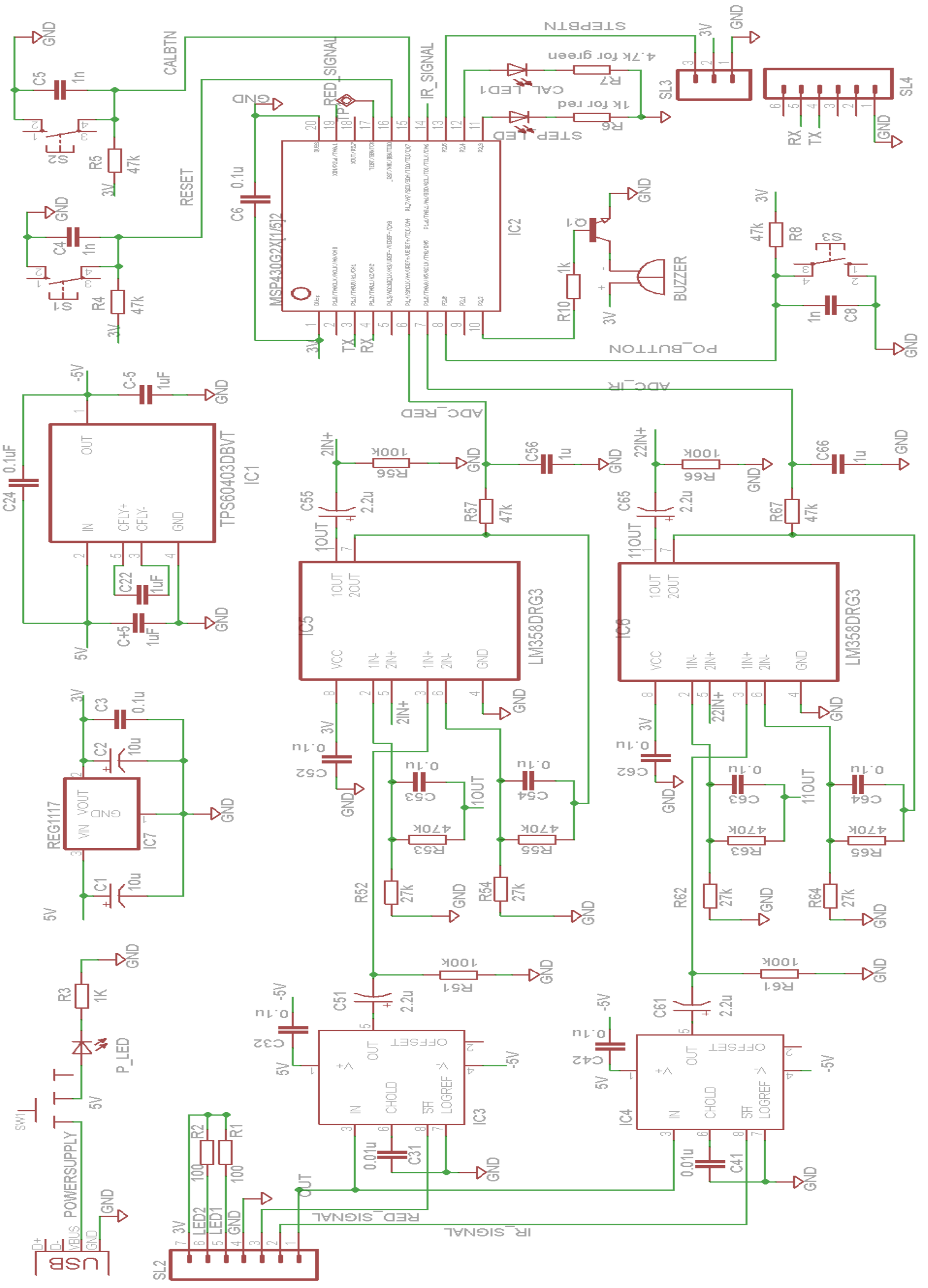

Figure 30: Schematic of Health Walker