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Integrated Non-Invasive Biomedical Sensor Module for Measurement of Vital Signs of Human Body for Remote Health Monitoring

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ABSTRACT: An Integrated non invasive biomedical sensor module defines a multi-user remote health monitoring system that is proficient of consistently sensing and gathering the very basic human body parameters called the vital signs from the individual and storing it wirelessly in a remote data server. These data can be analysed by health care professionals to derive the health status of an individual or the prevailing health trends when applied in the domain of public health surveillance with a view to aid in public healthcare. The system can also be applied to examine and collect additional information derived from the sensed biomedical parameters like heart rate variability from PPG, and for patient monitoring, tracking and collection of specific data.

KEYWORDS: Photoplethysmography, Pulse measurements, Sensor networks, Microprocessors, Bluetooth, Remote health monitoring, Ultrasonic sensor, Body mass index, Vital signs, IR thermometer, Blood oxygen.

I. INTRODUCTION

As the nation's healthcare infrastructure continues to develop new technologies in the field of bio-medical instrumentation and assure to provide readily available health information that can help people to tackle personal and public health apprehensions. In general, implantable medical sensors, wearable, and portable computing devices present numerous prospects to offer timely health information to public health professionals, physicians as well as consumers. By supplying real time health information or measured bio-medical parameters collected continuously, a sensor based health care information infrastructure that senses very basic health parameters can be used to maintain the patient's medical records effectively. Remote health monitoring (RHM) is a technology to enable monitoring of patients health trend outside the conventional clinical setups, which may increase remote access to health care and decrease healthcare service costs [19][1]. More over vital human body parameters can also be used to evaluate a community or group of people. This larger approach allows analyst to assess health trends and concerns in different populations [1]. For example, a methodical study of human body anthropometric measurements, can be used to evaluate the dietary status of children in underdeveloped countries. These measurements can be used to determine the pervasiveness of mal-nutrition and predict the need for dietetic support.

These basic human body parameters termed as Vital signs often short named to just vitals, are a set of the six most important bio-medical parameters that signify the status of the body’s fundamental life-sustaining functions. These measurements are taken to help evaluate the general physical health of a person, and give traces to potential illness or show progress toward recuperation. The normal ranges for a person’s vital signs vary with gender, age, weight, and overall health [2][1]. The six main vital signs routinely monitored by health care professionals and physician include the following:

a. Pulse rate (Heart rate)
b. Blood Oxygen
c. Body heat (body temperature)
d. Height

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e. Weight
f. BMI

This paper proposes the implementation of a remote healthcare monitoring system (RHM) as shown in Fig. 1, by integrating several types of bio-medical sensors to sense the vital medical parameters such as Blood Oxygen, Pulse Rate, Body Temperature, Height, Weight, BMI often referred to as the Vital signs of the human body [19][2]. The data is made available wirelessly for the health care providers to diagnose the health trend and analyse the individual's basic health status.

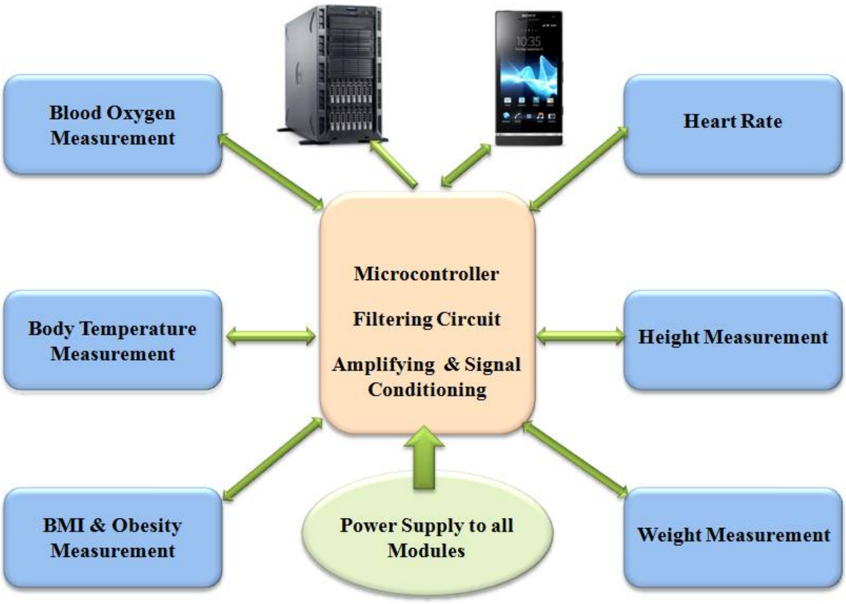


Figure 1. Graphical Abstract of the proposed system

II. SYSTEM ARCHITECTURE

This paper recommends a design for a user friendly, low cost and reliable Integrated non-Invasive bio-medical sensor module for remote health monitoring. This allows an individual to examine the vital health parameters as shown in Fig. 1, using onboard specialized sensor network integrated to a single brain microcontroller ATMEGA328U, which is governed by an interactive interface in the form of an android application. The specific sensors are so chosen to minimize the power requirements, maximize the reliability and accuracy and based on proven technology. The system is connected wirelessly using blue-tooth module HC05 and Wi-Fi module ESP8266 to the android device and data server. All these elements are powered by a single, transformer less 5v regulated DC power supply source. On selecting a particular test on the android application by the user, the corresponding sensor is triggered by the main microcontroller ATMEGA328U. This optimises the power requirement, reduces microcontroller computation and minimizes active state of individual sensor. The raw signal data acquired from the sensors are then processed, conditioned and amplified for desired output by an independent signal processing circuit comprising of analog front end (AFE) to process the raw analog data and a Digital circuit to convert it to digital form, all integrated into a single PCB. After the check, the health conditions are sent to the person's android device via blue-tooth/Wi-Fi [2]. The entire report can also be viewed, stored and referred on the device using an app as well as simultaneously stored in the main server stamped with the individual's mobile number. The main server is considered as a database of healthcare information system which is maintained by a designated health care unit which would render advises or help if deemed necessary. It would also enable one to access the health parameters from anywhere and anytime by simply typing in the Identification Number (Cell Phone Number).

III. HARDWARE DESIGN AND IMPLEMENTATION

A. Blood Oxygen and Pulse rate measurement using PPG

A noninvasive medical technique of photoplethysmography has been used for measuring the oxygen saturation and pulse rate of an individual [12]. Oxygenated hemoglobin and deoxygenated hemoglobin i.e. hemoglobin not fully saturated with oxygen, absorb different wavelengths of light differently as per Beer-Lambert’s Law as shown in Fig. 2.

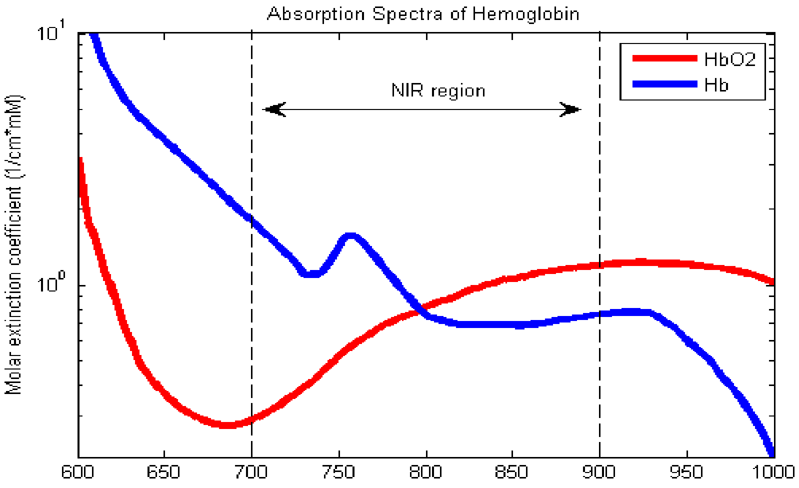
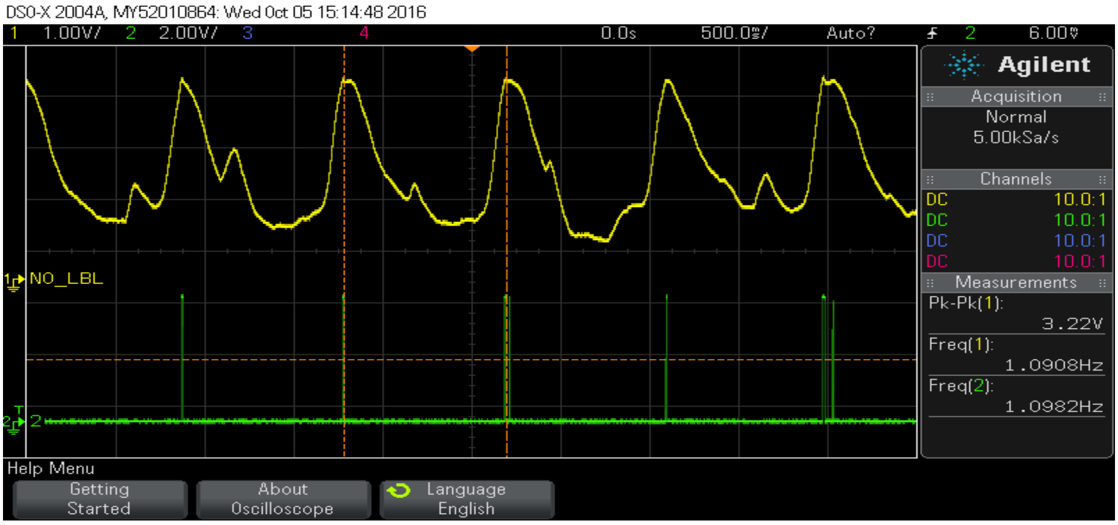


Figure 2. Absorption graph of Haemoglobin

The proposed system consists of two light sources and a photo-detector connected to a signal processing unit to measures the light intensity of the received light at the photo-detector [18]. The red LED used emits red light at 660 nm of wavelength and the IR LED emits infrared light at 960 nm of wavelength [8]. The signal received by the photo-detector has a DC component corresponding to the blood volume and an AC component corresponding to the pulsation of the blood through the arteries [10].


DS0-X 2004A, MY52010864: Wed Oct 05 15:14:48 2016

1 1.00V/ 2 2.00V/ 3 4 0.0s 500.0ms/ Auto? 2 6.00V

Acquisition
Normal
5.00kSa/s

Channels
DC 10.0:1
DC 10.0:1
DC 10.0:1
DC 10.0:1

Measurements
Pk-Pk(1): 3.22V
Freq(1): 1.0908Hz
Freq(2): 1.0982Hz

Figure 3. PPG Signal of a subject during testing as seen on Oscilloscope

This ratio, measured at red and IR wavelengths is used to calculate the oxygen saturation of the blood. Likewise the light transmitted through or reflected from the body part will fluctuate according to the pulsatile blood flow caused by the pumping of the heart and thereby was computed to derive the heart rate [11]. This proposed circuit utilizes the MAX30102 heart-rate & SpO2 sensor with integrated IR and red LEDs, MAX1921 step-down converter which converts the 2V to 5.5V supply input and generates the 1.8V rail for the heart-rate sensor, and a level translator MAX14595, which provides an interface between the SpO2 & heart-rate sensor and the microcontroller, which generally use a different logic level. This system has high accuracy with an error margin of less than 3% . This is more than adequate for determining hypoxemia. The information provided by this method is not only accurate, but immediate and continuous. The signal output for pulse rate is shown in Fig. 3.

B. Non contact body Temperature Measurement

The non-contact IR temperature sensing technique has been used in this system to measure the human body temperature. As Per Stefan-Boltzmann law, any object that is above absolute zero (0°K) emits light in the infrared spectrum which is directly proportional to its temperature. The infrared temperature sensor used here is Melexis MLX90614. Its integration with the microcontroller is shown in Fig. 4. The special infrared thermopile inside the MLX90614 senses the thermal radiation sometimes called blackbody radiation emitted by the human body being measured, in its field of view, and produces an electrical signal proportional to the temperature. This voltage produced by the thermopile is picked up by the 17-bit ADC of the application processor and conditioned before being send to the microcontroller.

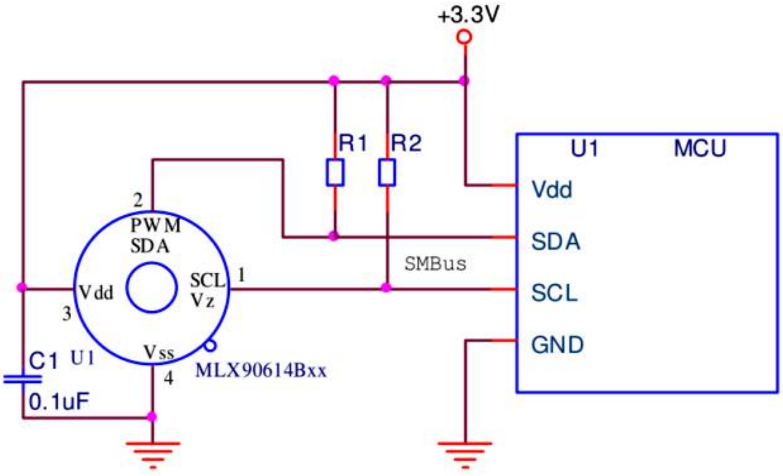


Figure 4. Pin-out of MLX90614

The MLX90614 IR temperature sensor senses the object as well as the ambient temperatures. The object temperature is the non-contact body heat measurement intended from the sensor, while the ambient temperature gives the temperature of the die of the sensor. The ambient temperature is used for temperature compensation in ultrasonic sensing for height measurement. The sensor is capable of measuring the object temperature ranging from -70 to 382.2 °C (-94 to 719.96 °F), and the ambient temperature measurement from -40 to 125 °C. Both the object temperature and ambient temperatures have a resolution of 0.02 °C**.**

A graph was plotted for different temperatures of water measured through a mercury thermometer and subsequently by proposed IR temperature sensor as shown in Fig. 5. It was observed that there is an error of approximately 2.7% on an average. This error was found to be linear and is basically because of radiation loss and atmospheric interference since the IR Temperature sensor senses the surface temperature while the mercury thermometer measures the internal temperature. Since the error is linear across the required range, the same has been corrected for in the microcontroller during processing.

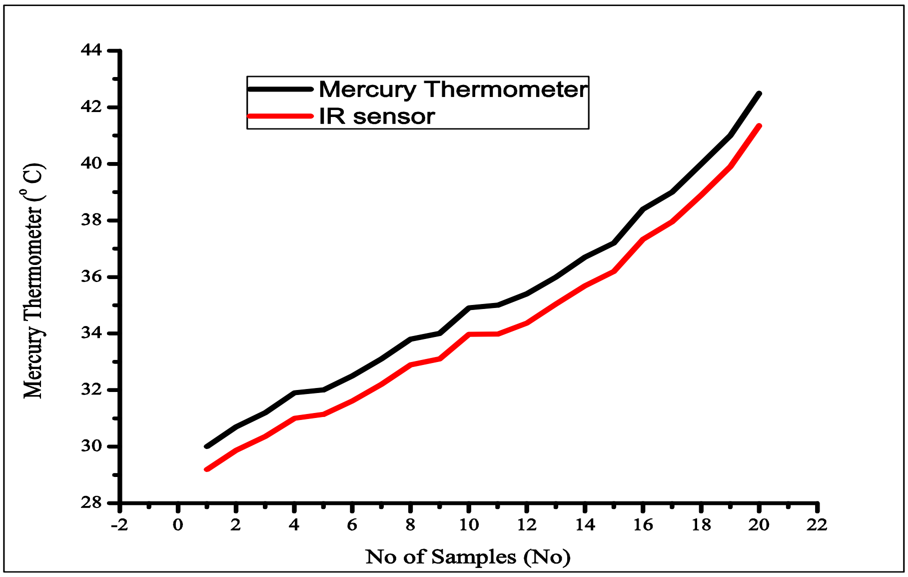


Figure 5. A comparison for temperature measured using IR sensor and Mercury Thermometer

C. Anthropometric measurements

As a part of anthropometric measurements, the proposed system uses an ultrasonic sensor to measure the height of a person to an accuracy of 0.3 cm [13]. When triggered, the sensor produce an ultrasound at 40,000 Hz propagating through the air medium. When subjected to an obstacle on its path, it rebounds back to the receiver as shown in Fig. 6. Calculating the time of travel and the speed of the sound after temperature compensation, this system computes for the height of the person [15]. The ultrasonic sensor used here is US-015. The VCC and the Ground pins of the module are connected to the analog and the Ground pins while the trig and echo pins to any Digital I/O pin on the ATMEGA328 microcontroller respectively. In order to generate the ultrasound, the Trig is set to high state for 10 µs. This sends out an 8 cycle sonic burst which travels at the speed of sound and the reflected wave is received in the Echo pin [14]. The ATMEGA328U microcontroller computes for the total time of travel of the sound wave and there after calculates the height of the person using the given formula

$$H = H_c - (t * v)/2$$

Where 'H' is the actual height of the subject, 'H_c' is the height at which the sensor is placed and is acquired during calibration of the system, 't' is the total time in microseconds computed by the microcontroller for the total time of travel of the sound wave till it is received at the receiver, 'v' is the velocity of sound in cms/µs. Since the ambient temperature factor influences the speed of sound in air, a temperature compensation with temperature reference taken from the IR temperature sensor MLX90314 is computed for during processing.

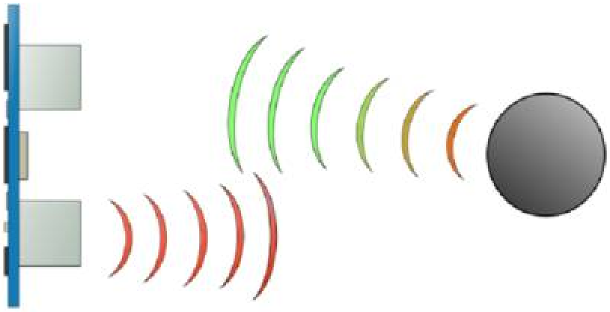


Figure 6. Functioning of an ultrasonic sensor

For the weight measurement the proposed system uses four strain gauge load cells which senses the weight of the person by means of the variation in the internal resistance of the stain gauge. This signal in terms of voltage is processed, conditioned, amplified and converted to digital output by the load cell amplifier circuit as shown in Fig. 7. The digital output from the amplifier circuit is then fed to the microcontroller for computation of the weight. This load cell amplifier circuit uses the HX711 load cell amplifier IC, that consist of a signal amplifier and a precision 24-bit ADC specifically designed for weigh scale and industrial control applications. It can directly be interfaced with any load cell. The HX711 not only provides the basic functions but also features better response, higher integration, immunity, and greater reliability as compared with other chips of the same class. The HX711 improves the performance, accuracy and lowers the cost of the circuitry.

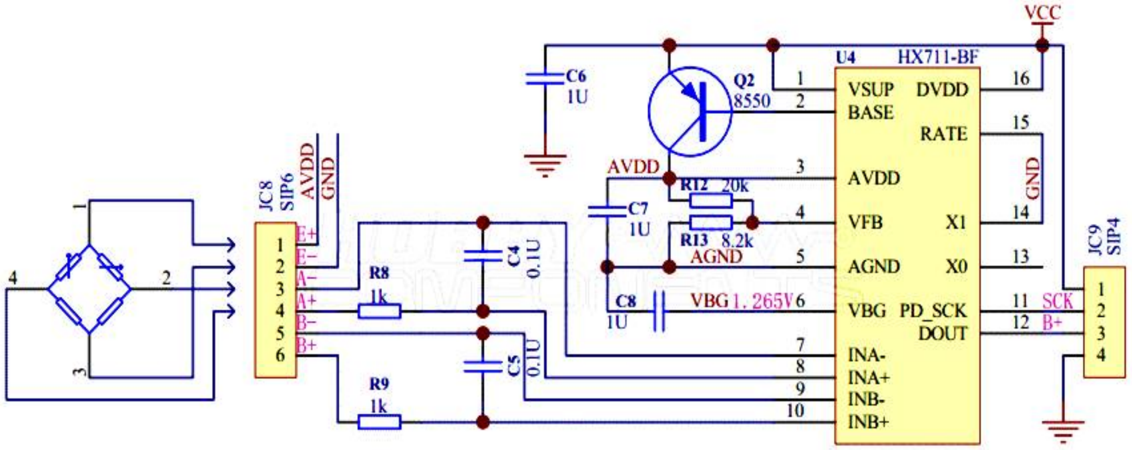
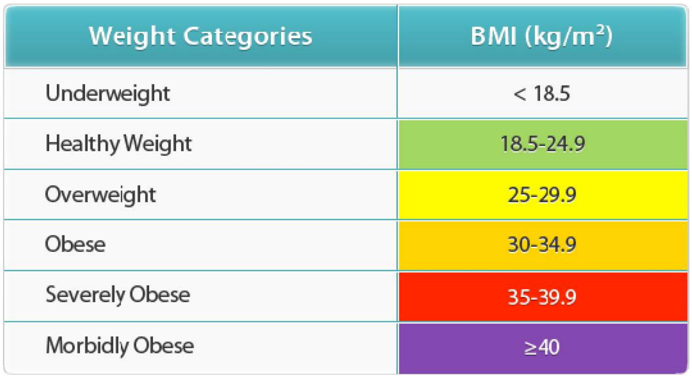


Figure 7. Circuit diagram for the load cell amplifier using HX711

Once the height and the weight is acquired by the individual sensors, on command to calculate the BMI, the microcontroller computes for the BMI using the metric formula

$$\text{BMI \%} = (\text{Weight (kg)} / \text{Height (m)}^2\ )$$

The ATMEGA328U MCU then compares with a lookup table as shown in the Fig. 8, to prompt for the status on the body fat medically termed as obesity.



Weight Categories	BMI (kg/m^2)
Underweight	< 18.5
Healthy Weight	18.5-24.9
Overweight	25-29.9
Obese	30-34.9
Severely Obese	35-39.9
Morbidly Obese	≥40

Figure 8. BMI Lookup table

IV. DEVELOPMENT, TESTING AND EVALUATION

A working laboratory prototype of the Integrated Non-Invasive Biomedical Sensor Module for Remote Health

Monitoring System as shown in Fig. 9 has been fabricated. Five different types of biomedical sensors have been integrated with the ATMEGA328U microcontroller obtain six vital human body parameters with acceptable accuracy, resolution and repeatability as per medical standards for biomedical analysis. All the signal conditioning circuit for the individual sensors were designed to operate at par with 5v supply with a max current of about 20mA on an average. A single regulated power supply module to cater for the power supply requirements of all the sensors and its corresponding SPCs has been designed and installed. A blue-tooth module HC-05 and a Wi-Fi module ESP8266 has been integrated with the main processor for data communication with external devices like Android Device/Data server/Monitoring Device. A working beta version of the android application has been developed to interface the system and the end user as shown in Fig. 10. A working lab prototype as of now has been prepared for demonstration.

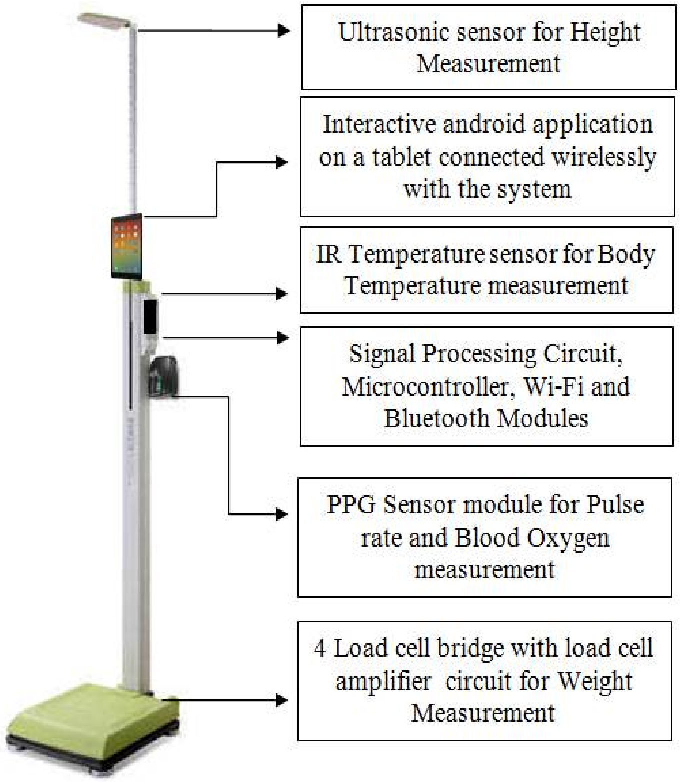
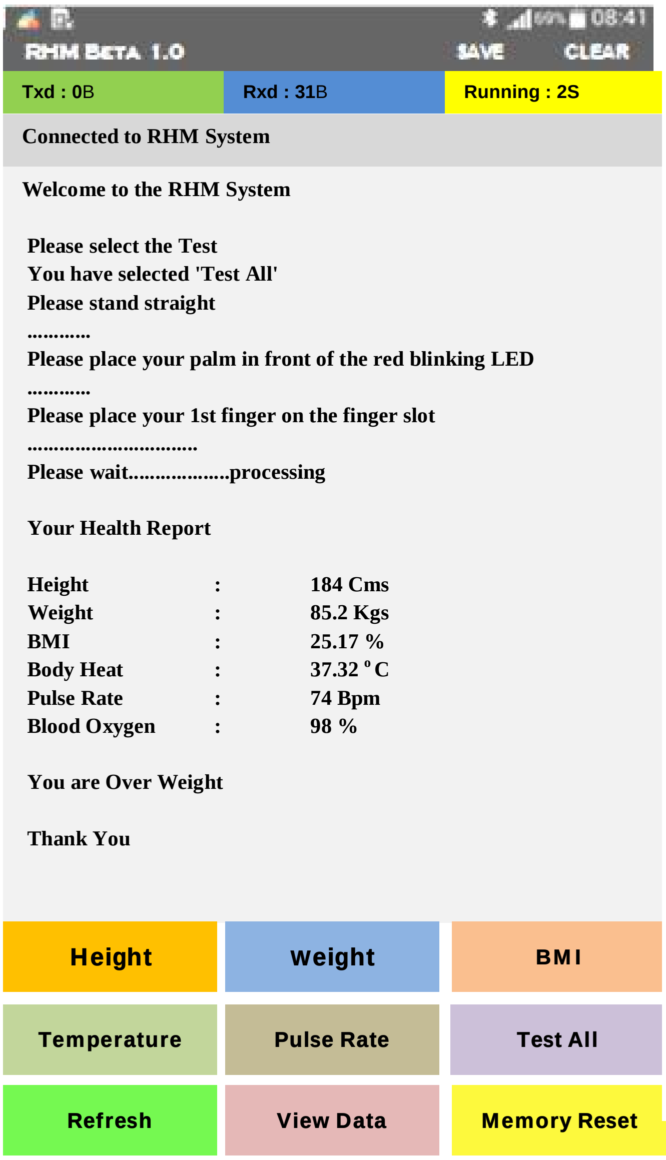


Figure 9. Laboratory prototype of the proposed RHM System

At each level of integration of the five different types of sensors used, it was tested and compared with a standard result for accuracy, repeatability and resolution. This prototype has been thoroughly tested and evaluated over 10 different subjects for its accuracy and reliability. So as to validate these results, a parallel measurement of the same parameters were acquired from that of a standard equipment generally used at clinical setups by medical professionals. A near zero error was found in case of Height and Weight measurement. Likewise an acceptable error of less than 3% was figured out in case of heart rate and blood oxygen measurement while the body temperature measurement was computed for with 0.02 °C accuracy and resolution.

V. CONCLUSION

This system makes possible for the patient to measure different physical parameters remotely, and for the physician to check the results anywhere without personally meeting. The proposed system is intended for various biomedical applications. It could be installed at any domain like Military and Police Establishments, Schools, Colleges, Physical training centers etc to monitoring the health trends of people. It could be placed in isolated villages and the health status of the local population could be analysed remotely. It can even find a place at all public places for self check by individual. It has a prime utility at all hospitals and health care centers for pre medical checks.



Connected to RHM System

Welcome to the RHM System

Please select the Test
You have selected 'Test All'
Please stand straight
....
Please place your palm in front of the red blinking LED
....
Please place your 1st finger on the finger slot
....
Please wait..................processing

Your Health Report

Height : 184 Cms
Weight : 85.2 Kgs
BMI : 25.17 %
Body Heat : 37.32 °C
Pulse Rate : 74 Bpm
Blood Oxygen : 98 %

You are Over Weight

Thank You

Figure 10. Android application showing the test results.

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