Home Healthcare Assistant (HHA)

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***Abstract* — To satiate diverse design experiences sought after by the team members, the Home Healthcare Assistant (HHA) device was developed. It serves to emulate a clinical health examination at home by obtaining responses to a health questionnaire from the patient, and by acquiring data from a collection of health-monitoring sensors. All examination data is wirelessly transmitted to a computer-accessible database that a medical professional may utilize to monitor patient health and to diagnose health issues. In our proof-of-concept device, the questionnaire presents general queries about patient health, and the sensors used measure body temperature, pulse, blood oxygen, body weight and blood pressure.**

***Index Terms* — Field Programmable Gate Arrays, Wireless Communication, Microcontroller, Embedded System, Biomedical Measurement, Internet of Things, Medical Diagnosis.**

I. INTRODUCTION

Members of Senior Design Group 8 for the Spring/Summer 2015 sequence included three Electrical Engineers and one Computer Engineer. The Home Healthcare Assistant (HHA) Senior Design Project aims to utilize members' academic strengths and to achieve unique goals in garnering specialized experience as desired by team individuals. To alleviate ever-increasing healthcare expenses, the HHA project assists patients with chronic ailments by obtaining responses to a health questionnaire and by performing a checkup of their vital signs in a sequence of events labeled as the "HHA examination." The statistical data amassed from numerous HHA examinations is compiled by date in a remotely-accessible database and offers medical professionals a record of the patient's health parameters. This information may aid with the passing of informed judgments pertaining to the diagnoses and treatment of patient ailments, with the end goal of reducing inpatient overhead costs incurred by hospitals. The device also allows for doctors to perform swifter diagnoses than a scenario where a patient suffering from a chronic illness suddenly visits the Emergency Room due to deteriorated health. Although the current implementation of the HHA exists as a proof-of-concept device that asks general questions and utilizes a diverse collection of sensors, the device is highly scalable and customizable to fit the needs of any patient with a chronic ailment. Specifically, the device may be programmed to ask focused questions based on the patient's illness, and may utilize a specialized arrangement of sensors that best monitor a particular patient's health. In addition, the HHA aims to be an intuitive-to-use low-cost alternative to existing technologies on the market. The research and development work pertaining to the completion of the HHA project is elucidated in this document.

II. SPECIFICATIONS

The HHA design specifications are listed below:

1) Case dimensions 11.5" x 11.5" x 8"
2) Monitor visibility 4 ft. with 20/20 vision
3) Monitor Resolution 640 x 480
4) Input power supply voltage 12 V
5) Maximum device weight 20 lbs
6) Body temperature sensor accuracy ±10%
7) Heart rate sensor accuracy ±10%
8) Blood oxygen level accuracy ±20%
9) Weight scale accuracy ±10%
10) Intuitive user interface with instructions

III. SYSTEM COMPONENTS AND DESIGN

A. System Hardware Overview

The HHA contains two main processing units: the Digilent BASYS 2 FPGA development board, and a PCB with the MSP430F5529 microcontroller at its core. The FPGA board presents various screens of text on a VGA monitor that include questions and sensor-use instructions to the end user. User responses are recorded via a PS/2 keyboard connected to the FPGA board, and are sent to the microcontroller via a custom communication protocol (labeled "COMM") devised specifically for the HHA. The microcontroller interfaces with all sensors, performs analog-to-digital conversion on sensor data, and wirelessly transmits HHA examination results via the CC3100 booster pack. Power requirements for all subsystems are met with a 12V input to 12V, 5V, 3.3V output switching regulator PCB. A high-level HHA hardware block diagram is presented in **Fig. 1** below.

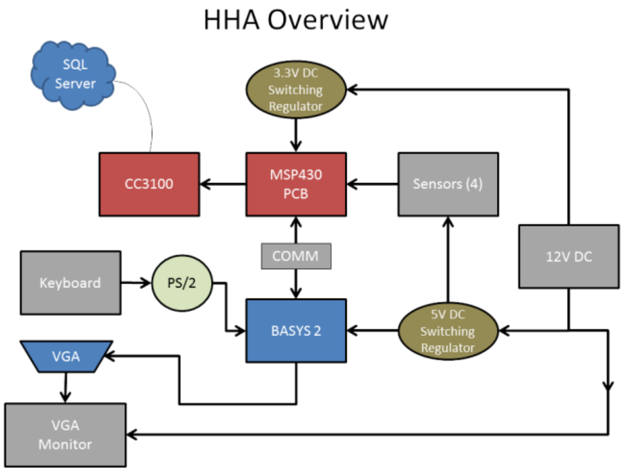
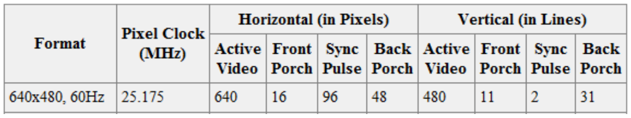


Fig. 1 – HHA Subsystems

B. FPGA-based User Interface

The Digilent BASYS 2 FPGA development board contains a Spartan 3E chip with 100k logic gates. It can function on external power at 5V DC, possesses on-board flash memory that allows the FPGA to remain programmed after a hard reset, and offers an 8-bit VGA connector as well as an IBM PS/2 port. The device was already owned by a team member who desired FPGA programming experience as part of the HHA project. To best utilize the board to its fullest capabilities, the user interface was decided to be implemented upon the BASYS 2. This task entailed displaying screens of text on a 640x480 resolution VGA monitor, fetching user input via a PS/2 keypad, and forwarding the information to our fabricated MSP430F5529 microcontroller PCB that is in charge of sensor data acquisition and wireless data transfer to database. All FPGA code was written in Verilog HDL.

The VGA protocol requires the strict timings of **Fig. 2** be met for five signals that are sent to the VGA monitor in order to display 640x480 video at 60 Hz. These signals include the Horizontal Synchronization pulse, the Vertical Synchronization pulse and the Red, Green and Blue (RGB) registers that contain individual pixel color information.



Format	Pixel Clock (MHz)	Horizontal (in Pixels)				Vertical (in Lines)			
		Active Video	Front Porch	Sync Pulse	Back Porch	Active Video	Front Porch	Sync Pulse	Back Porch
640x480, 60Hz	25.175	640	16	96	48	480	11	2	31

Fig. 2 – VGA timing information

The RGB registers fetch pixel data from a manually-written 32x32 pixel bitmap of all alphanumeric characters and some special characters stored in memory. An instance of such a bitmap for the character 'K' is shown in **Fig. 3**. Character information is fetched according to hardcoded statements in Verilog that display screens of text on the visible 640x480 pixel region of the monitor. A screen counter is incremented based on user input acquired from the PS/2 keypad, allowing for the next sequence of code to be activated in order to display the next screen of text.

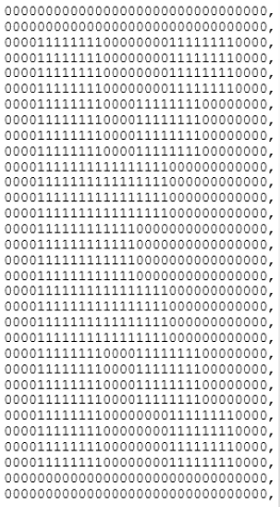


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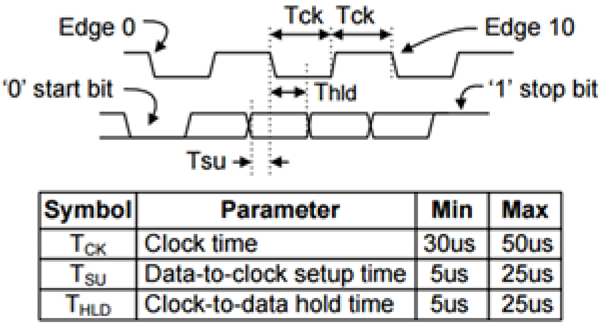
Fig. 3 – 32x32 pixel bitmap of character 'K' handwritten and stored in FPGA memory alongside all alphanumeric characters and some special characters. When fed to RGB registers, the bitmap allows for the generation of black and white text. An iterative approach initiated with 8x8 bitmaps led to the conclusion that 32x32 pixel bitmaps met the HHA screen visibility requirement for legibility at 4 ft by a person with 20/20 vision.

The PS/2 protocol for keyboard input acquisition requires the timings of **Fig. 4** be met. A keyboard clock signal starts to toggle only when a button on the keypad is pressed, alongside a data line that passes 11 bits of data: a start bit, an 8-bit scan code, a parity bit and lastly a stop bit. The scan code represents the unique key pressed on the keypad, which allows the Verilog program to decode user input. User responses to the questionnaire are then forwarded to the microcontroller according to a custom protocol called "COMM" that was written for the HHA.



Symbol	Parameter	Min	Max
T_{CK}	Clock time	30us	50us
T_{SU}	Data-to-clock setup time	5us	25us
T_{HLD}	Clock-to-data hold time	5us	25us

Fig. 4 – PS/2 signal timing diagram

The custom communication protocol that allows for communication with the microcontroller utilizes one global enable line, a (pseudo) enable line, and a data line. The data bit acquires a value of 1 or 0 depending on the user response to a Yes/No question, and for the initial response the enable line is set to 1 after data acquisition. The global enable is also set to 1 at this point to declare that communication has started. Following the initialization, the next data bit is obtained, after which the enable line toggles from 1 to 0, indicating that the next answer is ready to be read. The enable line keeps toggling as such to indicate new responses, and this method of communication works well as user data is acquired at a very slow rate (0.5 Hz or less) compared to the 16 MHz and 100 MHz clock rates of the MCU and the FPGA, respectively.

The Verilog top module represented in **Fig. 5** demonstrates the I/O signals of the FPGA program. Three sub-modules were utilized within the top module – one to drive the VGA display, one to acquire PS/2 keyboard input and to transmit user responses to the MCU, and one to store alphanumeric character pixel data in memory.

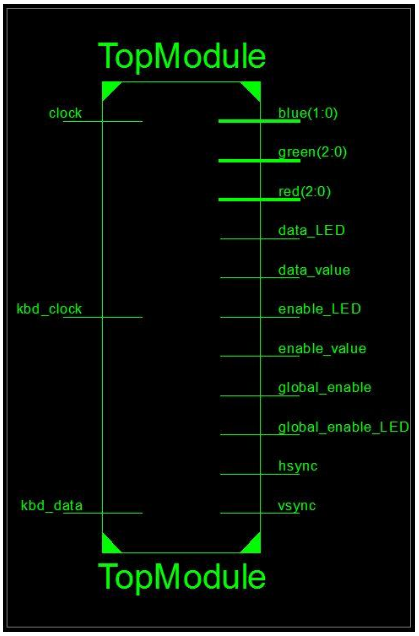


Fig. 5 – Verilog top module of FPGA program

C. MCU Main Processing PCB Unit

The MSP430F5529 processor and Launchpad were chosen due to the vast amount of documentation, knowledge bases, and example code of the Launchpad used in conjunction with the CC3100 for creating Internet of Things (IoT) projects like ours.

The MSP430F5529 processor features the following specs:

- Low Supply-Voltage Range (1.8-3.6V)
- 25MHz 16-bit RISC processor
- 128KB Flash/8kB RAM
- 4 16-bit Timers
- 2 I2C, 4 SPI, and 2 UART pins available for I/O

as well as containing a 40-pin BoosterPack connector and USB port on the Launchpad for easy flashing.

The CC3100 features the following specs:

- Wi-Fi CERTIFIED™ Chip
- IEEE 802.11 b/g/n Radio
- 256-Bit AES Encryption Engine
- WPA2 personal and enterprise support
- Dedicated ARM MCU for the Wi-Fi network processor subsystem

Since both the CC3100 and MSP430F5529 are both TI products, they naturally work in conjunction with relative ease. The booster pack easily attaches to the MSP430 Launchpad through the 40 pin header connections onboard which allows for a smoother development and debugging experience.

Programming for the two components together works within the same platform, whether C or Energia is used. As show in **Fig 6.**, the centerpiece of communication, the MSP430PCB, will receive multiple inputs from a variable number of sensors (which we have prepared as a theoretical four-sensor device) as well as the FPGA which handles the UI and user input. The aforementioned COMM protocol will be used solely for communication between the FPGA and PCB, while the sensors will utilize the MCU’s on-board ADC pins to transmit analog data which the MCU will submit to Pubnub’s datastream database through Wi-Fi.

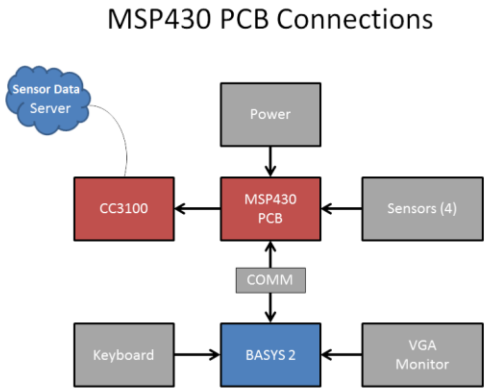


Fig. 6 Main PCB connections

D. Web Server

For the web server, we had a choice of a local-webserver or a cloud-based solution such as Microsoft Azure’s cloud computing service, or Pubnub’s datastream service. This data integrates with another cloud service, Freeboard.io, which can visualize data in graphs. A sample of what this data would look like graphed can be seen in **Fig. 7**, where temperature and oxygenation (measured with light passing through a finger) can be graphed in realtime as the server receives the data.

Fig. 7 PubNub live data graphing

Cloud-based solutions allow for minimal setup of hardware and software such that once the setup is completed, uniform key, certificate, or other method of authentication is provided along with an API to facilitate integrating different devices to a service. After careful consideration, the team decided to go with Pubnub’s service since it provided the simplest form of integration with the MSP430 that would allow us to have a free and easy to use service for our proof of concept display. **Fig. 8** shows the class diagram for the full database that patients and healthcare workers would be able to fill in and access, respectively. For the sake of this project, our proof of concept database contains multiple data values for a single user.

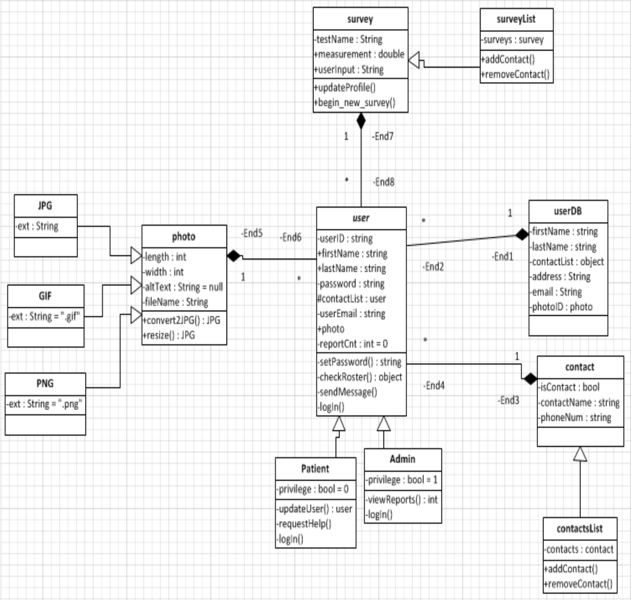


Fig. 8 Class diagram for database.

IV. VITALS

The current health status of a patient is obtained through data acquired from readings of their vitals. The HHA provides several sensors that measure vitals such as body temperature, heart rate, blood oxygen levels (SpO_2), weight, and blood pressure. Since the HHA is a proof-of-concept device, it has the potential to be upgraded to also include measurements of other important vitals such as a glucose levels and electrocardiogram (ECG) readings.

A. Body Temperature

The most common way of measuring body temperature is orally which is also the way the HHA will be measuring the patient's body temperature. Each medical institution has their own parameters to what they consider to be a healthy, high, and low core body temperature. The HHA will be utilizing the mildest case of a fever (100.4° F) and the beginning onset of hypothermia (95° F) from a list of said institutions.

Using the LMT87LP temperature sensor with a disposable digital oral thermometer sheath, body temperature measurements can be taken. Values received from the LMT87LP go to both the MSP430F5529's 12-bit analog-to-digital converter (ADC) and through sets of comparators which enable status LEDs for the patient to see whether they have a fever or hypothermia. The advantage of this method is that the medical professional will be receiving the exact temperature value while the patient can always check their body temperature without needing the device to be programmed or sending values via Wi-Fi. The circuit also contains potentiometers that allows the fever and hypothermia parameters to be modified. **Fig. 9** shows the stand-alone analog circuit that gives the patient feedback through LEDs.

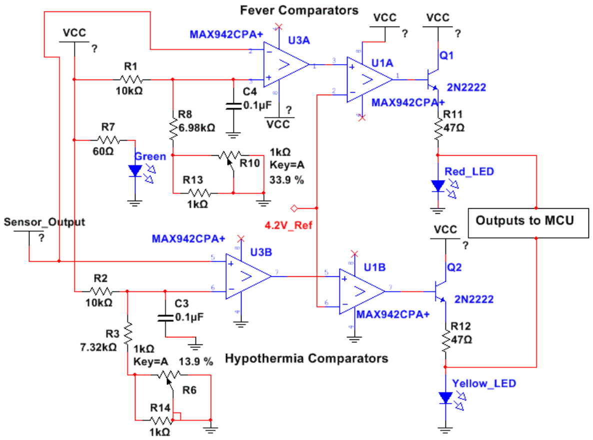


Fig 9. Stand-alone body temperature schematic with status LEDs for feedback from the sensor to the patient.

B. Pulse Oximeter

To measure both heart rate and blood oxygen levels, the HHA will be using a Nellcor DS-100A Adult Finger Clip as the housing of the pulse oximeter. By removing the photodiode inside and using a TSL14S chip as a replacement, it can be proven that a pulse oximeter can be designed with relatively little external circuitry meaning it is a cost-effective method. To access the LEDs already installed inside the case, pin 2 and pin 3 needs to be accessed through the cable as shown in **Fig. 10**.

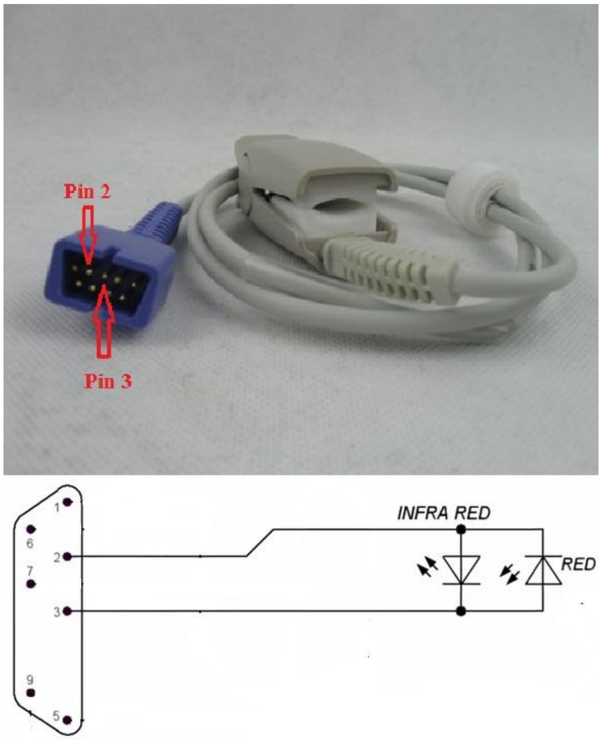


Fig. 10 Nellcor DS-100A Adult Finger Clip with Pins 2 and 3 marked. Pins 2 and 3 are used to drive the alternating LEDs.

Due to the LEDs utilizing the same 2 pins, an H-bridge circuit is needed to alternate between LEDs. The H-bridge also provides the ability to have different currents flowing through each LED which will be needed due to the fact that the red LED draws 20mA and the infrared LED draws 50mA. **Fig. 11** shows the H-bridge circuit designed to drive the HHA pulse oximeter LEDs. Unfortunately, due to time and design constraints, the red LED is using a 20mA driver (CL520N3-G-ND) but the infrared LED is utilizing only a resistor to control the current flowing through the LED. The MSP430 pins assigned to this circuit will be controlling when the LEDs are turned on.

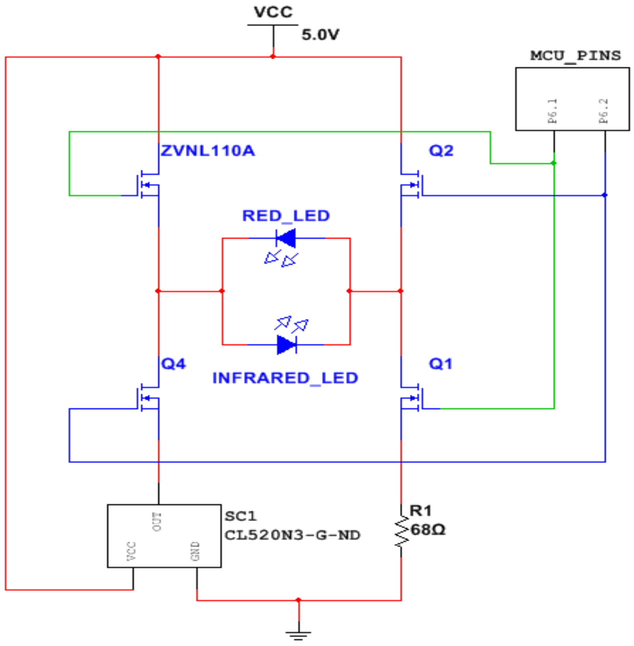


Fig. 11 H-Bridge circuit to drive the LEDs.

The TSL14S sensor will detect the amount of light absorbed by the patient's finger for each LED. The amount of red light absorbed will measure how much deoxygenated hemoglobin is absorbed through the finger while the infrared light absorbed measures how much oxygenated hemoglobin is in the blood. As the artery expands due to heartbeats, the amount of hemoglobin flowing through will increase which helps differentiate what is blood and hemoglobin from the other non-pulsing components that make-up the patient's finger.

The HHA's pulse oximeter light sensor goes through a 5-Hz low-pass filter to filter out any unwanted noise caused by ambient light and movement. The output of the filter is then sent to the MCU's ADC which then allows the MCU to store and analyze the data to determine the patient's heart rate and blood oxygen levels with the help of Beer-Lambert's law. **Fig. 12** shows a graph for both the red and infrared light absorbed on a patient.

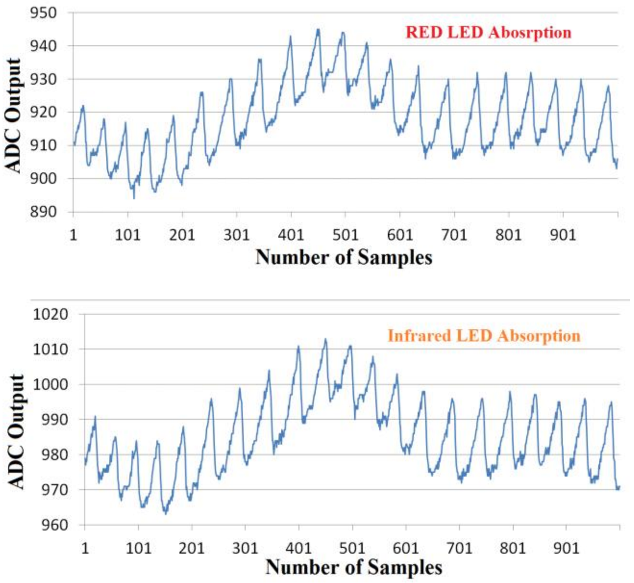


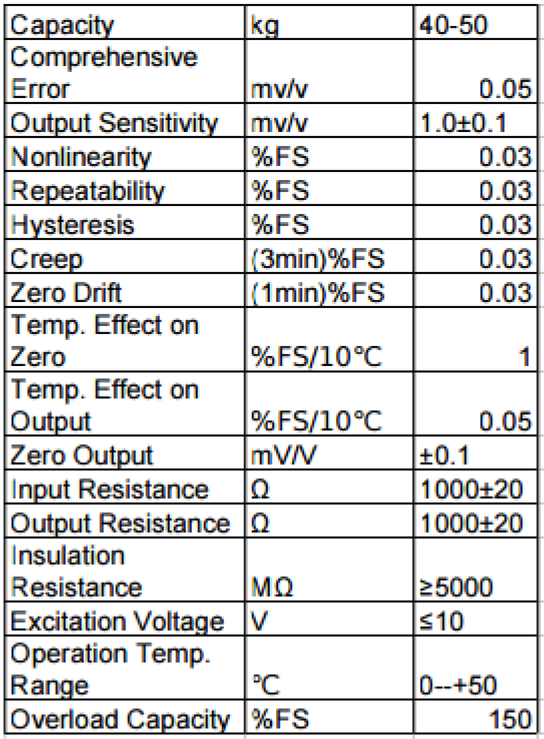
Fig. 12 Red and Infrared LED absorption graph during patient testing.

The peaks in the waveform are equivalent to a heartbeat and the test runs for approximately 20 seconds. This means that a single LED is pulsing at approximately 50Hz which is enough to obtain decent data without overflowing the MSP430's memory when storing the values. Also, the max cardiac frequency in a person is 5Hz (usually 1-2 Hz) making 50Hz sampling a good enough resolution. The change in amplitude between peaks signified that the patient has shifted his position and is applying less/more pressure inside the fingertip clip as opposed as to when the test first started.

The calculations of the SpO_2 are based on a 98% blood oxygen level reference using a commercial pulse oximeter due to the nature of the HHA being noninvasive. This means that our data tries to emulate an already built and tested pulse oximeter device which has an integrated look-up table of invasive measurements to accurately measure blood oxygen levels. Due to time constraints, a "best-fit" curve could not be designed to create a look-up table.

C. Weight Scale

The SEN – 10245 load sensor was chosen because it met all the reguirements for the project. **Fig. 13** shows the datasheet for this sensor.



Capacity	kg	40-50
Comprehensive Error	mv/v	0.05
Output Sensitivity	mv/v	1.0±0.1
Nonlinearity	%FS	0.03
Repeatability	%FS	0.03
Hysteresis	%FS	0.03
Creep	(3min)%FS	0.03
Zero Drift	(1min)%FS	0.03
Temp. Effect on Zero	%FS/10°C	1
Temp. Effect on Output	%FS/10°C	0.05
Zero Output	mV/V	±0.1
Input Resistance	Ω	1000±20
Output Resistance	Ω	1000±20
Insulation Resistance	MΩ	≥5000
Excitation Voltage	V	≤10
Operation Temp. Range	°C	0--+50
Overload Capacity	%FS	150

Fig. 13

The way this strain gauge works is by acting like a resistor. The circuit consists of a Wheatstone bridge configuration as shown in **Fig. 14**. Usually a voltage of 5V-10V is applied to one set of corners and then the voltage difference is measured on the other set of corners.

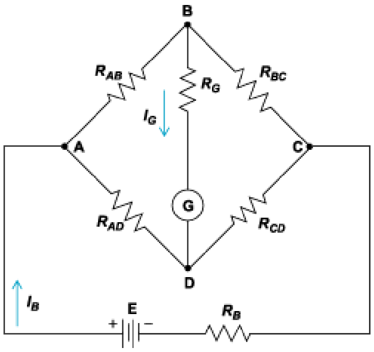
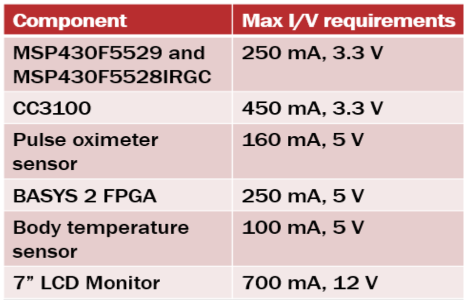


Fig. 14

V. POWER REGULATION PCB

The I/V requirements of HHA components are listed in **Table 1**. These requirements were used in the design of a power regulation PCB fed by a 12V 80W wall adapter connected to 120V AC mains. The PCB regulated the 12V DC input to 3.3V and 5V for the respective components as required, in addition to supplying a direct out of 12V.



Component	Max I/V requirements
MSP430F5529 and MSP430F5528IRGC	250 mA, 3.3 V
CC3100	450 mA, 3.3 V
Pulse oximeter sensor	160 mA, 5 V
BASYS 2 FPGA	250 mA, 5 V
Body temperature sensor	100 mA, 5 V
7" LCD Monitor	700 mA, 12 V

Table 1: I/V requirements of HHA components

The power supply connections from the power regulation PCB are indicated in **Fig. 15**. 12V DC are fed direct to the VGA monitor, and it is also used to supply 5V and 3.3V buck switching regulators to power all other HHA components.

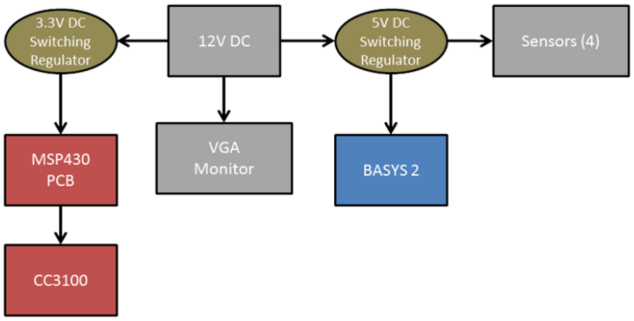
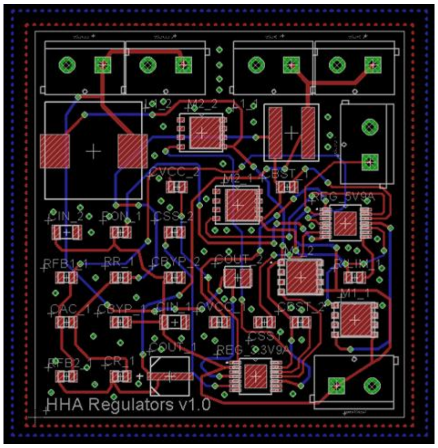


Fig. 15 – HHA power regulation system

Schematics for the 3.3V and 5V switching regulators were generated using the Texas Instruments Webench tool.



Eagle CAD was then used to generate the board layout from these schematics, as shown in **Fig. 16**. Osh PARK fabrication house was used to manufacture the power PCB, and PCB parts were obtained from DigiKey. Two copies of the board were soldered using hot air, one primary and one for backup in case of failure.

Fig. 16 – Power regulation PCB board layout

VI. CONCLUSION

The ultimate goal of Home Healthcare Assistant is to create a low cost, compact, easy to use, energy and time efficient automation system for healthcare workers. This project allows the everyday homeowner to provide a healthcare worker with the necessary vitals needed for evaluation of a patient before that patient sets foot into a medical office. The ability to provide these vitals ahead of time can improve future wait times of doctors' offices and provide an easy to access and interpretable medical history. These functions can greatly help to monitor the medical activity of a patient from a nearby or remote location with an easy access website. This project aims to achieve expandability and optimization, and already there is a solid foundation provided for expansion.

VII. ACKNOWLEDGEMENT

Group 8 of the Spring 2015 – Summer 2015 Senior Design class would like to acknowledge and thank the Department of Electrical Engineering and Computer Science at the University of Central Florida, The TI Innovation Lab, and Dr. Richie for the help and advice we received.

VIII. REFERENCES

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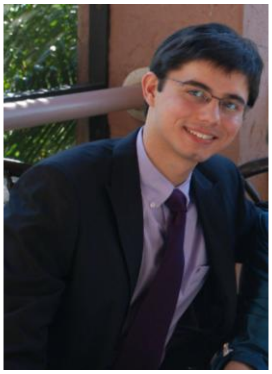
[3] "Stream Sensor Readings Data with TI LaunchPad". Web. 17 Jul. 2015. <http://www.pubnub.com/blog/pubnub-streaming-texas-instruments-iot/>.

IX. THE TEAM

Nicholas Cinti is an Electrical Engineering student attending UCF and graduating in August 2015. He has an interest in systems engineering, where he was working as a CWEP participant as Lockheed Martin. After graduation he plans on finding a job then attending graduate school.



Alexander Diaz-Rivera is a graduating computer engineer from the University of Central Florida. He hopes to continue his education with a focus on computer networks and security. His interests include computer networks and digital media.

Jonathan Stagnaro is a graduating Electrical Engineer from the University of Central Florida. He plans to attend an internship and continuing to search for his Master's degree in the Spring of 2016. He has an interest in power, analog, and filter designs.

Zishan Zaidi is pursuing accelerated BS-MSEE degrees at UCF and holds an internship at ACD Telecom, focusing on bringing a prototype drone to market. His technical interests include control systems and FPGA design.