Knight Nite

Mark Hughes Atkins (EE), Marcus Hobbs (CpE), Ahkeim Pierre (EE), Hieu Pham (EE)

DEPT. OF ELECTRICAL ENGINEERING AND COMPUTER SCIENCE, UNIVERSITY OF CENTRAL FLORIDA, ORLANDO, FLORIDA, 32816-2450

ABSTRACT — The objective of this project is to build a reliable sleep monitor system that can be used to help treat users with sleep disorders. Our goal is that the system will monitor and apply basic applications to help the user sleep. The system will monitor respiration and body heat and compare the outputs against thresholds. If the thresholds are exceeded a treatment protocol will be enabled. The monitoring system will be placed on the user's head, with shades covering their eyes. There will be a vital sensor to measure user's temperature and pulse, an audio sensor monitoring the user's respiration comparing the outputs against known parameters. The unit will be ready to implement a treatment protocol upon any abnormality. Furthermore, the objective build a reliable sleep monitor system that can be used to help treat users with sleep disorders

INDEX TERMS — OPERATIONAL AMPLIFIERS, LOW-PASS FILTERS, DIODES, ANALOG-DIGITAL CONVERSION, DATA ANALYSIS, DATA TRANSFER, MICROPHONES

I. INTRODUCTION

Sleep deprivation and sleep disorders severely impact a person's physical and mental abilities, overall health, and quality of life. Furthermore, sleep loss can be shown to directly and significantly affect the national economy. Sleep deprived employees are not as efficient and can pose a safety risk in jobs requiring operation of heavy machinery for example. Reports from European national driving authorities indicate drowsy and fatigued driving represents 10 to 30 percent of all automobile crashes. The National Highway Traffic Safety Administration estimates 100,000 crashes are the direct result of fatigue every year [16]. Public health authorities estimate many billions of dollars are spent on doctor visits, hospitalization, and medicine. The general conclusion of many medical professionals and economy analysts is sleep deprivation and sleep disorders have high economic costs and severely affect the quality of health of individuals.

The medical community frequently prescribes powerful medications to combat insomnia and sleep disorders. A Center for Disease Control report on sleep aid use among adults indicates that approximately nine million Americans take prescription pills for sleep [1]. The most affected group is the elderly with an estimated seven percent of all adults aged 80 and older depending on prescription medication for sleep. The use of prescription medication for sleep, frequently have severe side effects, including physical dependency and cognitive impairment, affecting the mental and physical quality of life of users. However, the medical community and sleep deprived population pursue any means including dependency on drugs to get a good night's sleep.

There are many sleep diagnostic and sleep aid devices on the consumer market. For example, there are medical grade diagnostic systems intended to detect sleep disorders such as sleep apnea and restless leg syndrome. Additionally, there is the Continuous Positive Airway Pressure (CPAP) intended to treat sleep apnea. In general, medical grade devices are expensive and only available by prescription from a medical professional. Cheaper alternatives exist in the form of smart phone applications and inexpensive devices. The simplest devices aim to provide the user a record of sleep activity and wake her in the lightest stage of sleep. However, there are no devices on the market that can claim to provide an active solution to the most common sleep disorder insomnia.

The Knight Nite system intends to provide sleep diagnostics and an active sleep aid. The active component of the system will aid the average person with insomnia and other sleep disorders get to sleep in a shorter time and stay asleep for longer. Furthermore, the system will record the user's sleep activity with the aim of providing an indicator of common sleep disorders like sleep apnea. The user will be equipped with sensors packages in a small form factor. A record of sleep activity and control of the system will be provided in an easy to use smart phone application. The motivation behind this project came from the lack of products on the market that actually aids someone with a sleep disorder. There is a myriad of sleep products that monitor and display the behavior of the user's sleep patterns. However, they only do just that, monitor and display. Therefore, Knight Nite will implement sleep monitoring and use data from monitoring sleep patterns to aid the user.

II. SYSTEM CONCEPTS

After researching many other similar existing projects and ideas, a modular approach was viewed as a more favorable design approach for Knight Nite. By having all of the sensors and subsystems have their own microcontroller and printed circuit board design, the system was much simpler. The red sections are assigned to Hieu Pham. The green sections are assigned to Mark Atkins. The yellow sections are assigned to Ahkeim Pierre. The rest of the purple traces and data processor are assigned to Marcus Hobbs. Each microcontroller for each subsystem will relay information pertaining to their subsystem to a centralized data processor. This data processor will be controlled by the user and will have the ability to relay back control information to the individual microcontrollers with the exception of the vital system's microcontroller. Because the vital systems microcontroller is strictly a data information collector, there will be no data in control from the data processor to the vitals microcontroller.

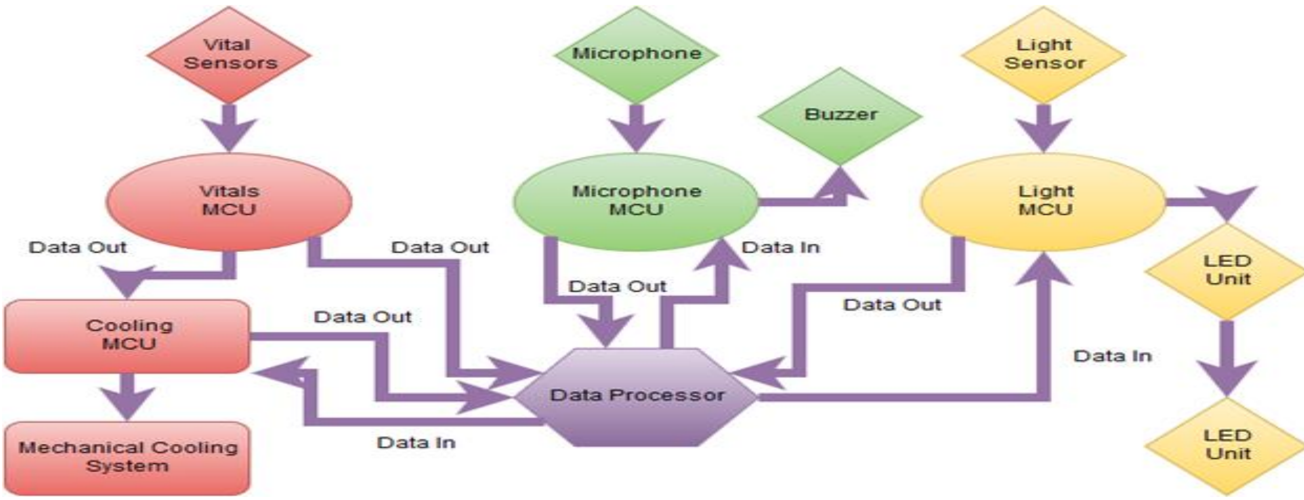

Fig. 1 illustrates the modular design of Knight Nite and the group's work distribution for this project.

III. HARDWARE

The vitals subsystem has many hardware components that work with along with other systems via a control algorithm. There are temperature, motion, and heart rate sensors that monitor the user during sleep in order to collect data for the user to interpret what affects their sleep at night. Furthermore, the cooling system features a liquid pump that runs water to the user's forehead via small vinyl tubing. This system is controlled by its own control system based on the temperature of the user's forehead. The lighting system features multiple LED lights built on a custom PCB that wakes up the user based on upon the time the user desires. Furthermore, the lighting system has a photodetector that records data based on the amount of ambient light that is present throughout the night. The audio system features a microphone on its own breakout board, with a siren to act as an alarm. The audio breakout board will allow the analog signal being monitored to be converted into a digital signal for data processing.

A. Lighting

The lighting system has two main functions in this project. The first function of the lighting system is to measure ambient light. A digital light sensor will be used to measure the ambient light in the environment while the user is sleeping. We want to use the light data to determine the impact that the ambient light has on the user's sleep pattern during the night. The different light intensities sensed will be compared to the vitals in order to find the correlation. In addition, the lighting system will provide light to help the user wake up in the morning. Low-power blue LEDs will be used to generate the light necessary to begin the wake-up process. Blue LEDs, specifically, are a good choice for our lighting requirements because blue lights are known to increase levels of Cortisol, a hormone that helps the human body wake up [1]. The LEDs will be incorporated into a sleep mask so that ambient light will be blocked out while, at the same time, being able to shine light directly on the user's eyes. A microcontroller will send a control signal to a solid state relay to switch power to the LEDs at the time specified by the user. We decided to go with a solid state relay because it provides electrical isolation, quick switching time, and low power consumption.

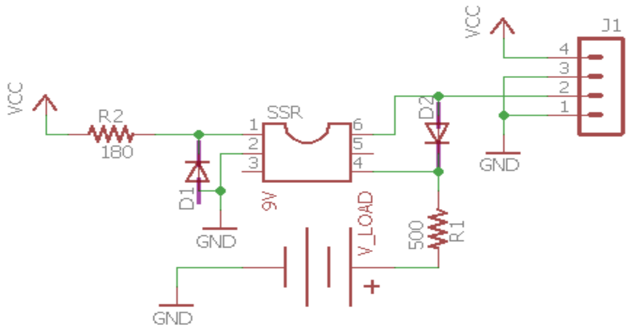

Fig. 2 illustrates lighting system schematic design for Knight Nite

B. Audio

The audio system unit is an independent implemented subsystem of Knight Nite. It will convert the analog signals to digital using the analog to digital converter (ADC) component of the local MCU before sending the data to the Knight Nite's main MCU for data processing. Using the ADC component of the MCU is an electronic device that converts a continuous physical electrical quantity to a digital value. The physical quantity is generally voltage however it can also be current. An analog signal is sampled at a specified "sampling rate" to get the digital value of the amplitude of the signal. The higher the sampling rate is, the more data points we have per second and thus the more accurate representation we have of the analog signal. However there is one issue we could run into and is that the higher the sampling rate, the more space it takes to store the data.

One way to get a good balance between storage and quality is the Nyquist Theorem. The Nyquist theorem states the sampling rate on an ADC must be at least two times the highest frequency you want to capture. For example, if we were recording music, the highest frequency humans can hear is 20 kHz so if we wanted to record music with good storage to quality balance we would need at least at least 40 kHz sampling rate.

C. Vitals

The hardware for the vital unit consists of multiple sensors to monitor the behavior of the user during sleep. The requirements for the hardware are important in order to obtain accurate measurements and readings as well as the sensors being easy to work with. For this project, skin temperature, heart rate, and movement will be measured. There are an abundant amount of sensors and ways to measure these parameters therefore the sensors that are chosen will have to be narrowed down to which are the most cost efficient, accurate, and reliable to engineer into an entire project.

D. Emergency Wake Up

In the event of an emergency where the use needs to wake up, a control algorithm based on the block diagram below will be implemented. If the heart rate sensor shows zero readings, the vital systems microcontroller will immediately send signals to the data processor in order to notify all of the other subsystems to wake up the user as soon as possible. The low level block diagram is shown in Figure 3.

Based on the Figure 3, the cooling system will immediately take action by trying to lower the forehead temperature significantly. Based on studies by the Vanderbilt Heart And Vascular Institute, lowering the body temperature to 86 degrees can significantly decrease the risk of brain damage for a patient in the event of a heart attack. Therefore, Knight Nite will be able to at least lower the forehead portion of the user if the user were to have a heart attack.

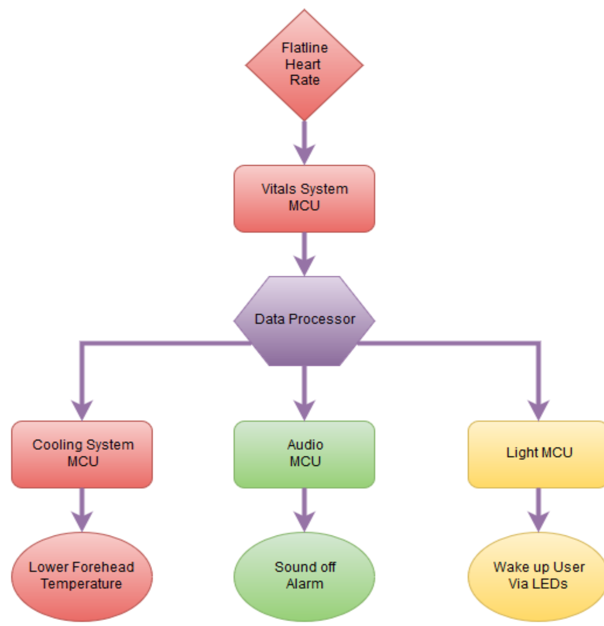

Fig. 3 illustrates the block diagram of the emergency wake up diagram

Meanwhile, the audio microcontroller will enable a siren in order to alert someone in the near area that the user is in trouble and needs medical attention immediately. Although the user will not ever want or plan to have a heart attack, Knight Nite provides them a peace of mind while sleeping to ensure that they will receive help if needed.

The light system microcontroller will be sending signals to all LEDs to turn on at maximum intensity to help wake up the user. This process can be programmed in multiple ways depending on further testing. For example, the LEDs can be turned on at maximum intensity and stay on for a long period of time. However, they can also be programmed to flash intermittently to try to get the user's attention more effectively.

IV. SOFTWARE

The Knight Nite software design is logically partitioned based on the separate responsibilities of the visualization and control unit (VCU) and distinct subsystems. The responsibilities of the VCU are primarily data processing, supervisory control, and graphical user interface presentation. The responsibilities of each subsystem in general are sensor data acquisition and automatic process control. Each subsystem communicates bidirectional with the VCU over a Universal Serial Bus. The subsystems communicate normalized sensor data, receive commands, and send device status to the VCU. Figure 4 is a block diagram describing the logical organization or architecture of the software. The approach taken in the Knight Nite software is a layered architecture for simplicity. The analysis and design of the software is done using an object oriented approach. However, the implementation of the VCU application and subsystem programs will take a structured programming approach.

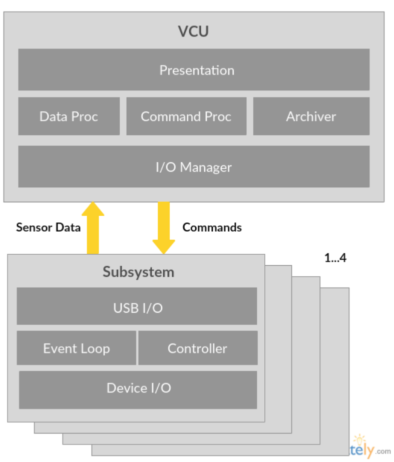

Fig 4 illustrates the software design block diagram.

The VCU application processes sensor data, archives data, provides supervisory control of subsystems, and presents a graphical user interface. The application software is separated logically by concerns. The data processing class is responsible for transforming sensor data to engineering units and distributing data to the user interface and data archiver. The data archiver is responsible for formatting and writing data to long term storage. The command processor maintains the commanded state of each subsystem as well as formatting commands transmitted to subsystems. The input/output manager transforms packets to application data and transmits commands to the subsystems. The GUI manager is responsible for maintaining user interface state and partitioning user interface concerns from data processing.

Figure 5 illustrates a snapshot of dynamic activity of the VCU application using UML sequence diagram notation. In particular, the following sequence diagram describes the sequences of actions taken to process sensor data in the VCU.

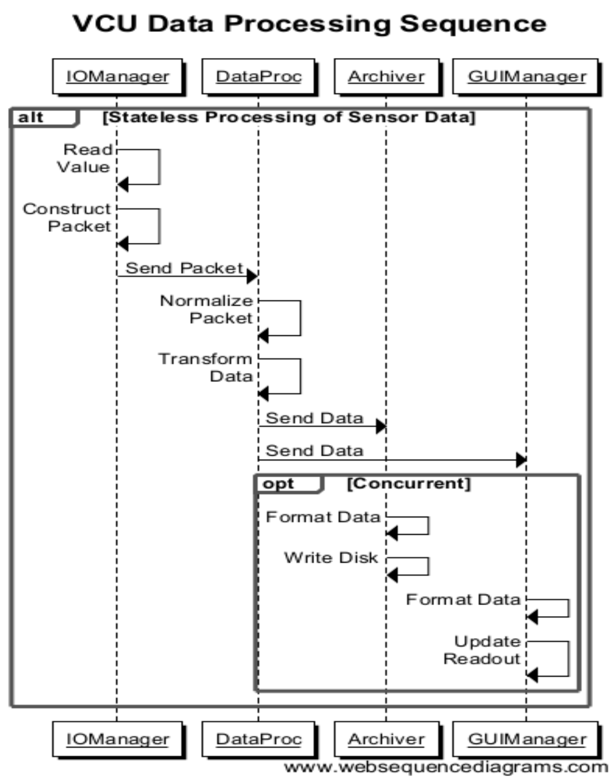

Fig 5 VCU Data Processing Sequence diagram

The VCU graphical user interface presents sensor data in engineering units as readouts and dynamic graphs. Additionally, the GUI presents device status and supervisory control of each subsystem. The GUI is state full and managed by a persistent GUI manager object in the VCU application. The interface elements are built using the Android standard interface components and the GraphView dynamic graphing library. The Eclipse integrated development environment provides a solution to place interface components in a simplistic design tool. Other interface concerns are addressed programmatically for example updating graphs with sensor data values at 10 Hertz. Unless otherwise noted, all user interface code is written in the Java programming language and is not intended to be portable. The state of supervisory commands is maintained in the VCU application by a persistent command processing object. For example, the set point of the cooling system is monitored and adjusted by actions taken by the command processing object. User interface objects only maintain the state of user interface components not the backend processing of data and device state. Unless otherwise stated, all user interaction with the VCU application is by a touch enabled Android smart phone.

The graphical user interface is logically partitioned into three general functions. The main display presents the user with three functions activity, status, and alarms. The user chooses a function and is presented with a display specific to that function. The activity display provides the user with dynamic graphs of subsystem sensor data and a graph of the user's sleep activity over time. Items on the graph can be shown and hidden by push buttons on a menu bar at the top of the display.

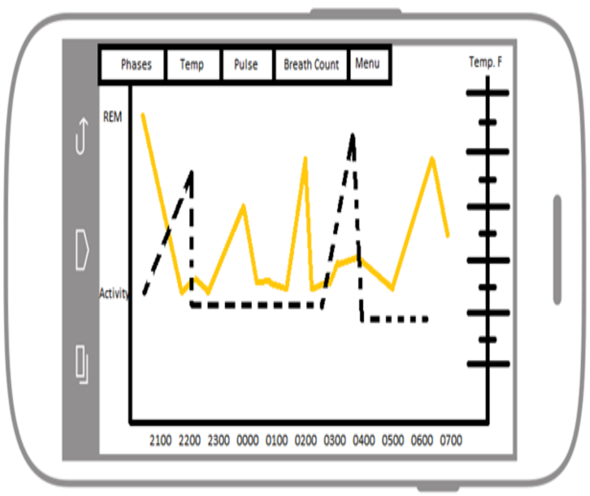

Fig 6 illustrates a storyboard of the activity display.

The status display presents the user a set of readouts for each subsystem and all supervisory controls. The status display is tabular enabling the user to select the subsystem of interest. The cooling tab of the status display allows the user to set the temperature of the cooling system. The cooling system can be turned on and off but defaults to on. Figure 7 presents a storyboard of both the main and status display.

Fig 7 illustrates main and status displays on the android application

The alarms display presents the user a set of controls for setting alarms. The system will generate an audio based alarm to wake the user when particular average threshold value are met. For example, if the user's respiratory rate falls below the average acceptable amount for a grown adult, the system generates an audio alarm. The alarms display presents the user controls to configure alarm thresholds and choose the audio alarm.

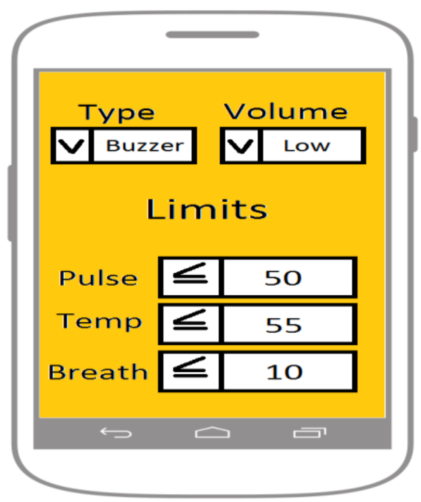

Fig 8 illustrates the alarm display

Each subsystem program shares similar concerns. The subsystem program must read sensor data from a peripheral device or analog-to-digital interface and convert the data into a shared structured data type. The sensor data is encapsulated and transmitted over USB to the VCU. Additionally, the subsystem program may do automatic process control. The process control algorithm takes parameters and can be reset and suspended. Every periodic update of the control algorithm produces a control signal transmitted to a device. The control software sends a control signal to a device input/output software component that formats the signal and handles communication with the device. Each subsystem depends on the VCU to do data archival. Unless otherwise stated, each subsystem program shares a common codebase in the C programming language. The microcontroller manufacturer STMicroelectronics provides specialized software development tools such as compilers, assemblers, and debuggers to enable programming of the MCUs. The Knight Nite software requirements assume the program as designed will be appropriately sized for both static and dynamic MCU memory. Figure 9 describes a snapshot of dynamic activity of a subsystem program using UML sequence diagram notation. The following sequence diagram shows the sequence of actions taken to do automatic control.

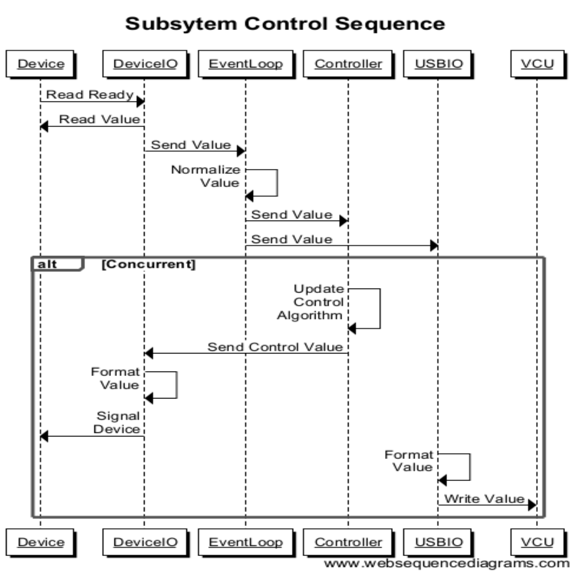

Fig 9 illustrates subsystem program using UML sequence diagram notation

V. Power

The design process for the power systems in Knight Nite needs several considerations before being implemented. While the system needs to be efficient and cost effective, there are several ABET standards and constraints when it comes to the safety of the design. Because most of the power supplies on the market already meet the safety requirements, this was taken highly into consideration for the final build of materials for the power system. Some of the subsystems such as the cooling subsystem and its mechanical water pump feature takes in only DC power. These systems can be powered by a simple battery or utilize and simple wall outlet power supply with an AC to DC converter.

In order to control the power systems using the STM32 microprocessor for the cooling system and alarm, a simple switching circuit was built on a custom printed circuit board as shown in figure 10. This circuit was designed using a NPN transistor which allowed us to short the circuit between the subsystems power supply and the load. Since the microcontrollers are powered via USB through a central HUB, this eliminated many power concerns for the microcontrollers while only focusing on the necessary power requirements for the major subsystems.

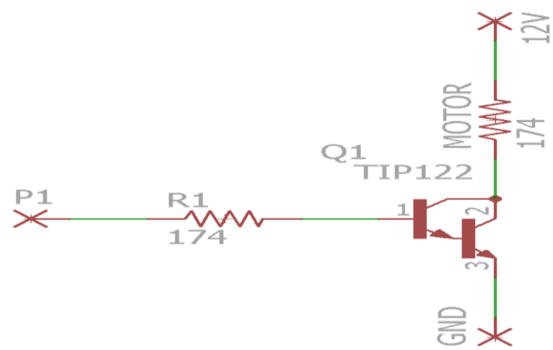

Fig 10 illustrates transistor power switch schematic design

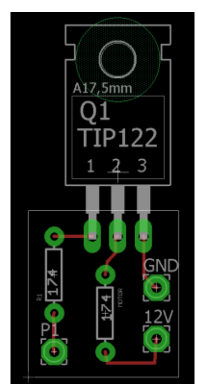

Fig 11 illustrates printed circuit board of the transistor design

VI. System Implementation

The bulk of Knight Nite's functionality is based on software. Software development will be accomplished using the STM32F401 development board, which has both programming and debugging tools built into the board.

Power, programming, and debugging for the STM32F401 will be achieved over USB. We will be using an Eclipse based Integrated Development Environment (IDE) and the C/C++ programming language to program the development board. Information from our three sensors will be sent to an Android mobile device via USB. Mobile device programming will be done in Android Studio using Java programming language. An accelerometer was chosen to monitor the movement of the user during sleep. Although an accelerometer only measures acceleration, movement of the user will constantly be tracked due to the gravitational forces of the earth. The MPU6050 will be implemented in the design. There are accelerometers on the market that monitor movement in x, xy, or xyz directions. The MPU6050 measures in all 3 directions which can be compared to accelerometers in most of today's smart phones such as the iPhone. The STM32F40X microcontroller is used with the temperature sensor in order to monitor the forehead temperature of the user. The sensor itself is simple in design and only features 2 signal pins and a pin for both ground and power. The heart rate pulse sensor heart rate monitor will be implemented on a PCB and which contains a simple MCP6001 operational amplifier and several passive devices. The design will feature an APDS 9008 photo sensor that will run in conjunction with operational amplifier. This sensor will have the ability to output a digital signal to the project made printed circuit board which contains an STM32F4 cortex microcontroller. From this system, the microcontroller will be able to send the heart rate data to all other subsystems that may need to utilize the information. Since the microphone is monitoring the user's breathing intervals, the audio system will convert the analog signal produced into a digital signal using the local analog to digital converter (ADC) channel of the MCU located within the audio subsystem. Instead of constantly using the ADC over a certain interval of time, some resources might be saved using the peak detector circuit. The idea is that the microcontroller reads from the peak detector output only once in the equivalent time interval instead of continuously reading. The peak level read will be a representation of the highest level of snoring during that time interval. The lighting system will implement two distinct functions. One of the functions will be to collect light from the environment and convert that into data that a microcontroller can interpret using the light detection system. The second function is to provide lighting for the user to wake up. The microcontroller will send a control signal to a relay that will switch power to LEDs to wake the user up.

VII. Conclusion

The objective of this project is to build a reliable sleep monitor system that can be used to help treat users with sleep disorders. Our goal is that the system will monitor and apply basic applications to help the user sleep. The system will monitor respiration, and body heat and compare the outputs against thresholds. If the thresholds are exceeded a treatment protocol will be enabled.

The monitoring system will be placed on the user's head, with shades covering their eyes. There will be a vital sensor to measure user's temperature and pulse, an audio sensor monitoring the user's respiration comparing the outputs against known parameters. The unit will be ready to implement a treatment protocol upon any abnormality. Furthermore, the objective build a reliable sleep monitor system that can be used to help treat users with sleep disorders.

Considering the user, the device will be simple enough to the extent where the user will be able to use all of the functions and interpret the data through the user interface without being confused. Although there will be many complex components within Knight Nite, the end goal is to produce an effective and simple product that can aid users with sleep disorders to fall asleep faster and stay asleep longer.

ACKNOWLEDGEMENT

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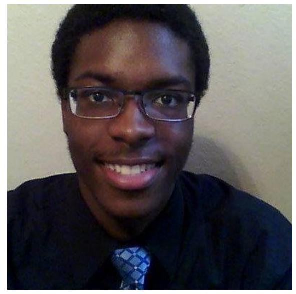
The Engineers

Hieu Pham is currently a graduating senior at the University of Central Florida and will receive his Bachelors of Science in Electrical Engineering. He is currently enrolled in the Air Force Reserve Officer Training Corps at Detachment 159 and will be commissioning following graduation in August of 2016. Upon graduation, he will be heading to Laughlin Air Force Base Texas where he will go through undergraduate pilot training.

Mark Hughes Atkins is currently a graduating senior at the University of Central Florida. He will receive his Bachelors of Science in Electrical Engineering this August. He is currently working as a System Integration Test Engineer part-time at Northrop Grumman Corporation in Orlando, FL. Upon graduation, he will transition into a full-time position with Northrop and pursue a Master's degree in Business Administration.

Marcus Hobbs is currently a graduating senior at the University of Central Florida. He will receive his Bachelors of Science in Computer Engineering August 2016. He specializes in software development and testing.



Ahkeim Pierre is a senior in the Department of Electrical Engineering at the University of Central Florida. He is obtaining his Bachelor's degree in Electrical Engineering. Ahkeim currently works with Lockheed Martin as a Reliability Engineer. Upon graduating, he plans to work as an Electrical Engineer at Harris Corporation in Melbourne, FL focusing on digital circuit design.

REFERENCES

[1] Wilson, Donielle. "How Cortisol Affects Your Sleep." Doctordoni.com. N.p., n.d. Web. 16 June 2016.

[16] "Facts and Stats." Drowsy Driving Stay Alert Arrive Alive RSS. N.p., n.d. Web. 28 Apr. 2016.

[2] W. H. Cantrell, and W. A. Davis, "Amplitude modulator utilizing a high-Q class-E DC-DC converter," *2003 IEEE MTT-S Int. Microwave Symp. Dig.*, vol. 3, pp. 1721-1724, June 2003.