GoodKnight

A system to monitor and aid the quality of sleep.

GROUP ONE

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1.0 Executive Summary

The importance of sleep is subject to many cultural interpretations. It is not uncommon for people to pride themselves on sleeplessness, hear clichés like "you can sleep when you're dead," or encounter other anti-sleep sentiment. The general implication being that sleep is a sign of weakness, an inconvenience that squanders time, and optional. Recent publications [1] speak of a "sleepless elite" that thrives on less than five hours of sleep without ill consequences, thanks to a genetic gift. While many mimic the revered sleeping patterns of the sleepless elite for years, perhaps from societal pressure, they are actually chronically sleep deprived.

Whether maligned or revered, however, sleep is still an extremely important part of life. The conventional ideal of a nightly eight hours or more of sleep takes up at least a third of a lifetime. Proportionally, a six-hour and austere four-hour sleep schedule represent a quarter and a sixth of a lifetime, respectively. Even a single hour of sleep takes up more than four percent of a lifetime. If quality of life is considered important, it follows that quality of sleep is also important, no matter how little sleep an individual needs.

Irrespective of cultural belief, sleep is critically important to overall health. While anti-sleep mantras about wasting time are popular, so too is the revered trinity of fitness: "diet, sleep, and exercise." Sleep deprivation is associated with a host of ill effects and is even used as a form of torture. Sleep is generally regarded as restorative, beneficial to memory and learning, and beneficial to the immune system. The nature and exact purpose of sleep is a matter of intense ongoing research, however.

Genetic variability is expected to create differences in the exact amount of sleep an individual requires in the same way it accounts for other physical differences, such as height and metabolism. Just as customized fitness routines and diets are becoming popular, a customized sleeping experience will cater to individual needs. Other aspects of health and progress are already religiously tracked quantitatively, including calories consumed, repetitions of an exercise, weight measurements, and exam scores.

The sleep management system that is the goal of this project is intended to not only help the user quantify this experience but to improve the quality of a significant proportion of life. Sleep monitoring offers a chance to consciously observe a part of life that is usually unconscious, and to discover the conditions necessary for optimum sleep quality. This project will not only equip the user to combat mental and physical fatigue associated with poor sleep and a potential path to discovering somnipathies (sleep disorders), but allow for a broader and more generalized understanding of sleep habits and associated health effects not easily discovered in a limited laboratory setting.

This project includes research into the medical nature of sleep, especially the stages of sleep and associated physiological states that make tracking sleep possible. After identifying the primary physiological changes associated with sleep, the required network of sensors needed to monitor those changes will also be researched. A specialized system will then be developed to analyze this data and identify the stages and quality of sleep. It will provide feedback to the user as well as customized control, such as alarm features and possibly the ability to alter local climate or light levels.

The sleep management system will provide the data to the user in as convenient a way as possible. The availability of this data opens the system up to integration with other health aggregation systems, allowing data mining useful to individuals and researchers alike. An emphasis is placed on modularity such that the user is in control of his or her own data and how to use that data. A perception exists that technology is bringing about longer, busier days with less sleep. This system will use technology to help manage that time.

This project consists of research, a timeframe for development, and all design, experimentation, and fabrication necessary to develop a functioning prototype of the desired system. Careful planning will result in a practical design and a strategy for implementation. The final system will be capable of monitoring certain physiological indicators to track sleep and allow the user to use this information in a custom manner for alarms or other purposes. The overall application is medical in promoting proper sleep and wellness as well as practical in efficient management of time.

2.0 Project Description

2.1 Motivation for the Project

Sleep is very important to a person's overall health. Sleep deprivation is associated with a wide variety of physical and mental illnesses, and oversleeping may also be associated with health complications. Obtaining an optimal amount of sleep is not easily achieved by following simple strategies like allotting eight hours of rest with an alarm clock set at a deadline.

The sleep management system would be used to improve the quality of the person’s sleep by providing them with useful information regarding their sleeping habits. Armed with this knowledge, an individual can make better decisions regarding appropriate times, places, climates, ambient light levels, or even body positions for sleeping and napping.

This system intends to combat sleep inertia, which is a feeling of grogginess and sleepiness often encountered when awakening. Awakening during certain sleep stages or at the wrong time relative to one’s circadian rhythm can worsen sleep inertia. By identifying the stages of sleep and circadian rhythm of users, this device could help them wake up feeling alert and refreshed.

Currently, there is also a large difference in the types of machines used to monitor sleep, ranging from the high-end medical devices used in professional sleep study down to simple mobile apps that claim to wake the user in a light stage of sleep. One of the main motivations is the creation of a sleep system that could be considered a consumer product, which would be in the middle of the spectrum of sleep systems.

2.2 Goals and Objectives

The sleep management system will be able to monitor the pulse, movements, and temperature of the user at a minimum. It must interpret this data to determine whether the user is in a light stage of sleep or a deeper stage of sleep, and wake the user with an alarm during the lightest stage of sleep in a window of time specified by the user.

The sensor devices must be comfortable enough for the user to sleep normally. Ideally the wearable device or devices should communicate wirelessly for maximum comfort. The sensors should also be able to survive nights of restlessness where they may endure some physical abuse.

The peripherals should prioritize low power. Since the sensor device will be worn when the user is sleeping it should be assumed that the device is able to function for the full duration of their sleep. So to be able to last a full night on a single charge is an objective that must be met. When selecting parts for the peripherals, finding parts that have a low power mode will take priority over similar products that do not offer that mode. The selection of the battery will be vital to the success of this object. A battery will need to be an appropriate size so as not to make the device bulky.

Collecting accurate data will be critical when detecting the different stages of sleep. To verify that the data is accurate, the sensors must first be tested and calibrated if necessary. Once the sensors are verified to be accurate, the software algorithms will also need to be thoroughly examined and tested to achieve a high degree of accuracy. The software should include functions to check the accuracy of the system and determine if calibration or maintenance will be required. With a high degree of accuracy the device could be used in medical applications. This would increase the usefulness of the project and allow for additional features to be incorporated at a later stage.

The peripheral will be worn when the user is sleeping, therefore the device should be comfortable. When defining comfortable in terms of our project the device must not be bulky or heavy. If the device is bulky it could interfere with their sleep and interfere with the measurements. The same could be said for a heavy device. A goal would to design a device that the user can forget is attached to their body allowing for a more accurate set of data collected when they sleep.

The system should be comparable to currently available products on the market. Here comparable is defined as tracking a similar number of events throughout the night. When comparing this project to the products available on the market, price will not be considered because of the larger discounts offered to products produced in large quantities.

If time permits, the focus will be on improving the reliability of the system. Throughout the build and design phases this will be under constant consideration, but to create a reliable system it must be put through rigorous testing. To subject the system to rigorous testing would require a significant portion of time that is not an option during the fast pace of this course. To have a reliable system in terms of this particular project, it should function under stated conditions for a full night. If the system were to fail during a period that it is operating, the failure should be controlled to a safe extent without catastrophic consequences.

2.2.1 User Friendly

The first goal of the project will to be user friendly. Making the project user friendly means: making the device as intuitive as possible, and for the parts that are not so intuitive, making it easy to learn how to use. This includes the software and the hardware. Making the device as intuitive as possible such as making the sensor device similar in appearance to something that everyone is already familiar with such as a headband or a bracelet.

The sensor device will need to be designed so that the user can just attach it to their body. When it is connected to the body the user should be able to expect it to start collecting data without any interaction.

The software of the base unit will need to have a user interface that is user friendly. To be user friendly the interface will need to present the information in a helpful way while not overwhelming the user with raw data from the sensors. So to do this, the raw data will be displayed using graphs to visualize the data. Not only will the base unit provide data visualizations, it will also give the user options to personalize how they would like the alarm to function for them. Options should be presented to the user to allow for a buzzer, audio clip, vibration, or a combination of these.

Another aspect of being user friendly is making it non-intrusive. This means making the device in a way that it doesn’t pierce the skin or cause discomfort on the user. The wearable components will have to be designed to provide the user the utmost comfort, while still prioritizing accuracy when collecting data from the sensors. It should also not interfere with the sleep of the user to be non-intrusive.

2.2.2 Modular

A second goal of the project is to have a modular design. Dividing the system into smaller parts it will provide more flexibility for scaling up the project if time permits.

A modular design has the advantage of being easy to troubleshoot each module. When the hardware is broken down into the separate circuits it will allow for our team to progress through the prototyping phase at a faster pace. This can be achieved by designing simpler circuits that can be debugged with relative ease compared to a larger complex design.

Maintenance is also a factor when creating a modular design. It is easier to maintain and repair a device when the modules can be isolated to spot troubles. When an issue is isolated to one of the modules, then it will just be a matter of determining whether it is a fault in the circuitry or a simpler problem. When designing a system with maintainability in mind, it is important to consider how each module will be repaired.

2.2.3 Scalable

The last goal of the project is to have a scalable system. The modular design of the system will allow for it to be scaled up in the future. If the current specifications of the system are met before the deadline, then the system will be scaled up accordingly with extra features.

With the limited time given for the project it is not possible to include all the ideas, features, and sensors that would provide the best feature set. This is why scalability is a goal of the project; the design may be improved beyond the basic requirements of the system in the future.

The software and hardware of the project will be designed with scalability in mind. The software will employ generalized functions and standards that will allow for some flexibility when sampling from the sensors. As for hardware, keeping the design modular will make scalability relatively straightforward.

There are several future objectives that are not considered necessary to monitor sleep stages. These extra features would improve the design by adding improved precision, enhancing the user experience, and expanding the scope of the project.

One of the ideas considered was to monitor blood pressure. Monitoring blood pressure would allow for improved precision in regards to detecting the user's sleep stage. Not only would it be used to improve the detection of the sleep stages, it can be used to inform the user about his or her blood pressure during a significant portion of the evening. This would improve the practicality the system. Since many people often have to measure their blood pressure for medical reasons, this would be a convenience for those users.

The software on the base station could be further developed to include relevant information regarding the user's upcoming day. The system could present weather forecasts, traffic reports, and other important news alerts that would be useful in the morning. This information could be gathered from local news sources near the user's location. Obtaining the beginning of morning nautical twilight times (BMNT) from the Internet could allow the alarms to synchronize with sunrise. By providing this information it could be argued that it will allow the user to sleep an extra few minutes given the time it would save them discovering it on their own.

Given sufficient time, an application for the major smart phone operating systems such as Windows, Android, and iPhone will be developed. The current design incorporates a display on the base station that will relay information to the user. This information could also be displayed on a smart phone, but doing this would require extra development time to deploy. A smart phone version of the system could provide a simplified version of the hardware since it does contain some of the sensors used. Most smart phones have an accelerometer and a microphone these sensors can be used to create a basic sleep monitoring system.

A more ambitious, but riskier objective is trying to identify sleep disorders. The system would not be able to officially diagnose any sleep disorders because that would require a medical professional. Using the criteria for each sleep disorder that would have physical symptoms observable by the sensors used in this project, it should be possible for the system to detect sleep disorders. Once a sleep disorder was detected, it could provide the user with information regarding their sleep and present the criteria for the sleep disorder to allow the user to make an educated decision on how they want to proceed.

The entire project concept can be expanded beyond sleep monitoring and track activities during the day also. This could include counting steps, stairs, and calories burned based on user activity or wirelessly tracking weight from a scale.

The base station software could be further developed to upload the user information to a web site. By providing a web site with their personal sleep history, the users could access it and share the information with anyone they wanted.

2.3 Requirements

A sleep monitoring system consists of a smart alarm clock with integrated measuring devices and special features. Therefore, many of the standard requirements for this project are similar to the specifications of an alarm clock. Below is a list of requirements that would need to be implemented in order to have full functionality of a system that is able to monitor someone's sleep throughout the night and help him or her make smarter decisions about their sleep habits.

2.3.1 Basic Requirements

The basic requirements are design-critical requirements needed to satisfy ABET course objectives and provide at least some degree of functionality to the system. Without first accomplishing the basic requirements, no advanced features can be considered. The following bullet points are the basic requirements:

- Be able to measure body temperature, body movement, ambient temperature, ambient humidity, heart rate, and sound.
- Be able to transmit these measurements wirelessly.
- Be able to sound an alarm in a user-specified time interval.
- Be able to sound an alarm at specific periods of the night based on measured physiological cues.
- Be able to display body measurements taken throughout the night during sleep (Hypnogram).
- System should be able to run for at least 8 hours continuously.
- System should be comfortable.

2.3.2 Desired Features

A desired feature goes beyond the basic requirements of the system to provide enhanced functionality to the user. These features would be incorporated if time permits after completing the basic requirements of the design. The following bullet points are the desired features:

- Provide a portable and convenient interface for users to check their data measured during sleep over a user-specified period of time.
- Make recommendations on when to go to sleep in order to have an optimum sleep cycle.
- Make the user aware of possible sleep disorders they might have.
- Provide the possibility to change the alarm clock sounds with a custom sound file the user selects
- Provide a persistent alarm that does not cease until the user gets out of bed or performs some task.
- Provide a vibrating module to supplement the audible alarm clock with physical vibrations to aid in waking the user.

2.3.3 *Extraordinary Features*

An extraordinary feature would provide outstanding functionality to the user. These are an extension of the desired feature set that would provide a more polished overall system competitive with commercial products of a similar nature. Extending the device with support for multiple mobile platforms will provide a new dimension of user interaction and expansion for the system. These are features that may or may not be within the scope of the project development time frame but are worth consideration. The following bullet points are the extraordinary features:

- Provide a variable snooze function based upon the user's sleep pattern to allow an extra sleep cycle or portion of sleep stages.
- Differentiate between multiple users sharing a single bed.
- Offer an application for Android, Windows 8, or iOS devices.
- Allow users to create an account via a web app to store and access their results over the course of device usage.
- Be able to share sleep data via Facebook/Twitter or any other social networks.
- Expand system capabilities to monitor and track other health aspects, such as distance walked, weight measurement, or heart rate during exercise.

2.3.4 Hardware System Requirements

The hardware system requirements are described in Table 2.3.4.1.

Power Supply Voltage	AC 110-230 V
Wearable Device Battery Life	6 hours+
Wearable Device(s) Weight (total)	< 5 lbs.
Temperature Sensor Accuracy	+-25%
Pulse Oximetry Accuracy	+-25%
Humidity Sensor Accuracy	+-25%
Audible Alarm	30-90 dB
Functional Temperature Range	5-35° Celsius
Minimum Wireless Range	5 feet
Battery Recharge Time	< 24 hours for 100%

Table 2.3.4.1 – System hardware requirements

2.4 Division of Labor

In order to have a successful project development, the project labor needs to be divided into equal amounts of work for each team member. Moreover, considering the team's experience, the labor will be split according to how much throughput each member can accomplish. For instance, a member who has had experience with embedded software development will have much higher throughput than a member who has not developed any software for embedded systems. So the project will be divided into equal amounts of workload corresponding to each member's ability.

In addition to a member's experience, certain modules of the project will need to be thoroughly tested in order to eliminate error propagating to other modules within the project. For example, a faulty, untested temperature sensor might give false readings on someone's body temperature and could mean catastrophic results in determining his or her sleep cycle. In this circumstance, the particular hardware module would need to be thoroughly debugged, increasing the time and work needed to make it function properly.

Breaking down the project into smaller modules that correlate with each team member's skills and abilities, a block diagram was produced to show the main roles of each team member and their project domain. The block diagrams are shown below in Figures 2.4.0.1, 2.4.0.2, and 2.4.0.3.

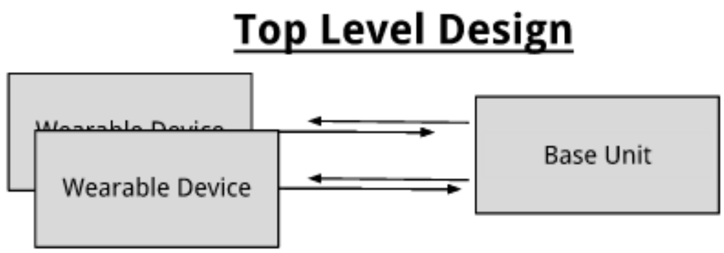


Figure 2.4.0.1 – Block diagram for the entire system

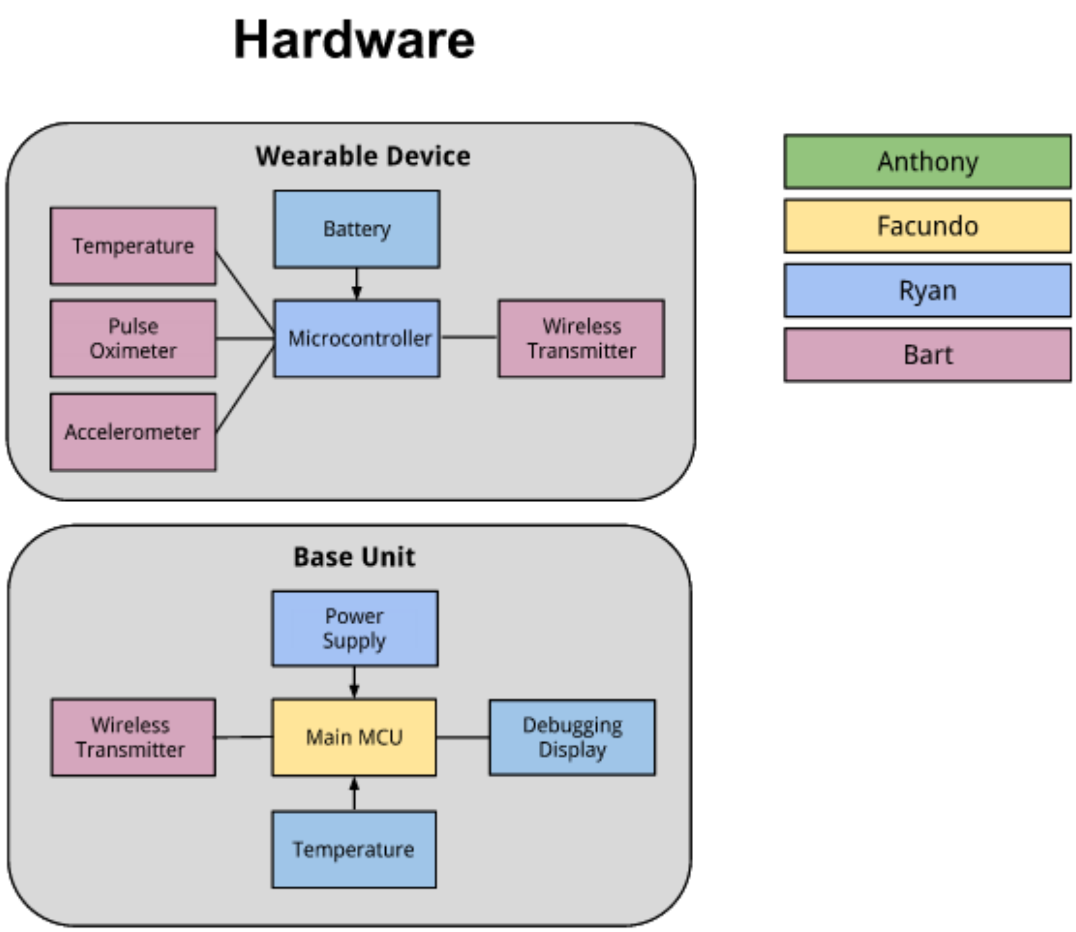


Figure 2.4.0.2 – Division of labor for the hardware modules.

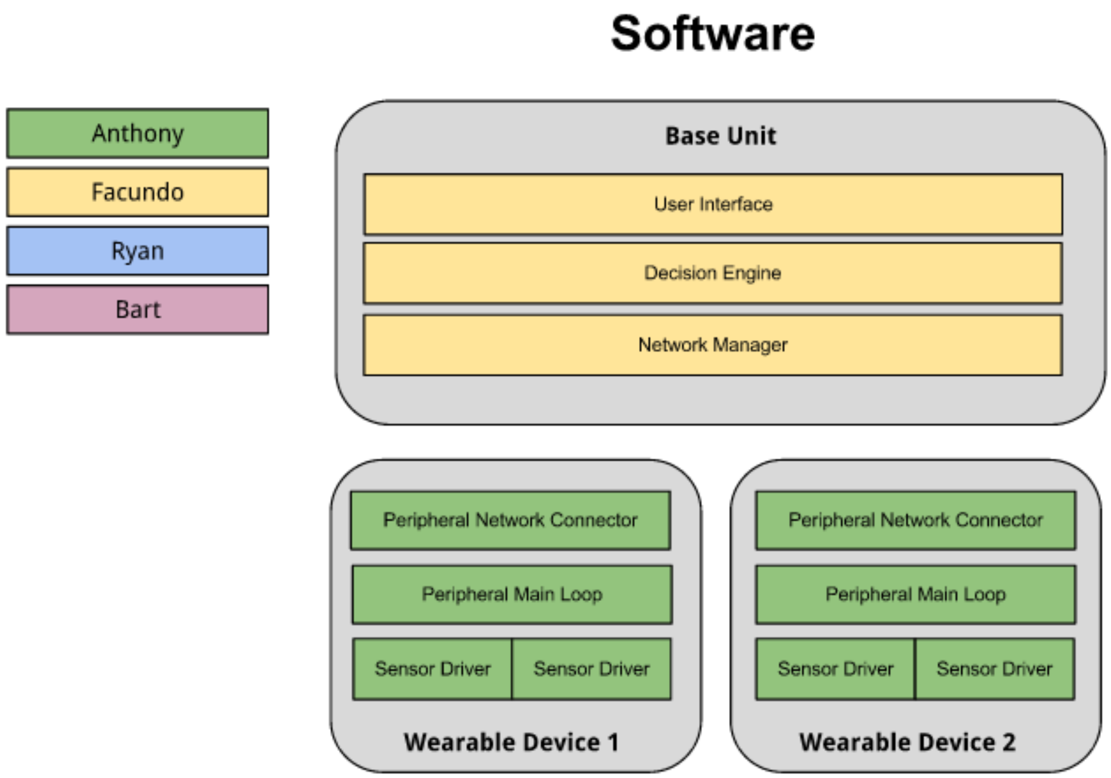


Figure 2.4.0.3 – Division of labor for the software modules.

2.4.1 Anthony Bharrat

Anthony will be mostly working with the interface between the peripherals and the main microcontroller. He will be focusing on designing and implementing the messages that are going to be transmitted back and forth between the peripherals and the base station, delivering commands, sensor data, and system states. In addition, he will do the embedded development for each wearable device and the corresponding device drivers for each sensor used.

2.4.2 Facundo Gauna

Facundo will be in charge of all the high-level software development. He will work on creating an easy-to-use user interface allowing the user to control the device. He will support the development of the control network for the project. He will also create a decision engine algorithm for the main microcontroller that will be used in the base unit.

2.4.3 Ryan Murphy

Ryan will be in charge of integrating the hardware components in the peripherals with the microcontrollers. In addition, he will design the printed circuit boards for manufacturing. He will implement the temperature measurement systems and design the power supplies for the base unit and peripherals.

2.4.4 Bartholomew Straka

Bart will focus on designing hardware components; specifically, he will be developing the wireless transmitters, heart rate sensor, inertial measurement unit, and power supplies. Therefore, his work will consist mainly of analog design implementations. His role will be critical to the accuracy of the entire project. He will spend a lot of time testing components and designs.

3.0 Research related to Project Definition

3.1 Medical

3.1.1 Science of Sleep

Sleep is defined in this project as a temporary period of reduced physical movement of voluntary muscles, reduced consciousness, and reduced sensitivity to external stimuli. It is characterized by distinct brain activity and can be further classified into separate stages. In spite of significant scientific advancements in many medical fields, the exact purpose and nature of sleep is not well understood [2].

3.1.1.1 Sleep Stages and Physiology

Human sleep is divided into four stages. Of these, three stages are classified as non-rapid eye movement (NREM) sleep and the fourth is classified as rapid eye movement (REM) sleep. Since 1968, Rechtschaffen and Kales divided NREM sleep into four stages, but the American Academy of Sleep Medicine (AASM) combined the two slow wave sleep stages into a single third stage in 2007 [3].

Dreaming typically occurs during REM sleep, although it is possible to dream during NREM sleep. In general, the body is paralyzed during REM sleep but not in other stages. A complete cycle through the stages of sleep generally lasts around 90 minutes, with subsequent cycles gradually lengthening in duration [4]. An average night’s sleep might consist of three to five such cycles. A person may experience difficulties or deprivation of a particular stage of sleep independent of others.

The overall aim is to wake people at the end of a complete NREM-REM cycle, which is variable in time. Simply setting alarms in increments of 90 minutes is not likely to result in reduced sleep inertia because a cycle may last anywhere from an hour to two hours, and is known to increase in duration throughout the night. Awakening in the middle of any stage of sleep is likely to result in sleep inertia and poor sleep in general, although waking during a lighter stage of sleep is preferable to a deeper stage.

Sleep stages are usually determined from electroencephalograph, electrooculography, and electromyography. None of these data sources are expected to be within the scope of this project. It is necessary to explore possible physiological clues exhibited by each stage of sleep that may be monitored with simple electronics in order to help wake the user at preferable time.

The structure of sleep based on the amount of time spent in each stage is known as sleep architecture. Sleep architecture changes with age, with younger individuals sleeping for a longer duration overall and spending more of that sleep in deep sleep and REM [5]. Older individuals sleep fewer hours and spend less time in deep stages and REM. Drugs, alcohol, diet, exercise, and circadian rhythm also affect sleep architecture. A hypnogram is a graph of sleep stages versus time throughout a period of sleep, and can be considered a map of sleep architecture. This project aims to track sleep stages well enough to graph a hypnogram for the user.

Stage 1 (S1/N1)

This stage is a transition from an active brain state such as wakefulness or REM sleep to a less active brain state. Technically, the transition is documented by the change from alpha waves to theta waves on an electroencephalograph (EEG). Alpha waves occur in a more relaxed period of wakefulness with a frequency of 8-12 Hz. As a person drifts from relaxation into N1 sleep, the brain waves slow to 4-7 Hz, increase in amplitude, and become more rhythmic [4].

The difference between deep relaxation and N1 sleep is subtle. When first going to bed, a person may not report having been asleep if awakened during this stage. It is therefore considered a light stage of sleep. Daydreams and hallucinations are possible. The muscles are still active, and muscle twitches sometimes experienced when drifting off known as hypnic jerks may occur during this stage [6]. The eyes may still move, but gradually slow.

Stage N1 may last from one to seven minutes, representing roughly four to five percent of an overall NREM-REM cycle [7]. Note that a typical “snooze” function on an alarm clock of roughly ten minutes is likely to interrupt N1 or N2 sleep just as a person falls more deeply asleep and scarcely allow for more satisfying rest. Because this stage of sleep is brief and the physical clues are scant, it might be identifiable only by a gradual decrease in heart rate, reduced physical movement interspersed with possible twitches, and timing clues.

Stage 2 (S2/N2)

The second stage of sleep is also considered a relatively light stage of sleep. However, a person drifts deeper into sleep and becomes less responsive to external stimuli. The 4-7 Hz theta waves continue, except there are short bursts of activity in the form of 12-14 Hz spindles and high-amplitude spikes called K-complexes [8]. The purpose of this activity is not fully understood but is theorized to help deaden sensitivity to non-dangerous external stimuli and process knowledge and memory.

Stage N2 may last from 10-25 minutes, representing approximately 45-55% of total sleep 7]. This stage is fortunately accompanied by more pronounced bodily indicators than N1 sleep. Breathing and heart rate both slow and become regular. Body temperature also steadily declines. Less body movement is expected [9]. A heart rate sensor, body temperature sensor, and inertial measurement unit will be useful in determining when a person is in stage N2 sleep.

Stage 3 (S3&S4/N3)
The last stage of NREM sleep is known as slow-wave sleep and is the deepest stage of sleep. Brain activity slows from theta waves to 0.5-4 Hz, higher-amplitude delta waves [4]. The previously categorized S3 stage of sleep marked the onset of such delta waves with periodic activity as in S2 and the S4 stage marked a deeper period of delta waves. The two have since been combined and classified as N3 by the AASM.

This period is sleep is thought to potentially be restorative to the body, boost immune strength, build and repair tissues, and help in memory reorganization and learning. A significant percentage of the body’s daily secretion of human growth hormone occurs during slow wave sleep [9]. Deprivation of N3 sleep may promote insulin resistance and hence possibly lead to the development of type 2 diabetes [10]. Awakening from this stage of sleep also results in the highest degree of sleep inertia [11]. Consequently, N3 is one of the least ideal stages of sleep in which to awaken and this project will seek to minimize such occurrences.

Time spent in stage N3 is more variable than the first two NREM stages. At the beginning of the night, N3 takes up a larger portion of the sleep cycle. After subsequent sleep cycles, N3 takes up less time and REM sleep takes up more of the cycle [8]. Deprivation of N3 sleep will lead to an acceleration to N3 with a longer duration on the next instance of sleeping [12]. Time spent in N3 is also correlated to the amount of time spent awake prior to sleeping, and possibly diet and exercise. Total time spent in N3 per cycle is around 20-40 minutes or 16-21% of sleep, and with many consecutive sleep cycles may be entirely replaced by REM and not occur at all [7].

Although it is the deepest stage of sleep, it is also a stage of sleep where sleep disorders such as sleepwalking, bedwetting, and sleep talking are commonly exhibited [12]. During sleep monitoring by this project, excessive movement and noise or other indicators while the user is expected to be in stage N3 and is not awake may therefore be a potential sign of parasomnias requiring professional evaluation.

Some physical signs of stage N3 sleep include a lack of eye movement, the least amount of physical movement in NREM sleep, dropping blood pressure, and slower breathing [13]. The slower breathing and lower blood pressure is expected to result in reduced heart rate and weaker readings if using pulse oximetry. Respiration monitoring may also help identify this stage. Physical movement will be lower than other NREM stages. There is more blood supply to the muscles in this stage, so the temperature may increase or continue to decrease depending on the location of measurement [13].

Rapid Eye Movement (REM)

The final stage of sleep is rapid eye movement, or REM sleep. Although it is the last stage of sleep, it does not usually immediately follow stage N3. The progression of the sleep cycle will usually go back to stage N2 briefly and then into REM [7]. REM is time-variable like N3, and occupies a greater portion of sleep as cycles progress until taking up most or all of the portion occupied by N3 in previous cycles [7]. REM represents roughly 20-25% of total sleep [9].

REM is the stage where most reported dreaming occurs, although dreaming is possible in other stages. All muscles except for the eyes and those needed for respiration are paralyzed during REM sleep [14]. It is theorized that paralysis during REM prevents people from acting out dreams. Brain activity spikes to a level comparable to a waking state [14].

REM is considered important to learning and memory, although the process is not well understood [13]. Monoamine neurotransmitters are not released during REM, leading to the theory that this is necessary for restoration of the associated receptors [14]. Infants may spend up to 8 hours a day in REM, and time spent in REM declines with age, possibly suggesting its importance in development [14].

Deprivation from REM sleep will result in a REM sleep debt and more REM will be present in the next sleeping session, similar to the rebounds of stage N3 sleep following deprivation [15]. General sleep deprivation will result in rebounds of both N3 and REM, and such sleep is considered more efficient. Sleep inertia from awakening mid-REM is heavier than awakening during N1 or N2, but not as severe as the sleep inertia from interrupted N3 sleep [16].

Considering the role of N3 and REM in learning and restorative functions, as well as the body’s apparent need demonstrated by rebounds following deprivation, both N3 and REM are considered important stages of sleep. Consequently, the sleep management system will seek to preserve them by avoiding alarms while these stages are detected. This will also minimize sleep inertia and hopefully result in a better-rested user. All stages of sleep are important to health, but this is the best strategy for maximizing rest and alertness upon awakening.

Physiological indicators of REM sleep include increased heart rate, increased blood pressure, rapid and irregular breathing, rapid eye movement, erections for males and clitoral engorgement for females, high brain activity, and poikilothermic body temperature, which means a loss temperature regulation [14]. This project may detect REM through a combination of heart rate sensors detecting an increase compared to NREM sleep, possible respiration monitoring showing less regular breathing, inertial measurement units indicating the least amount of movement, and body temperature measurements indicating a drift towards ambient temperature.

Brief awakenings or extremely light sleep often immediately follow a completion of REM sleep, and this is considered the ideal time to wake the user. Body movement immediately following REM sleep will be the most important indicator of this opportunity.

3.1.1.2 Sleep Disorders

This project is not intended to diagnose or treat any type of medical condition. Some somnipathies, such as sleepwalking, will be obvious to any sleep monitoring system. Nonetheless, this system cannot decide on such matters for liability reasons and also because it will not be designed to do so. A system capable of aiding in diagnosis is called a clinical decision support system (CDSS). It is worth consideration that some sleep disorders will prevent the sleep monitoring system from functioning properly, perhaps in a nonobvious way. In such cases, and in obvious cases like sleepwalking, the system may provide clues that professional consultation is recommended.

The use of a microphone or respiration monitoring may help identify snoring, which is a possible sign of sleep apnea. However, there are many causes of snoring, including obesity, alcohol intake prior to sleep, or simply jaw position [17]. Users may have interest in monitoring their snoring activity for many reasons, from health concerns, amusement, or just because during sleep there is no awareness of whether one snores. Snoring may result in periodic waking throughout the night without a person realizing it, and may result in poor quality sleep. It is therefore a monitoring goal of interest, but not a requirement for this project.

3.1.1.3 Sleep Hygiene

This project focuses on quality of sleep. The stages of sleep are a very important aspect of overall sleep quality, but there are also other considerations. Taking into account all of these considerations in an attempt to improve sleep is known as practicing sleep hygiene. Good sleep hygiene promotes all of the health benefits of effective sleep: mental alertness, improved memory and learning, lower stress, safer driving, preventing obesity, and aiding the immune system among many other benefits. Sleep alone will not guarantee any of these benefits, of course, but is part of a health regimen that is helpful in realizing them.

One way to promote mental alertness directly is by combatting sleep inertia. Sleep inertia is the feeling of grogginess and general tiredness experienced after awakening. Sleep inertia is associated with impaired faculties such as the ability to perform basic arithmetic and also degraded situational awareness [18]. Sleep inertia becomes dangerous beyond individual suffering when a tired person gets behind the wheel of a vehicle.

Sleep inertia is caused by an insufficient amount of sleep. Even with sufficient sleep, however, simply waking up during a deep stage of sleep will bring about a heavy feeling of tiredness. This phenomenon may be responsible for the popular perception that “sleeping too much” actually causes tiredness instead of sleep deprivation. The sleep monitoring system attempts to reduce sleep inertia by waking a person up just after the end of REM sleep as a person transitions back into N2 sleep. However, this is absolutely not a substitute for getting an adequate amount of sleep.

The duration of sleep inertia is variable, lasting from a few seconds to several hours. For example, waking sleep deprived causes some tiredness. The sleep deprivation then results in “recovery sleep” at the next session of sleep. Awakening during recovery sleep then compounds the sleep inertia. Consuming large quantities of caffeine may later cause a “crash,” which is a secondary period of sleep inertia. Attempting to nap off the feeling of tiredness may either last too long and harm productivity, or result in yet another period of sleep inertia after a person wakes up at a non-ideal stage of sleep. This example illustrates how sleep inertia can become a serious stressor for a person regularly operating on just a few hours of sleep.

Using the sleep management system proposed in this project will help with sleep inertia caused by sleep deprivation and the timing of sleep. There are other factors, however. In addition to the sleepless elite mentioned in the executive summary, people genetically predisposed to need less sleep, there are also “morning people” less prone to morning grogginess. In general, periods of sleep are naturally governed by an individual person’s circadian rhythm.

Each person has a chronotype, or an individual circadian rhythm that regulates such things as body temperature, the release of certain hormones such as melatonin and cortisol, hunger, and sleep [19]. The mechanism for controlling circadian rhythm in the brain is the suprachiasmatic nucleus (SCN) located in the hypothalamus [19]. The SCN is particularly responsive to levels of light reported by the eyes, and can adapt the circadian clock with respect to the length of days [19]. The effect of external stimuli on circadian rhythm is known as entrainment.

Light can entrain the circadian rhythm of a person, so artificial light affects the sleep-wake pattern by suppressing the production of melatonin. The sleep monitoring system could in the future be connected to the lighting in a house or bedroom according to user settings such that it gives the user automated control of this entrainment that is more convenient to his or her daily schedule. Taking into account the length of days plus the times of sunrise and sunset could also be useful to the system in deciding when to wake a person or allow them to see how light affects his or her sleep.

Other factors affecting entrainment, known as zeitgebers, include alcohol use, drug use, caffeine, eating, and physical activity [20]. Alcohol in particular keeps a person in light stages of sleep and tends to suppress both deep sleep and REM [21]. The person therefore never gets the rest he or she needs to feel refreshed. This is worth mentioning because alcoholics, insomniacs, or just people attempting to exploit the sedative nature of alcohol may believe it to be a sleep aid and consume it as a so-called nightcap, when it will in fact likely worsen their tiredness later.

This system has no way to prevent users from abusing drugs or alcohol, but their use especially just before sleeping may diminish the overall effectiveness of the sleep management system. The system could remind users to avoid strenuous activity, exercise, or eating a few hours prior to bedtime. It could also play relaxing music or dim the lights. Allocating a sufficient amount of time in one's schedule for sleep is considered good sleep hygiene.

Zeitgebers may be exploited by the sleep management system to help fight sleep inertia. For instance, gradually exposing the user to light 30 minutes prior to the desired waking time will reduce grogginess on awakening [22]. Exercise and physical activity in the morning is also effective at reducing sleep inertia. The system can do little more other than remind the user to exercise in the morning, but it can also cleverly jolt the user into physical activity. For example, releasing a moving object the user must chase or waiting for a sufficient amount of activity on the wearable inertial measurement unit before shutting off an alarm.

An important characteristic of circadian rhythms exploitable by the sleep management system is body temperature. A falling body temperature indicates the second half a circadian rhythm cycle and the release of melatonin, which regulates sleep [20]. At a certain point in the circadian rhythm, often approximately two hours before waking, the body will reach its minimum core temperature. Waking the user after this point in time will result in less sleep inertia, and the secretion of melatonin ceases as the body temperature rises with the circadian rhythm cycle. Therefore a temperature monitor is critical to the overall effectiveness of this project.

Some individuals have an irregular circadian rhythm affecting their sleep patterns. They may practice polyphasic sleep because of this, which is sleeping in numerous intervals throughout a 24-hour period rather than a single sleep session. Some people actually practice this voluntarily for person reasons, and people in certain occupations such as the military may be forced to by their schedule. While the sleep management system cannot specifically treat sleep disorders, it may help individuals with such schedules at least wake up at during appropriate light sleep stages. The system will also keep an automated sleep diary and hypnogram that would allow such individuals to track the quality of their sleep and understand their personal sleep architecture.

3.1.2 Polysomnography

3.1.2.1 Traditional Methods

Polysomnography is a professional medical evaluation of sleep. The primary tools of polysomnography are electroencephalography (EEG), electrooculography (EOG), electrocardiography (ECG/EKG), and electromyography (EMG). None of these are actually methods that will be used directly in this project. One of the reasons for that is cost and complexity. The other reason is that a minimum of 22 electrodes are connected to a person, which violates the comfort requirement of this project.

Electrooculography measures eye movement and makes REM sleep obvious. The details of eye movement are certainly important in a professional medical evaluation, but not critically necessary to identifying sleep stages. The difficulty in implementation versus the payoff makes EOG a very low priority for this project.

Electromyography measures muscular electrical activity. In polysomnograpy, four leads are used for EMG: two on the chin and two on the legs [23]. While information about muscle movement from EMG is useful in studying sleep stages, the placement in polysomnography is partly to identify sleep disorders. The leads on the chin help diagnose bruxism, or grinding of the teeth, and the leads on the leads are to detect restless leg syndrome [23]. The sleep management system is not intended for medical diagnosis, so a suitable replacement for EMG is a simple accelerometer or inertial measurement unit to monitor physical movement.

Polysomnography also makes use of a sensor in the nostril to monitor respiration. This sensor may be a temperature sensor or a pressure gauge [23]. While it is well within the scope of this project to use such a sensor, placement in the nostrils is out of the question because of the comfort requirement. As an alternative, if time permits, a piezoelectric sensor, commercial pressure sensor, or microphone may be used to attempt to monitor respiration in this project.

Electrocardiography is used to monitor heart rhythm throughout the night and indicate any potential heart conditions as well as track heart rate through the sleep cycles. Pulse oximetry is also used in polysomnography, but more for tracking blood oxygen levels pertaining to sleep apnea rather than heart rate. This project will attempt to measure heart rate to aid in detecting sleep stages and as a secondary indicator of activity and respiration intensity.

Based on the sleep stage research, the EEG alone is perhaps the most powerful tool for identifying sleep stages in polysomnography. It is considered an extraordinary feature for this project. It cannot be implemented in the traditional method, via electrodes placed on the scalp after abrasion and with a conductive gel. At least one commercial sleep monitoring system, Zeo, uses EEG with conductive fabric in a headband. Commercial brain-computer interfaces (BCI) used as toys or video game controllers may also be modified, but are expensive. If this project attempts EEG, it will likely use conductive fabric in a headband like the Zeo.

3.1.2.2 Pulse Oximetry and Heart Rhythm

3.1.2.2.1 Electrocardiography

A traditional component of polysomnography is the measurement of heart rhythm through electrocardiography (ECG/EKG). An electrocardiogram is the recording of the heart's electrical activity. The potential difference between a pair of electrodes, called leads, placed on the skin on either side of the heart is measured. This is accomplished using more than one lead, commonly as a system of three, five, or twelve leads. A twelve-lead ECG actually uses ten electrodes, and twelve "leads" or voltages between various electrodes are measured.

The number of electrodes and precise placement required for full-scale ECG is prohibitive to nightly, comfortable, and consumer-friendly sleep monitoring. Additionally, optimal skin contact for electrodes is achieved through pretreatment with alcohol and an abrasive electrolytic paste, a routine tolerable for a clinical setting but not the bedroom. Twelve-lead ECG is intended to monitor the heart in detail, providing a level of study sufficient to identify the physical region of the heart affected by a particular ailment. This is superfluous to the intended purpose of identifying stages of sleep and simple pulse patterns.

Professional polysomnography accordingly uses only two electrodes for ECG. These can be placed on both sides of the upper chest [24]. For maximal comfort, ease of use, and efficiency, a simpler method for heart rate monitoring with a smaller footprint is desirable. Consumer heart rate monitors, often used for sports and fitness training, are available as chest straps that may transmit wireless to a wristwatch or other monitoring device. Some devices use conductive smart fabric for an ECG-style reading.

3.1.2.2.2 Pulse Oximetry

Pulse oximetry is monitoring the oxygenation of blood in the body. The level of oxygenated blood in the body varies with time as the heart beats. By extension, monitoring the ratio of oxygenated and deoxygenated hemoglobin also indicates the pulse rate. As an added benefit, determining the presence of oxygen in the blood may also provide helpful health indicators, such as improper breathing or low oxygen levels indicative of sleep apnea. High quality pulse oximetry may be helpful in identifying sleep apnea, hypopnea, or even an emergency situation such as carbon monoxide poisoning.

Pulse oximetry is commonly conducted using light emitting diodes and photodiodes. The absorbance of the transmitted light is used to determine the level of oxygenated hemoglobin, which has a different absorption coefficient than deoxygenated hemoglobin [25]. Absorption is the way in which electromagnetic radiation is taken up by matter, in this case the attenuation of light. More than one LED at different wavelengths may be used to monitor the ratio of oxygenated to deoxygenated blood because of this difference in absorption at different frequencies.

The detailed evaluation of blood oxygen levels to determine pulse requires thin sections of skin, such as fingertips, earlobes, or the ankle. An alternative that allows a somewhat wider range of use on the body is to measure the reflectivity of the blood as an indicator of oxygen levels or swelling of arteries. While complete pulse oximetry indicating precise oxygen levels is desirable, determining the heart rate is the main objective for this device.

A benefit of pulse oximetry is that it is less susceptible to pulseless electrical activity than ECG. Pulseless electrical activity is generated by the sinoatrial node, or “pacemaker tissue” in the heart, and will be detected by an ECG whether or not the heart is actually pumping blood.

One of the biggest challenges in this project is finding an effective location on the body for heart rate monitoring that is also comfortable and convenient. Pulse oximetry becomes difficult to implement on tissues that are not thin and transparent with good blood flow. Measuring reflectivity in other areas will not provide as good an indicator of blood oxygenation or of the heart rate itself.

The forehead provides a good surface for reflective pulse oximetry, so a head strap is an option. The venous part of the wrist may also be a good surface for reflective measurement, but the strap must be kept in position such that the sensor does rotate to the thicker opposite side of the wrist. The fingertips are a viable body surface for absorbance pule oximetry, so a glove is another option. The forehead may be the best choice since people can sleep on top of their limbs, reducing circulation and effective measurement.

3.1.2.2.3 Stethophone

Aside from using infrared and near-infrared reflection and absorbance, there are other potential options to detect heart rate. The beating heart actually generates sound. There are two sounds associated with a healthy human heart: the first is known as S_1, a “lub” sound, and the second is known as S_2, a “dup” sound [26]. Additional, abnormal sounds may also be present such as heart murmurs. Careful monitoring of heart sounds may therefore help in identifying cardiovascular issues.

The stethoscope is the most commonly used instrument for auscultation, which is listening to internal sounds within a body. Electronic stethoscopes, called stethophones, are manufactured but are beyond the budget of this project. These devices originally used a microphone in the chest piece of a traditional stethoscope, but this method produces too much noise. Commercial products now use piezoelectric and capacitive sensors

Assuming effective capture of actual heart sounds with an acceptable level of noise, additional analog and digital signal processing will be required to distinguish heart beats. Computer-aided auscultation is a subset of a larger Clinical Decision Support System (CDSS) industry that aids medical professionals in patient monitoring and diagnosis. Computer-aided auscultation uses sophisticated methods to differentiate S_1, S_2, and pathological heart sounds. While this level of detail would be excellent, this project is concerned mostly with determining heart rate.

More signal conditioning may be needed to identify the heart rate through a microphone than with infrared pulse oximetry. There are a variety of microphone technologies, by which devices typically vary capacitive, inductive, or resistive values based on vibrations of a diaphragm from changes in sound pressure. Since microphones are designed to transduce sound vibrations in the air and not through tissue, the expected signal-to-noise ratio of internal body sounds is expected to be very weak even with a body-facing unidirectional microphone. Sensor placement is also limited to the chest area.

3.1.2.2.4 Piezoelectric Sensor

An alternative to microphones or electrodes applied to the chest area may be piezoelectric sensors. Piezoelectric sensors produce voltage in response to mechanical stresses such as changes in pressure, strain, vibrations, or anything producing a tiny physical deformation. A piezo element pressed against the skin over the heart might respond to the vibrations from internal heart sounds better than a standard microphone.

Such a setup would also be sensitive to breathing and movement in general. Piezo respiratory sensors are actually on the market. This may have the added benefit of monitoring respiration throughout the night, but makes detecting heart rate challenging. This setup is also restricted to chest area placement like the microphone or electrodes. For better results, it is also assumed that the piezoelectric sensor would be placed against bare skin, meaning that a chest strap would be worn underneath any nighttime clothing. This may be a barrier to comfort and convenience. Body locations around arteries or anywhere that physically throbs or vibrates with pulse, like the neck or wrist where pulse is often manually detected, may also be good areas for piezoelectric detection of heart rate.

3.1.2.3 Actigraphy

Actigraphy is the monitoring of a person’s physical movements over time. Commercially available actigraphy devices are used for tracking both daytime activities such as well as nighttime activity. As an example, an actigraph device may be used to track physical exercise, count the number of steps taken in a day, or as an alternative to a full polysomnogram. The body location where the actigraph unit is worn depends on the intended function, but it generally worn around the wrist or hip.

The actigraph unit consists of an accelerometer or inertial measurement unit as the primary sensor. These sensors are already being considered for the project based upon research of movement during each stage of sleep. The system will therefore be using what is considered an actigraph. Its role in this project is to work in conjunction with other monitoring sensors. However, a paper published by the AASM suggests up to 90% agreement of actigraphy with a traditional polysomnogram [27]. That makes the accelerometer or inertial measurement unit a critical component in this project.

For sleep monitoring, the actigraph unit is usually placed on the non-dominant wrist. However, in the same paper on actigraphy published by the AASM, it is considered that the dominant wrist may be a better indicator [27]. In this project, a simple wrist-band will be developed that may be worn on either wrist or ankle, such that it may be determined later by the user which location is in better agreement with his or her personal sleep cycles.

Actigraph data may be evaluated in several different modes for sleep monitoring. There is zero crossing mode (ZCM), proportional integration mode (PIM), and time above threshold mode (TAT). The signal from the unit is monitored continuously and that data gathered from the different modes is stored in memory for a specific time interval, usually one minute. For instance, ZCM counts the number of times the voltage of the signal crosses a threshold of zero in the time interval and stores it. PIM integrates the area under the curve from the signal over the time interval. TAT measures the time the signal is above a certain threshold for the interval. ZCM indicates frequency of motion, PIM indicates the intensity of motion or level of activity, and TAT indicates the overall amount of time spent moving. PIM has the best correlation to actual polysomnography, and will therefore be the method used in this project [28].

3.2 Existing Similar Projects and Products

In recent years a new trend has emerged called “Quantified Self,” which involves self-tracking to gain knowledge about yourself [29]. This has led to a growing number of projects and products that gather data on the user and present it in a visually appealing way. Through research on theses existing designs it is possible to narrow down the existing devices to those that have similar specifications to this design.

The benefit of having existing designs is not something to be overlooked. It is a very important advantage to have past student projects as a research tool to gain insight into trouble areas that past projects have encountered and allocate extra time to account for any issues in this project. With a wide variety of designs currently already completed it gives the opportunity to evaluate the different approaches that can be used when considering how to design the various aspects of this project.

Some of the projects and products that will be examined were created in some cases 5 years ago. The design they may have chosen could have been limited by the technology available to them at the time. When considering how technology is always rapidly improving it would be a fair assessment to say that this project should be able to improve on many of the older designs just because of the technological advancements that have been made since then.

3.2.1 Existing Projects

One of the projects developed by a University of Central Florida senior design group in the Spring 2007 – Summer 2007 terms, was called "The PerfectSleep System" [30]. The project was built to detect sleep and improve the quality of sleep by controlling the user's external environment. It also would awaken the user at an optimal time functioning as an alarm clock. The idea of controlling the users environment while they are sleeping is something this design doesn't intend to do as a basic requirement with this project since the focus is more toward improving the quality of sleep by providing the user with detailed information regarding their sleep. An aspect of their project that is identical to a design feature that is planned is the alarm clock. The alarm clock has a preset time frame to wake the user when they are in a light stage of sleep, so as to not interfere with their sleep cycle when it is in one of the important stages such as deep or REM sleep. When an alarm clock interrupts deep sleep or REM sleep it can have negative effects throughout the day beyond just interfering with a good night's sleep.

The second project that has some similarities was also developed by a University of Central Florida senior design group in the Spring 2011 – Summer 2011 terms, was called "Comprehensive Health Monitoring System" [31]. The aim of this project was to measure relevant vital signs, store them, and recognize patterns from them to make judgments about a patient's health. This system is relevant to this project because it uses external sensors in a similar way to monitor vital signs. This design doesn't have all of the same sensors but a couple of them are similar, so this would be a good example of how to implement an array of sensors with a microcontroller. The system they use to monitor the user is made of multiple sensors at different locations throughout the user's body. This design is going to attempt to measure the physiological signs of sleep from as few locations as possible.

3.2.2 Existing Products

There are a lot of commercial products available that allows a user to perform self-tracking. These products gather data on various aspects of the user's life such as monitoring how many steps they walk, how many stairs they climbed, and what was the quality of their sleep. Some of the products that have been released over the past couple years are Fitbit, WakeMate, Renew Sleepclock, and Zeo Sleep Manager.

Fitbit is a device that uses a three-dimensional accelerometer and altimeter [32]. It uses these sensors to track steps, distance, calories burned, and stairs climbed. There is also an option to measure how long and how well you sleep at night using this product. One aspect of this product that stands out is the quality of the tools they provide to allow users to visualize their personal data. The users are able to log on to their website to upload data from the device to see trends and the history of their activity, and all the data is displayed in graphs and charts that are easy to understand for anyone using the product. This would be a good model to base some of the software that will be designed in this project.

WakeMate is a wristband that is worn when you sleep that measures body movements [32]. It uses a method called “Actigraphy” to map dips and peaks in your sleep cycle. The wristband can communicate directly with a mobile phone to calculate your idle sleep time that is closest to your alarm setting. This device is similar to what we want to achieve but our design will collect more data on the user to provide a more complete picture of their sleep. This product has a very basic interface developed for the user to view their sleep data, which is expected since it can only track movement while asleep. One of the interesting features of their service that will be similar to a goal of this project is the automatic data upload so that the user wouldn’t have to worry about doing it each morning.

Renew Sleepclock has an interesting approach to measuring sleep that none of the other commercial products that were discovered have [34]. It uses a low-power radio frequency emitter that sits behind the clock’s interface. This has a maximum range of 5 feet; it can track your motion and breathing patterns while you sleep. The device provides information on the quality of sleep along with showing visuals such as graphs of your sleep over various periods of time. While this projects design has a similar goal, it will not use radio frequency to gather the information like this product does. It is a clever approach to monitoring a person while they sleep since some people may find it hard to sleep wearing a device on their body.

Zeo Sleep Manager uses a headband to track your nightly sleep patterns and sends the data wirelessly to a complimenting smartphone application [35]. It graphs the user’s sleep data showing the time spend in light, deep, and REM sleep as a hypnogram. Along with that it also shows the user how long they took to fall asleep. An interesting aspect is the special sleep quality score, unique to this product, used to determine the quality of sleep and compare it to what someone in that age range should have as a score. They have some software tools that allow the user to track different factors that may have impacted their sleep score for that night to help them improve it or just continue to monitor it.

3.3 Communication Technologies

One of the basic requirements of the project is to be able to transmit data wirelessly. A wired connection from the wearable sensors to the base station violates the comfort requirement for this project. While it may be possible to perform the required sleep monitoring and alarm functions with a single wearable device, making wireless communication unnecessary, this does not provide the user with convenient access to their information and does not allow the system to be scalable or modular.

The requirement is for an effective wireless connection at a minimum of five feet from the sleeper’s position. This is to accommodate placing the base station conveniently on a nearby piece of furniture. Other desirable features are low power requirements for the peripheral devices, low interference, ease of use, reliability, and possibly security. Note that wired connections between the wearable peripherals is still considered, the wireless requirement is between the peripherals and the base station.

3.3.1 Bluetooth

Bluetooth is a short-range communications technology standard for exchanging data. It is simple and secure. The key features of Bluetooth are robustness, low cost, and low power.

The idea of Bluetooth technology is that any Bluetooth device in the world can connect to other Bluetooth devices located in the area. When two Bluetooth devices are connected to each other, this is called pairing. Bluetooth has a master-slave structure that is packet based. One master can communicate with up to 7 different slaves in a piconet. A piconet is a network of devices connected in ad hoc using Bluetooth. Each device in a piconet can communicate with up to seven other devices in that piconet and each device can also belong to several piconets simultaneously.

Bluetooth uses radio technology that splits up the data being sent and transmitted into chunks through 79 bands in the range of 2,400 - 2,485 MHz. Interference protection and more efficient transmission can be achieved by splitting the frequency band by 79 parts at 1 MHz intervals.

Bluetooth is a communication protocol that is designed for low power consumption, but with short range. There are three classes to Bluetooth. Each class has a different power consumption and range. Table 3.3.1.1 below shows the differences between each class.

Class	Power Consumption (mW)	Range (m)
Class 1	100	100 (approx. 328 feet)
Class 2	2.5	10 (approx. 32.8 feet)
Class 3	1	1 (approx. 3.28 feet)

Table 3.3.1.1 – Power consumption and range of different Bluetooth classes

From the table above, Class 2 Bluetooth seems like a possible communication candidate for this project. Class 2 only uses 2.5 milliwatts of power and it can connect to another Bluetooth device within 10 meters. Class 1 Bluetooth's power consumption is 40 times more than Class 2 and the range exceeds that required for this project.

Pros:

- Bluetooth technology is cheap.

- Bluetooth is not a line of sight technology. This provides some immunity from objects potentially blocking the communication path, and it comes with ranges of up to 100 meters (for Class 1 devices).
- Bluetooth uses low-powered 2.4 GHZ band for radio communication.
- Since v1.2, Bluetooth avoids interference from other wireless devices adaptively.
- Simple and easy to use: setting up Bluetooth connectivity is automatic.
- Bluetooth can connect up to a maximum of 7 devices within a range of up to 10 meters.

Cons:

- When the range and radio frequency of Bluetooth increases it can be prone to security risks.
- Some Bluetooth only has up to 2.1 MBps data transfer rate.
- When using Bluetooth technology, the connection can sometimes run very slowly or drop periodically.

3.3.2 Wi-Fi

Wi-Fi is the most prominent wireless connectivity technology. It is based on the IEEE 802.11 standards, which detail how to communicate in the 2.4 and 5 GHz radio bands.

A number of encryption protocols exist such as WEP, WPA and WPA2. They have a history of being decrypted using various methods that will not be described in this paper. One of the concerns regarding monitoring the sleeping habits of the user is that someone could use that potentially sensitive information without the consent of the user. Any Wi-Fi modules chosen must therefore support the most up-to-date encryption protocols available.

Pros:

- Global set of standards for connecting computers, mobile phones, and other devices together.
- High throughput.

Cons:

- Power consumption is higher compared to other communication standards.
- Properly configured encryption standards can be breakable.
- Access points on the same channel can prevent right-of-entry to other access points. In high density areas like apartment buildings this can be a problem.

3.3.3 Wired

Wired communication is the transmission of data over a wire-based communication technology. The use of physical wires means that electronic signals are being transmitted over a metal conductor. This is the most dependable way to transmit and receive data. Wired communication is very reliable because it is not affected by wireless signals such as cellular phones or microwaves, especially with proper insulation. Wired is also cheap and has high life expectancy. Below is a list of the pros and cons of wired communication:

Pros:

- Reliable – Wired communication is not affected by other wireless signals like microwaves and cell phones.
- Wires offer very high speed.
- Wires are inexpensive.
- Wired connections have high QoS (Quality of Service).
- A wired connection does not require power to maintain connectivity.

Cons:

- Wired communication is affected by rain, moisture and other weather conditions.
- Length of wire can be limited
- Wired communication can be affected by noise made by magnetics and machinery.

Even though wire is cheap and reliable, connecting the peripherals both to each other and the base station wirelessly is preferred. A sleeping person may become entangled in wires throughout the night and the comfort is expected to be low. Additionally, even well insulated wires will suffer from high noise as a user tosses and turns on top of the wires. Nonetheless, if wearable devices are in close proximity to one another on the body, it will be considered.

3.3.4 Radio Frequency (RF)

Radio frequency is a portion of the electromagnetic spectrum that ranges from 300 kHz to 300 GHz. Radio frequency works by creating electromagnetic waves at a source and being able to pick up the wave at a certain destination. These waves travel through the air at near the speed of light. Many frequency bands are reserved for military, industrial, scientific, and medical use or are otherwise owned and require licensing.

Radio frequencies use that is very low-powered does not require the Federal Communications Commission (FCC) to give any licenses for anyone to use these bands. However, many frequencies are in use and interference is expected. To use RF securely would require the creation of a custom networking protocol for this project. The ease of use may therefore be low. Bluetooth and Wi-Fi are examples of an existing standard using RF that is readily available. Below is a list of pros and cons of radio frequency:

Pros:

- Low power
- Can create custom protocol

- No overhead
- Availability of many band frequencies

Cons:
- Interference on common radio frequencies
- Unsecure
- Creating a custom protocol lowers ease of use

3.3.5 ZigBee

ZigBee is a wireless technology developed for applications that need low cost and low power wireless mesh networks. The ZigBee is based on an IEEE 802.15.4 standard for wireless personal area networks (WPANs). It also operates in unlicensed bands such as 868 MHz, 900 MHz, and 2.4 GHz. For non-commercial use the ZigBee specification is free to the general public. The ZigBee Alliance provides membership, which gives access to unpublished specifications and permission to create products for market use. But the membership in the ZigBee Alliance can cause problems for open source developers because there is an annual fee that conflicts with the GNU General Public License.

ZigBee is mostly used for periodic data transfer or single transmission from a sensor or device. The raw data rate is 250 kbps per channel in the 2.4 GHz band, 40 kbps per channel in the 915 MHz band, and 20 kbps per channel in the 868 MHz band. The data rates are shown below in Table 3.3.5.1.

Bands	Data Rate for each Band
868 MHz	20 kbps
915 MHz	40 kbps
2.4 GHz	250 kbps

Table 3.3.5.1 – Data rate for each frequency band

Depending on the environment, the transmission range for the ZigBee is between 33 and 246 feet (10 and 75 meters). The maximum output power of the radio is around 1 milliwatt (mW). Below is a list of pros and cons for the ZigBee:

Pros:
- Transmission range is between 10 and 75 meters (33 and 246 feet).
- Maximum output power of the radios is around 1 mW.
- Supports a flexible network structure.
- Many manufacturers are integrating MCUs with ZigBee transceivers.

Cons:
- Low data rates

- Poor interoperability

3.3.6 Infrared (IR)

Infrared technology allows devices to communicate via short range wireless signals. Infrared allows digital data to be transferred bi-directionally. Infrared communication uses infrared light to transfer data. There are three common infrared standards. All three types differ in performance. IrDa-SIR has a data rate of 115 kbps, IrDa-MIR has a data rate of 1.15 Mbps, and IrDa-FIR has a data rate of 4 Mbps. Table 3.3.6.1 summarizes the data rates for the different types of infrared.

Infrared Type	Data Rate for each type
IrDA-SIR (slow speed)	115 kbit/s
IrDA-MIR (medium speed)	1.15 Mbit/s
IrDA-FIR (fast speed)	4 Mbit/s

Table 3.3.6.1 – Data rate for each Infrared type

Infrared communication is great for short-range transmission, but is easily obstructed. For infrared to work there must be a direct line of sight between the transmitter and receiver. Below are the pros and cons of infrared communication:

Pros:
- No need for receiver to search for frequencies
- No radio interference
- Low power consumption

Cons:
- Vulnerable to interference like walls and daylight
- Infrared requires a direct line of sight
- Short range

3.3.7 Comparisons between Communication Technologies

Communication is very important for this project. There will be accessories that need to communicate to a docking station. The preferred technology and standard of communication needs to be selected before device exploration is possible. The most suitable technology should possess most of the desired features for transmitting data in this project, offer good performance for the cost, and be compatible with other components of the sleep management system.

Wired and infrared communication will not be compared in this section. For this project, wired and infrared communication will not be considered or used. Even if wired connections are limited to the peripheral devices on the person, it inhibits comfort and limits the modularity and scalability compared to wireless. Infrared communication would not be a good candidate for this project either, because it needs a direct line of sight from the transmitter to the receiver. If the person wearing the sensor (transmitter) happened to sleep on top of the sensor or covered the sensor as is expected with blankets, it would not be able to communicate with the base station (receiver).

3.3.7.1 ZigBee versus Wi-Fi

From the initial research in the ZigBee section, the ZigBee has a maximum output power of 1 mW. Wi-Fi on the other hand has a higher maximum output power. For this project to work, the wireless accessories need to able to stay powered for at least 8 hours. Wi-Fi has a high data rate, but the ZigBee has a data rate of 20-250 kbps. Wi-Fi would be able to send and receive much more data in a short period of time than the ZigBee. They both are able to transmit data from a long range.

3.3.7.2 ZigBee versus Radio Frequency (RF)

For this project, power consumption is very important. Radio Frequency has less power consumption than the ZigBee. Radio Frequency is not secure, but ZigBee is secure. Both Radio Frequency and ZigBee can use the 2.4 GHz band. Radio Frequency would be superior to ZigBee, but is more susceptible to interference, will not offer the same performance versus cost, and has less ease of use when the protocol is designed from scratch. Interference and designing the protocol from scratch translates to poor reliability for RF. ZigBee uses a network structure; it has an error correcting protocol where the generic Radio Frequencies do not. ZigBee is also designed for personal area networks, which is what the sleep management system will essentially be using.

3.3.7.3 Bluetooth versus ZigBee

For this project, Bluetooth is a great candidate for communication. Bluetooth is designed to connect with mobile phones, laptops, and other devices. In this project, connecting to mobile devices that have Android, iOS, or Windows 8 is a desirable feature. Many mobile devices have Bluetooth integrated. The ZigBee on the other hand is supported by very few mobile devices. However, manufactures are integrating the ZigBee into their microcontrollers. Both Bluetooth and the ZigBee are low powered, although Bluetooth power can range from 1 mW to 100 mW depending on the Class. Bluetooth can send and receive more data than the ZigBee.

3.3.7.4 Communication Technology Selection

The main specifications for each communication technology are summarized in Table 3.3.7.4.1 below.

	Bluetooth	Wi-Fi	ZigBee	RF
System Resources	250 KB +	1 MB+	4 KB – 32 KB	N/A
Battery Life (days)	1-7	1-5	100	1-7
Bandwidth (kbps)	720	11,000+	20-250	64-128
Range (meters)	1-100	1-100	1-75	1000
Feature	Cost, Convenience	Speed	Low Power, Cost Effective	No Overhead

Table 3.3.7.4.1 – Comparison of Communication Technology Specifications

Bluetooth is the best candidate for this project. It is low powered, is able to transmit and receive a sufficient amount of data, and low cost. While ZigBee shares many of the same desirable characteristics, Bluetooth enjoys nearly universal device support and interoperability, being integrated in the majority of mobile phones and tablets. It therefore also offers the best ease of use and performance to cost. Wi-Fi is also nearly universally supported, but is both resource and power intensive. The project must ensure that the wearable devices can last through a night's sleep. Additionally, some Bluetooth chips available offer Bluetooth Low Energy and ANT/ANT+, both of which are low power, reliable, and designed for personal wireless sensor networks.

3.4 User Interface

In many embedded applications, user interface designs could be carried out with simple LCDs capable of just printing text in one standard color. However, due to the complexity and amount of data that must be presented intuitively to the user, a simple LCD is not a valid approach for the display. Instead, the user interface needs to portray a seamless, pleasant, and intuitive experience to the user in order to control the system. Currently, the electronics market addresses this feature with touch enabled, multicolored LCD displays.

Some displays have innovative technologies like capacitive touchscreens infused with touch-oriented operating systems that exploit the user's experience with captivating graphical user controls and excellent information presentation methods. In this project, the focus is largely centered on informing the user about his or her sleeping habits and the associated health effects. As a result, the user interface will be imperative to a successful interaction between the system and the user to provide large amounts of information in an intuitive and straightforward manner.

Ideally, information should be collected, processed, and sent to the user interface's host. The host, i.e. a standalone device or a subcomponent of the main processing unit, will present the information to the user including:

- The state of the system
- Previous user settings
- Data previously collected
- Data currently being collected
- Recommendations for a better sleep
- Progress in user's sleep over time

In practice, the user interface should be accessible to a broad range of users. For instance, a user interface hosted by a large device that the user has to physically acquire, such a device resembling an alarm clock, would provide inconveniences by adding to the inventory of the user's possessions. However, if the user interface was implemented with a device that the user already physically owned, such as a smart phone, the user would find it convenient to download an application onto his platform. Of course, in this case, the user's platform would have to interact with the hardware portion of the project bringing about the problem of compatibility.

In essence, creating a user interface will be as simple as creating an application that sends commands from the smart device to the add-on through a Bluetooth or USB connection. This method allows for modularity in the architecture since the user interface can be redesigned at any time without changing the functionality from the embedded system. This approach also creates many exciting choices in the development for the user interface and provides portability to other environments (e.g. Android, iOS, Windows 8). Portability is an extremely important trait because it would mean that the user could use any device that he wished in order to host the application, as long the application was available in the device's environment.

3.4.1 Application Environments - Mobile Operating Systems

Mobile operating systems have grown in popularity ever since more computing power began residing in smaller chipsets. The market conceived numerous operating systems that host a plethora of embedded devices ranging from phones, tablets, TVs, netbooks, industrial consoles, and cars. Below is a brief examination for each embedded operating system with emphasis on the candidacy for GoodKnight's User Interface (UI) application.

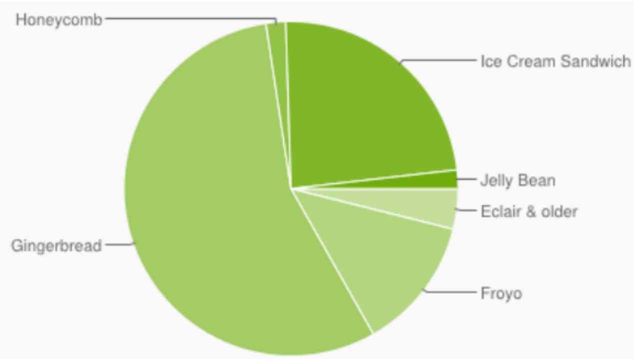
3.4.1.1 Android

Recently, Android has been an extremely popular choice for many people for both entertainment and productivity. More or less, Android's market share is analogous to Windows in the 90s, having a vast number of manufacturers creating ARM-powered devices to host the Android OS. Manufacturers are drawn to the open source nature of the operating system since they can tweak and adapt the operating system to run on their devices at no charge.

As of July 2012, Android holds roughly half of the market share within the mobile operating system market [36]. Naturally, Android is a top choice for the UI environment. Not only is it inexpensive to develop for, but it would also be increasingly practical for the end user to interact with. There are no development costs because Android is an open-source project and it is widely received by open source Integrated Development Environments (IDEs) like Eclipse.

With Android running on a diverse range of devices with varying hardware capabilities, many devices host different Android releases including: Cupcake, Donut, Éclair, Froyo, Gingerbread, Honeycomb, Ice Cream Sandwich, and Jelly Bean. Development should aim for compatibility with as many releases as possible to maximize the user base while still choosing a recent enough release to accommodate the desired feature set. According to the Android Open Source Project authors, the diversity of devices running Android's versions is shown below in Figure 3.4.1.1.1, which is reproduced from work created and shared by the Android Open Source Project and used according to terms described in the Creative Commons 2.5 Attribution License [37].

Version	Codename	API	Distribution
1.5	Cupcake	3	0.1%
1.6	Donut	4	0.4%
2.1	Eclair	7	3.4%
2.2	Froyo	8	12.9%
2.3 - 2.3.2	Gingerbread	9	0.3%
2.3.3 - 2.3.7		10	55.5%
3.1	Honeycomb	12	0.4%
3.2		13	1.5%
4.0.3 - 4.0.4	Ice Cream Sandwich	15	23.7%
4.1	Jelly Bean	16	1.8%



Data collected during a 14-day period ending on October 1, 2012

Figure 3.4.1.1.1 – Prevalence of Android Reproduced from work created and shared by the Android Open Source Project and used according to terms described in the Creative Commons 2.5 Attribution License.

From a development standpoint, Android is so popular that it is extremely easy to find vast amounts of support from online communities. On the contrary, because Android resides on so many embedded devices, providing full-support for most Android devices is nearly impossible. Moreover, since different manufactures tailor Android to run on their devices, it becomes a huge design challenge to predict the behavior of every Android device with the GoodKnight system being an embedded device as well. Device dimensions, speeds, and hardware specifications are so diverse that a direct serial or wired communication between GoodKnight's system and every Android device is impractical.

Android applications are developed mostly in Java. Java is an extremely popular, mature, and well-supported programming language. These applications can be developed with multiple IDEs, but the Android Open Source Project highly encourages the use of Eclipse as the IDE. Lastly, the applications can be easily debugged with a virtual machine simulating an Android device running any Android version.

Pros:

- Main programming language is Java.
- Developing costs are extremely low.
- Learning curve is decent.
- Android framework is vast.
- Popularity means accessibility to large user base.

Cons:

- Because of the vast number of devices supported, there are limitations to hardware/software interactions.

3.4.1.2 Blackberry

Blackberry devices were once amongst the most popular mobile operating systems in the market. After the release of the iPhone and Android devices, Research in Motion (RIM), the proprietor of the Blackberry operating system, has seen a dramatic decline of sales in North America. With decreasing popularity, the availability of Blackberry devices is decreasing as well. However, Blackberry remained a popular choice in South Africa, the United Arab Emirates, and Latin America as the top mobile platform for consumers early in 2012 [38].

RIM provides developers with ease of portability to make Blackberry an attractive platform. Developers can make applications for Blackberry using native C/C++ Software Development Kits (SDKs), Blackberry Android runtime (Java), the traditional Java Blackberry Application Programming Interfaces (APIs), or HTML5 with ActionScript.

Pros:

- Main programming languages are Java and C/C++.
- Developing costs are extremely low.
- Learning curve is decent.

Cons:

- Decreasing popularity and support for the platform.
- Decreasing availably of Blackberry devices in North America.
- Most Blackberry devices do not have touchscreens.
- Largest user base is outside North America.

3.4.1.3 Embedded Linux

Embedded Linux is found every day in many industrial and enterprise systems. It allows for more hardware support and reliability since the operating system is highly customizable. Developers have direct access to the Kernel to write drivers to support their hardware.

This OS comes in many distributions such as Angstrom, Ubuntu, Embedded Debian, and others. Many companies use Embedded Linux to manage their custom in-house infrastructure systems, implement distributed control systems, and application specific purposes. In contrast, commercial operating systems do not allow support for these features.

As a result, Embedded Linux could be a potential candidate for a sleep management system that is built for extra reliability and more functionality. If GoodKnight was an industrial control application used for high-precision and reliability, it could be used in facilities such as hospitals, clinics, and research centers. Therefore, there is little practicality for the end user but it would serve the purpose of presenting the information well.

Pros:

- Main programming languages are C and C++.
- Allows for reliable hardware/software interactions.
- Developing costs are extremely low.

Cons:

- Hardware/software interfacing relies on device drivers.
- Development environment has limitations.
- Learning curve is high.
- Unpopular with the average user.

3.4.1.4 iOS

Since Apple Incorporated introduced the iPhone in 2007, iOS has been an all-time favorite among consumers seeking a powerful and well-designed embedded device. The operating system offers seamless interaction with its hardware and allows excellent interfacing between an embedded system and an iOS application. This environment is a strong candidate for an application seeking to interact with an embedded device.

Unfortunately, development costs are high given the project budget. Apple requires developers to purchase development licenses, permissions, and other Apple devices to develop an iOS application. Moreover, for a developer not familiar with iOS or other Apple products, there is considerable overhead in developing with the new environment.

Pros:

- Mature platform offers a lot of support.
- An excellent development environment is offered.

- Extreme popularity means access to a large user base.

Cons:
- The main programming language is Objective – C.
- Development costs are high.
- Learning curve is high.

3.4.1.5 WebOS
The successor to PalmOS, WebOS, is another environment capable of hosting a GoodKnight application. The operating system is supported by Hewlett-Packard (HP) and runs on many HP devices. However, this mobile operating system is a poor choice because of its decline in support and popularity. On July 1st, 2011, HP released a tablet known as the HP Touchpad. Forty-nine days later, HP announced that the touchpad would be discontinued due to its dismal sales record [39].

Pros:
- Main programming language is C++

Cons:
- Highly unpopular
- Commercially discontinued; open-source project

3.4.1.6 Windows 8
Perhaps the most recent addition to the mobile operating system market is Windows 8. The operating system promises to offer better portability than its competitors. It is to be supported in phones, tablets, and Personal Computers (PCs) alike. Windows 8 not only promises to be fast, user-friendly, and powerful, but it also commits to being a welcoming environment program development.

Windows 8 accomplishes this portability by adding a layer, called the Metro User Interface (UI), to Windows' standard operating system architecture. The Metro UI layer is a touch-friendly interface that employs a series of tiles to launch applications. This Metro UI will also be running natively on tablets, phones, and other embedded devices as the primary user interface. It is this layer that will be the bridge between the different architectures implemented on PCs, tablets, and phones. This layer is so powerful that it prioritizes Windows 8 as a top choice for a development environment.

Pros:
- C# is the main programming language.
- C# is similar to Java; back-end could be ported to Java with minimal efforts.
- .NET framework is extremely sophisticated.
- Arguably uses one of the best IDEs available, i.e. Visual Studio.
- Learning curve is decent.

Cons:

- Platform is not yet mature.
- Development costs are moderate.
- User base not yet well-established.

3.4.1.7 Choosing the Environment

With the exception of Embedded Linux and WebOS, all the development environments are a fair choice for mobile development. Embedded Linux offers a poor tradeoff between performance and development effort since it would take a considerable amount of time trying to develop an efficient system that has seamless hardware and software. Android is derived from the Linux kernel; hence, it implements many features and advantages that Embedded Linux provides.

Concerning the resources available to this project, Android would be a great choice because the development costs are low, the learning curve is decent, and Java is a familiar language. In addition, because of the popularity of the platform, a variety of Android devices are readily available. Physical possession of these devices is essential to addressing development issues.

Windows 8 would be a great choice also. Because of its support for PCs, tablets, and phones, it would be a great development investment. In addition, having reasonable development costs and extremely powerful tools (e.g. Visual Studio, C#, .NET framework) shortens time of development and debugging. Balancing the popularity of Android versus the exceptional Integrated Development Environment (IDE) available Windows 8, both are contenders and a sound choice for hosting a GoodKnight application.

Lastly, iOS is also a good choice to host the application. iOS is an elegant and mature platform with rich development tools and reliable hardware APIs. This closed-source platform eliminates many anomalies that hardware and software interactions bring about. However, the high costs and closed nature of iOS make it a less appealing choice compared to Windows 8 and Android within the budget of this project.

If the project could be implemented with the same codebase for all the top environments (i.e. Android, Windows 8, and iOS), it would lessen a great amount of overhead in trying to port the application from one mobile environment to the other. It would also remove some of the obstacle of learning new environments and it would consolidate support by focusing the development to one codebase. Thankfully, this issue is addressed by a company called Xamarin providing "Mono for Android" and "Monotouch."

3.4.1.8 Mono for Android and MonoTouch

Xamarin, a pioneer in porting the Microsoft .NET framework to non-Microsoft platforms, has created a family of products that allows developers to develop using Microsoft technologies including the C# programming language, .NET framework, XAML, and Visual Studio IDE. Their method includes linking Mono, an open-source implementation of C# for non-Windows based systems, to Android's Java APIs. For example, it allows for the interpretation of Visual Studio compilations to Android Application Package Files (APKs).

Xamarin's approach is very appealing to many developers because of the use of Microsoft technologies. In addition, Xamarin's family of Mono-based products extends the aptitude of the .NET framework by allowing developers to port their applications to iOS and Android platforms from the same code base.

According to Xamarin [40], their product delivers:

- Cross-platform development
- Reusability of existing code
- Visual Studio IDE integration
- Code auto-completion
- Easy installation
- Android/iOS full features

Pros:

- Reuse code base to port Windows application to Android or iOS.
- Allows use of Visual Studio IDE.
- Allows use of the Android SDKs and the iOS SDKs.
- Allows developers to use the virtual machines provided by Android and iOS to run tests.
- Utilizes the .NET framework.
- Does not provide overhead to the application size and speed.
- Relatively inexpensive.

Cons:

- Mono is not always up to date with C#'s features.

3.4.1.9 Summary

Following the current trend of embedded devices, a GoodKnight system resting bed-side with the user could be implemented using a smart device that the user already possesses. Therefore, the interaction between the system and the user could be carried out with an application hosted by the user's device. Several mobile operating systems were examined to determine which platform would benefit the implementation of GoodKnight's user interface.

Android, Windows 8, and iOS are the strongest candidates. Unfortunately, due to the limited budget this project possesses, an iOS application cannot be financially supported. Moreover, with the introduction of the "Mono for Android" framework, a GoodKnight application can be developed for both Android and Windows 8 with minimal costs and overhead. Hereby, an application using this product would be highly advantageous because it make use of the two platforms' key features.

3.4.2 Aesthetics

According to the Merriam-Webster dictionary [41], something that is "aesthetic" is said to be "pleasing in appearance." Within context, a user-interface with good aesthetics is said to be visually appealing and easy-to-use. In fact, a user-interface that portrays good aesthetics could inherently exude a sense of quality to the end-user. For instance, by the same method that a luxury car portrays quality with its glamorous designed body, the same could be said about an application with a captivating and seamless user-interface.

In an essay titled "Interface Realisms: The Interface as Aesthetic Form" by Soren Pold [42], Pold discusses how the user interface is "now a central aesthetic form conveying digital information of all kinds." Further in the writing [42], Pold defines the purpose of the user interface "to represent the data, the dataflow, and data structures of the computer to the human senses, while simultaneously setting up a frame for human input and interaction and translating this input back into the machine." Therefore, according to Pold, the user interface with respect to this project should be representing the data obtained from sensor inputs while remaining attentive to interaction from the user. Moreover, not only should this user interface be a median between the user and the machine, but it should also be the destination for all sorts of digital information related to the project. For example, this project's user interface should portray the machine states, data collected, and current commands received from the user; in addition, it could also implement related data to a healthy sleep routine by presenting data obtained from sources outside of the system including:

- Time of Sunrise
- Current Ambient Temperature
- Current Date
- Current Time
- Share Recent Results via Social Networks
- Longest Continuous Sleep
- Shortest Continuous Sleep
- Coldest Night
- Hottest Night

With respect to Graphical User Interface (GUI) design, perhaps the most obvious way to deliver good aesthetics is through the application's user controls (e.g. buttons, labels, scrollbars), animations, color scheme, and information layout. The problem with achieving great aesthetics is that it requires iterative testing to confirm constancy in the design. However, this problem is addressed in many development environments for popular mobile operating systems like Android and Windows 8. For Windows 8, there exist third-party APIs that facilitate the process of creating consistent visually appealing interfaces with minimal overhead and development time. In fact, many of these APIs are available in the IDEs to facilitate the GUI development.

3.4.2.1 Third Party Windows 8 User Controls

Unlike Android, Windows 8 supports and encourages the use of custom built XAML-based user controls for improved aesthetics within an application. This feature is known as Rapid Application Development (RAD). RAD leverages the capabilities of an application's user interface by allowing modularity and customization of user controls. In this project, because the user interface would rely heavily on data visualization, i.e. how large amounts of collected data is presented to the user, there are numerous third-party Windows 8 user control APIs that provide captivating data visualization.

Graphs are going to be heavily used in the data visualization portion of the project. These graphs might be superimposed to further analyze and compare results from previous system runs. Therefore, it is imperative to compare a few commercial products to facilitate and leverage the development of data presentation within this project.

Telerik: RadControls for Windows 8

Telerik released a user control package shortly after Visual Studio 2012 and Windows 8 beta were released. The controls they have designed are appealing and easy to integrate. Telerik published a demo application on the Windows Store for developers to examine the performance of the controls and their capabilities. Figure 3.4.2.1.1 shows a screenshot of how a RadControl chart looks.

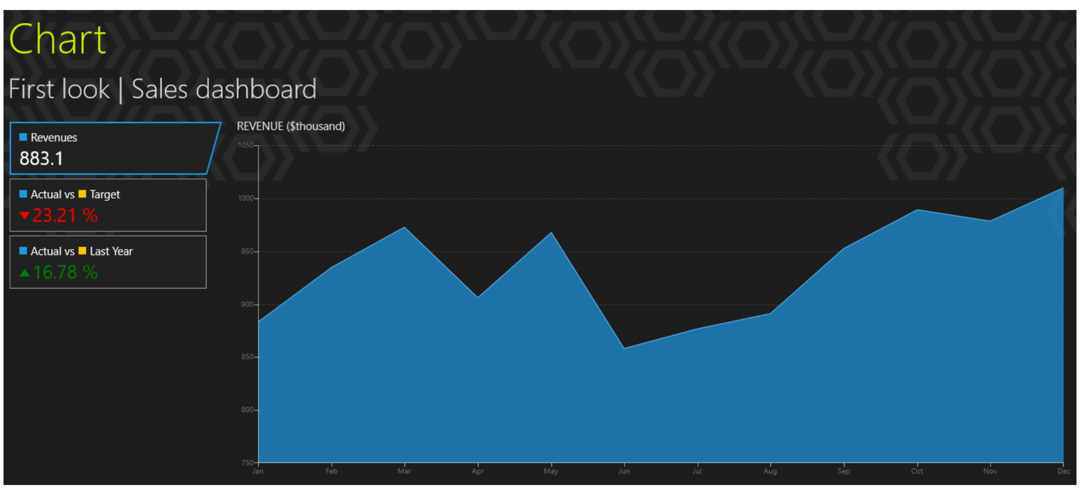


Figure 3.4.2.1.1 – Shows how a Telerik user control chart presents data. Reprinted with permission from Telerik.

ComponentArt: Data Visualization for Visual Studio

ComponentArt offers a very promising package, although it is the most expensive option. This package provides ample support for countless types of data visualization, including charts, grids, navigators, maps, and gauges. ComponentArt's product looks more complete than its competitors. Figure 3.4.2.1.2, shown below, is an example of a chart user control captured from a demo application ComponentArt made available to the public.

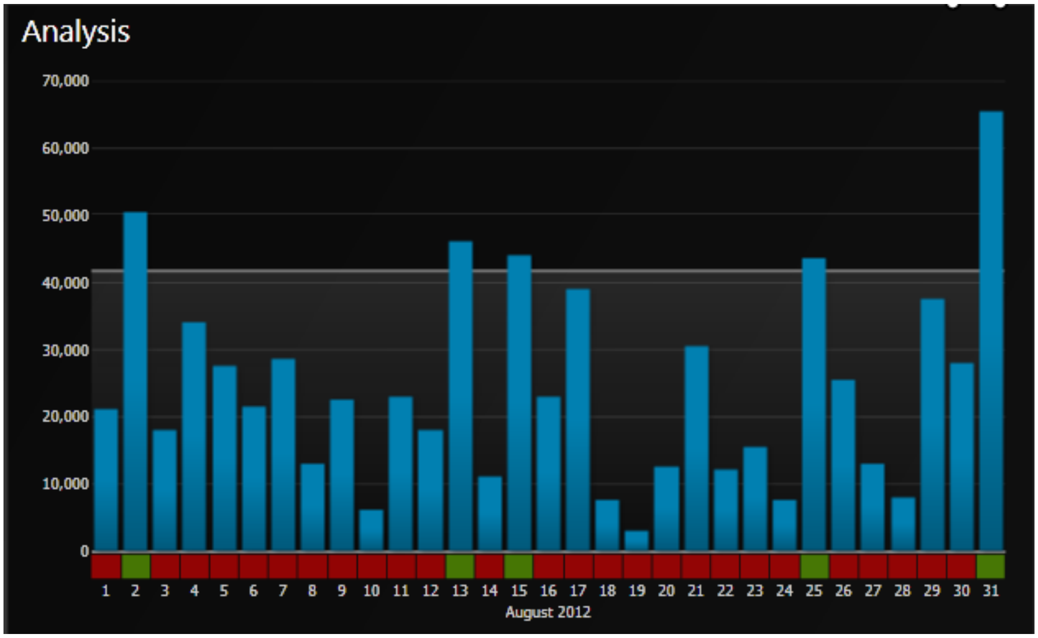


Figure 3.4.2.1.2 – Shows how ComponentArt's user control chart presents data. This graph is portrayed within an analyst context. It was obtained with permission from ComponentArt's published demo application.

Infragistics: WinUI for Windows UI

Although the least complete user control product, it is free of cost since it is a beta release. Examining the demo application that Infragistics created, it will be a promising package once it is complete. However, due to the project timeline, the project cannot afford to undergo interface risks by implementing a beta release. Moreover, if Infragistics halts development of this package, there will be little technical support to aid in the design process. As a result, this package should not be considered unless it exits the beta testing phase. Figure 3.4.2.1.3, shown below, gives an example of the current state of WinUI user control package.

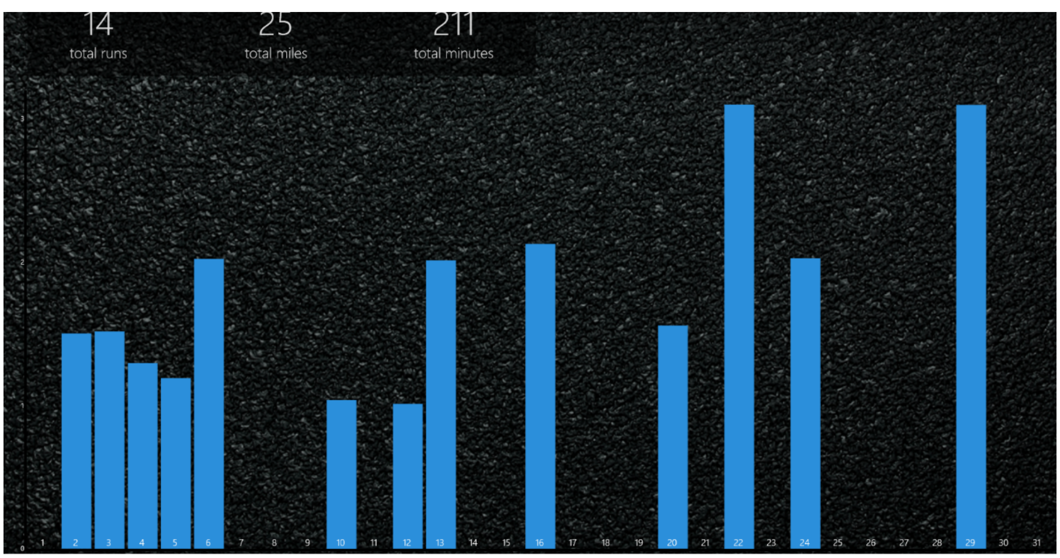


Figure 3.4.2.1.3 – Shows how WinUI's chart user control looks within a demo application Infragistics has published. Reprinted with permission from Infragistics.

Summary
Conclusively, considering the project's budget and deadline, Telerik's RadControls is best choice for this project's data visualization approach. Telerik offers the best price, a good number of user controls, and strong technical support. From using Telerik's demo application, RadControls were found to be relatively easy to use with a small learning curve. Table 3.4.2.1.1 shows a comparison of the specifications for all the user control packages examined.

	Telerik	ComponentArt	Infragistics
Licensing Costs	$199 *as of Dec. 2012	$899+	Free (Beta)
Visual Studio Integration	Yes	Yes	Yes
Product Trial Period	30 days	30 days	-
Demo Applications Available	Yes	Yes	Yes

Table 3.4.2.1.1 – Comparison of the specifications and features for all user-control APIs examined

3.5 Power

When designing the power supply for this project, it will not only need to meet the functional specifications, but will need to meet certain safety standards. All commercial power supplies that can be purchased will already meet safety standards, which will be an advantage when considering supplies to consider for the final design.

The power supplies for the portable devices will especially need to conform to safety standards since the power supply for that device will be designed. It will not be possible to purchase an off-the-shelf power solution for the portable device because of the size limitations. Knowing which safety hazards are common among power supplies would reduce the chance of overlooking them when designing each power supply.

Electric shock is an extremely deadly hazard that has a strong possibility of occurring if precautions are not taken. Electric shock can occur when the electric current finds a passage through the human body. This can have a wide range of effects on the body, ranging from an involuntary movement all the way to death. It is an extreme hazard that will not be taken lightly or overlooked.

Energy hazards may not be that much of an issue with the power supplies that are designed for this project. Generally energy hazards typically occur when the voltage potential is 240 volts or more, in this design the voltage potential will be significantly less but the hazard can still exist. It is still possible to occur at low voltages, which would cause a shock or a burn when metallic objects are worn on the body.

Fire can occur in the power supply design by overloading a component, abnormal operating conditions, or simply from a fault in one of the components. Fire is definitely a possibility when it is designed by someone with a lack of power supply design experience. It will be very challenging to prevent a fire without years of power supply design experience. To account for any possible chance of fire, the power supply will be designed so that the components will be spaced far enough apart to limit the spread of fire between each of the components. The power supplies will be designed using low cost components to reduce the impact of losing a power supply to fire. Paying careful attention to the amount of heat that each component is producing will be necessary in the earlier designs to determine potential trouble areas.

The physical design of the power supply could potentially be a hazard to the user. A poorly designed enclosure for the power supply can cause physical injury. Since a person will be wearing the device, it will need to prevent them from getting injured by moving parts and sharp edges or corners. This is especially important for this project were they will be wearing it during sleep.

All of these safety hazards will be thoroughly researched before implementing the completed power supply design. It will be necessary to test the power supply using industry testing procedures so that no injury will occur to anyone using the device. The designs for the AC and DC power supplies will be subject to change depending on how they perform during the tests, which will identify any issues that need to be improved in the designs.

When laying out a power supply design on a printed circuit board, there are many issues to consider. It will be important to use techniques that minimize the impact of parasitic inductance and capacitance of components. The resistance from the actual traces can also have an impact on power supply regulation and current capacity. To reduce the impact of these factors, it is important to understand how to measure and understand exactly what type of impact they will have.

The resistance of components and of the traces can degrade efficiency, create cooling problems, and may impact regulation. During the design of the power supply, the resistance of the traces will be calculated. Equation 3.5.0.1 shows how the resistance of a conductor can be easily calculated from its resistivity and physical dimensions. The equation states that the longer the path, the more resistance; or that the greater the cross section, the lower the resistance.

$$R = \frac{\rho l}{A}$$

Equation 3.5.0.1 – Trace resistance calculation

Parasitic elements are not only in the form of resistance, they can also add inductors, capacitors, and transformers. Any parasitic element can destroy the performance of a component even before it is mounted. The traces on a printed circuit board add inductance; the inductance for these traces can be calculated with Equation 3.5.0.2. A rule of thumb that is used when short on time is 6 nH/mm or 15 nH/in.

$$Inductance = 0.0002 \times L \left[\ln \frac{2 \times L}{W + H} + 0.2235 \frac{W + H}{L} + 0.5 \right] \mu H/mm$$

Equation 3.5.0.2 – Trace inductance, W is the trace width, L is the trace length, and H is the thickness of the trace

Because of the importance of the power supply, it is important to minimize the effects of parasitic elements. Taking into account how the power supply is affected by these elements will have a role in selecting a location on the printed circuit board. Selecting a location at an early stage of design is important and should be done before adding the other elements. The other elements of the design such as sensors will be built up around the power supply components when designing the printed circuit board. Reducing distance from the main elements will significantly reduce the impact of any parasitic elements and allow the system to operate as designed.

3.5.1 Power Supply Topology

All power supplies have the same basic components to them. Figure 3.5.1.1 is a simple block diagram illustrating these components. The first section is the transformer, which can either step up or step down the input line voltage; it also isolates the power supply from the power line. The rectifier section converts the alternating current input signal into a pulsating direct current. Because the pulsating direct current signal is not desirable, a filter section is used to convert the pulsating direct current to a purer and more desirable form for direct current voltage. The final section is the regulator, which maintains the output of the power supply at a constant level in in spite of large changes in load current or input line voltages.

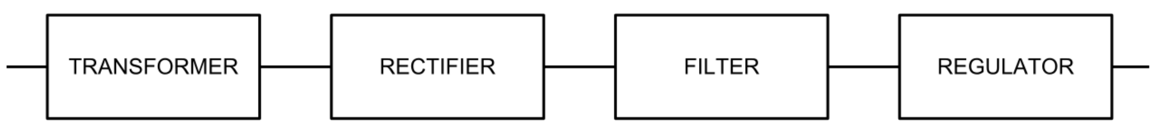


Figure 3.5.1.1 – Basic power supply block diagram

Power supplies have many different types of configurations that can create different voltage and current waveforms. Selecting the correct topology for the power supply will be important for creating an efficient design. It is still possible to achieve results using a topology that is not used for a specific design, but it requires more work to get it to function according to specifications.

The AC to DC power supply will be designed using the flyback topology. This topology was selected because it is an isolated design. All isolated designs have the advantage of being safe, because the circuits are connected with a transformer that uses a magnetic field. An isolated design can also step down the voltage level using the transformer.

The DC to DC power supply will be designed using the boost topology. This topology was selected because the input voltage is lower than the output so it will need to be increased to meet the specifications. It may also be advantageous to have an isolated design for safety reasons since this device will be connected to a person. When designing the boost circuitry, adding in a transformer to provide isolation will be considered even if it increases the cost since safety is a higher priority.

Both designs will need to focus on a small footprint, low cost, and efficiency. The DC to DC power supply will have efficiency and a small footprint as the main priority, with cost being less of a concern. This is because the size of the power supply will be limited by the size of the portable device. The AC to DC supply will focus on having as low a cost as possible, the size and efficiency are not a concern but are a plus. An off the shelf option would be the best solution for the AC to DC power supply given the low cost priority, but it is still possible to create a design that can offer a cheaper solution.

3.5.2 AC Power

The base station for the device will need to be powered from a standard outlet. It will require an AC to DC power supply that can deliver 5 volts and 1 amp. It is possible to either purchase a device from a retailer or design a device to perform this function.

A design for the power supply was created using Texas Instruments WEBENCH® Designer. This tool will create a basic power supply design based on the requirements supplied. The created design can then be adjusted to gain performance and substitute in parts that are available for the design. Figure 3.5.2.1 is the schematic that was created that uses the flyback topology. The power supply design parameters gave a 5% tolerance on the input voltage, a range of 115 volts – 125 volts, with an output of 5 volts and 1 amp. Figure 3.5.2.2 is a graph of the efficiency for the expected voltage and the minimum and maximum voltage values. Some additional graphs were produced for the design and are shown in Figure 3.5.2.3 through Figure 3.5.2.5.

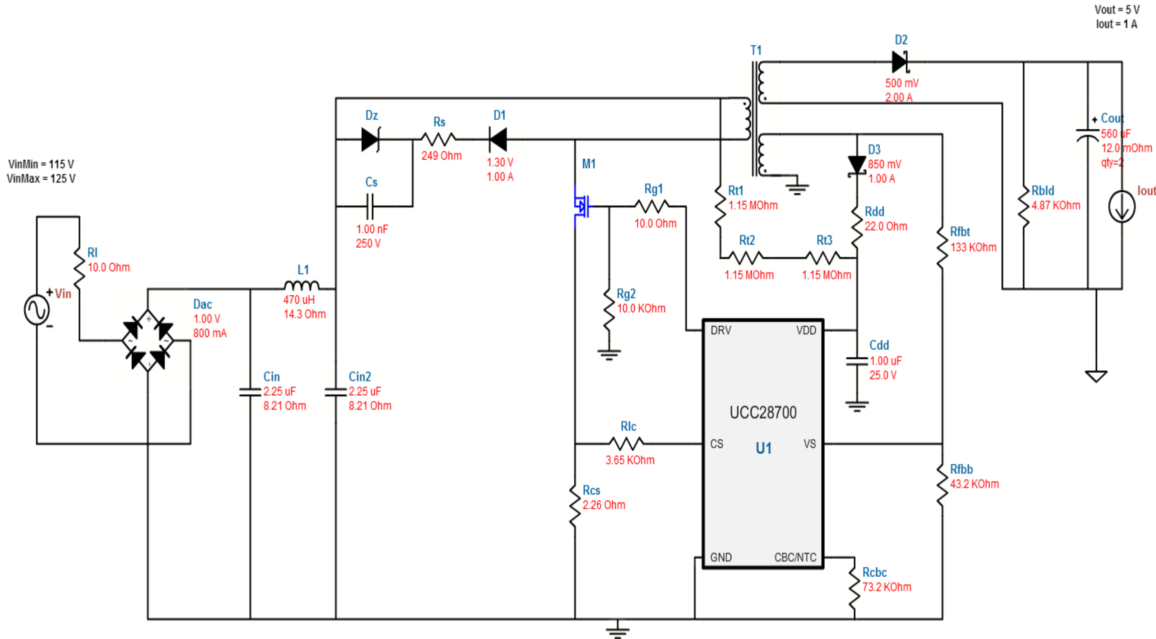


Figure 3.5.2.1 – Circuit diagram created using Texas Instruments WEBENCH® Designer

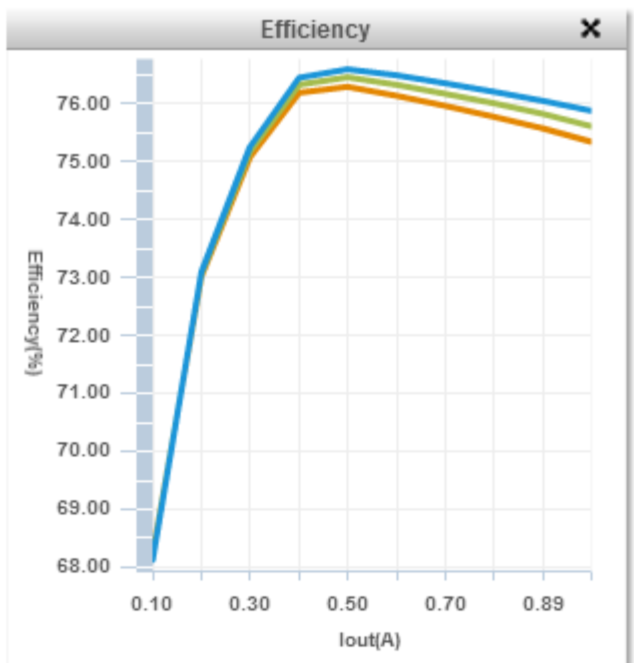


Figure 3.5.2.2 – Efficiency graph, the orange line represents Vin = 115.0V, the green line represents Vin = 120.0V, and the blue line represents Vin = 125.0V, created using Texas Instruments WEBENCH® Designer

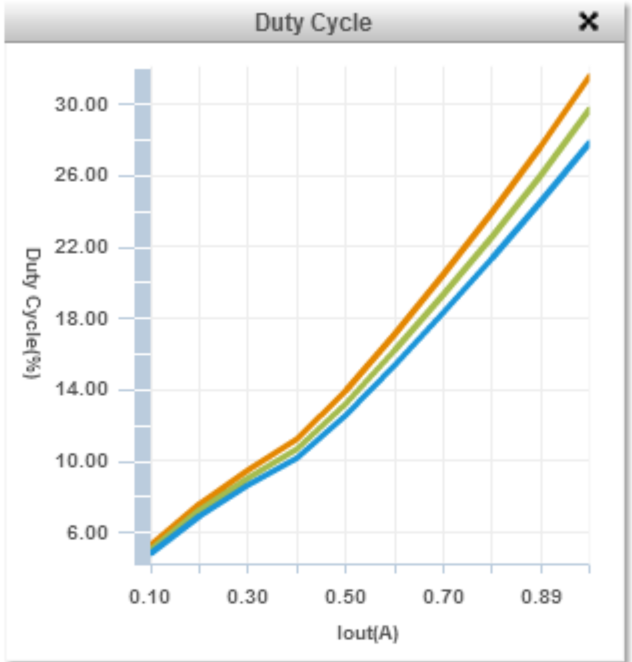


Figure 3.5.2.3 – Duty cycle graph, the orange line represents Vin = 115.0V, the green line represents Vin = 120.0V, and the blue line represents Vin = 125.0V, created using Texas Instruments WEBENCH® Designer

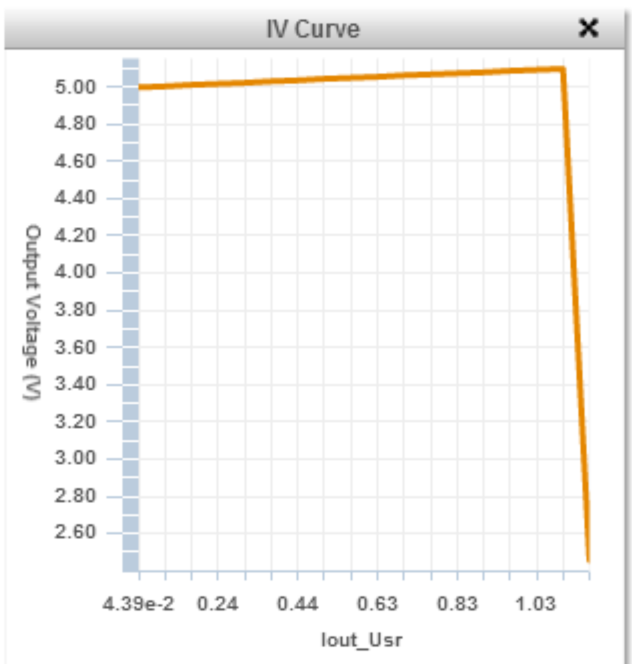


Figure 3.5.2.4 – IV Chart created using Texas Instruments WEBENCH® Designer

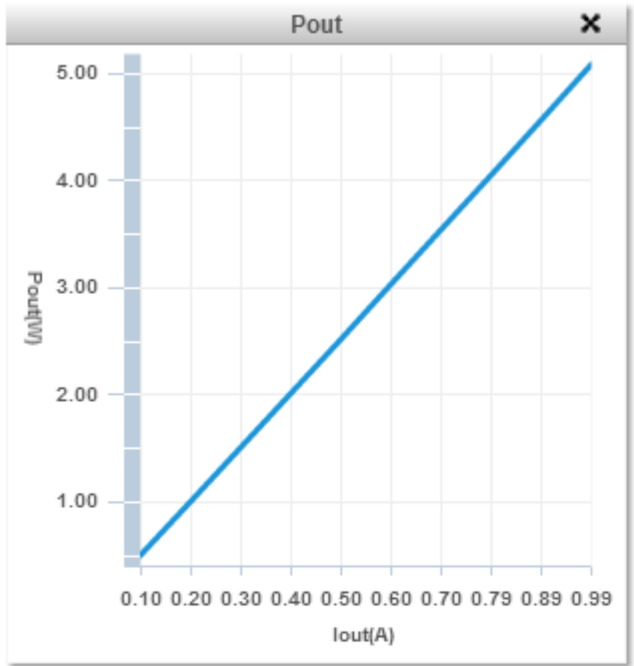


Figure 3.5.2.5 – Graph of power created using Texas Instruments WEBENCH® Designer

This design provides information on how the power supply will behave over a range of different conditions. In most cases the commercial products provide almost no information regarding how the power supply will behave in any condition other than the ideal case. It is important to know how a slight variation in input voltage will affect the output of the power supply, which is definitely a benefit to designing a power supply from scratch.

Other than designing the power supply, there is the option of buying a commercial power supply. The advantage of the commercial power supply is that it will save time, money, and will be more reliable in regards to safety. The power supplies that will be considered will need to have an output of 5 volts and 1 amp. They should also be relatively easy to integrate into the design, which means the output should be ready to supply the microcontroller or any other device that requires power.

Wall Adapter Power Supply - 5VDC 1A *by NLPOWER-CN*
This power supply has a center-positive 5.5x2.1mm barrel connector. This power supply will be considered because it provides a detailed datasheet. The datasheet provides a wide range of data regarding the operation of the unit and the safety precautions built into the device. This device offers short circuit protection, over power protection, and over voltage protection. To allow the base station to function with this supply, an adapter will need to be added to the design that accepts the barrel connector.

Product Information:

- Efficiency: 70%

- Input voltage range: 90 VAC – 264 VAC, 50/60Hz
- Power: 5 W
- Output current: 0.0 A – 1.0 A
- Line regulation: ± 1%
- Load regulation: ± 5%
- Operating temperature: 5°C to 40°C

Price: $5.95 *(for a quantity of 1)*

Wall Charger - 5V USB (1A)
This power supply has a USB ‘A’ connector for the output. By having an adapter that accepts USB cables this supply allows for the reuse of the USB cables that are provided with experimentation boards. Powering the microcontrollers through USB has the advantage of not needing to modify the board schematic file to accommodate a different charging method. The wall charger does not provide any datasheet so the operating information is unknown other than indicating that it can output 5 volts and 1 amp. The actual device has a sticker indicating that is certified by the Underwriter Laboratories which is a trusted source to verify that is has undergone product safety testing.

Price: $3.95 *(for a quantity of 1)*

3.5.3 DC Power

The power supply for the portable devices will be a DC to DC power supply with a battery as the source. To power the device for an extended period of time, the battery that will be selected needs to have a significant amount of charge.

A lithium-ion battery is an ideal source for this power supply. Lithium-ion batteries are used in devices such as cell phones, which demonstrate how long a single charge can last. Because the portable device will be designed to operate with low power it should extend the time the device can function on a single charge.

Each lithium-ion battery comes equipped with circuitry that prevents it from being drained completely. This circuitry is designed to protect the user from discharging the battery too fast, which can cause it to explode. Not only does the circuitry protect the battery from discharging too quickly, it prevents the battery from being drained completely. It is important when buying the battery to consider that the value listed for total milliampere-hours (mAh) is not the amount that is actually usable. Some calculations will need to be made to determine the amount of mAh that would be acceptable taking into consideration that possibly 30 percent of the rated mAh cannot be used.

It is important to properly care for the battery to reduce the risk of a fire or explosion. One important way to do this is to never drain the battery lower than 80 percent, these batteries are not designed to drain completely.

Selecting a battery to meet the design requirements of the project is not a simple task. The battery should have a small overall size that conforms to the small shape of the portable device. Limiting the size of the battery will limit the amount of mAh that are available, so a good ratio will have to be reached to meet the demands of the design.

Polymer Lithium-Ion Battery – 850 mAh
by Unionfortune
The polymer lithium-ion battery offers the highest energy density for batteries currently in production, which allows for a smaller size while maintaining a large amount of milliamp hours. The construction of a lithium polymer battery causes a reduction in the discharge and charging rates compared to a normal lithium-ion battery. Because of how this battery will be used, the life expectance of the battery should extend well beyond the basic requirement of a full night. Using the battery in this manner should also increase the life span, since it will not be pushed to its limits constantly. Some safety features are listed in the batteries specification sheet, including a built-in protection against overvoltage, overcurrent, and minimum voltage.

Product information:

- Nominal capacity: 860 mAh
- Nominal voltage: 3.7 V
- Charge cut-off voltage: 4.20 ± 0.03 V
- Cell voltage: 3.7 – 3.9 V
- Standard discharge current: 0.2 CA
- Max discharge current: 2.0 CA
- Standard charge current: 0.2 CA
- Max charge current: 2.0 CA
- Weight: 15 g

Price: $8.95 *(for a quantity of 1)*

This battery will require special type of charging circuit, which is referred to as LiPo charger. This charger will provide a constant current until the cell reaches 4.2 V, and once this occurs the charger will gradually reduce the charge current while holding the cell voltage at a constant 4.2 V. The battery is considered to be fully charged when the charge current drops to a small percentage of the initial charge rate.

A commercial charging circuit will need to be purchased to safely charge the battery during the prototyping phase of the design. Selecting a charger that provides CadSoft EAGLE files would be the best choice for this design. This is because the charger that is selected for prototyping may not conform to the final design of the portable device. It may be necessary to integrate the charger onto the printed circuit board with the other elements, to create a more compact device.

LiPo Charger Basic - Micro-USB
by Microchip
A simple charger for a polymer lithium ion battery. This charger will be able to charge a cell at a rate of 500 mA per hour. There are CadSoft EAGLE files and schematics available with this charger so that if needed it can be incorporated into the printed circuit board. It may be possible to mount this onto the wearable device's printed circuit board using the preexisting mounting hole that is on the charger's board. It will be mounted if the dimensions of the charger are similar to those of the portable device.

Product information:

• Programmable charge current:	15 mA – 500 mA
• Temperature range:	-40°C to +85°C
• Selectable preconditioning:	10%, 20%, 40%, or Disable
• Selectable end-of-charge control:	5%, 7.5%, 10%, or 20%
• Automatic power down	
• Thermal regulation	
• Four voltage regulation options:	4.20 V, 4.35 V, 4.40 V, 4.50 V

Price: $9.95 *(for a quantity of 1)*

The DC to DC power supply design will need to focus on efficiency to meet the design specifications. There are a lot of different variations of power supply topologies that can be used to create an efficient design.

The design for this power supply was created using Texas Instruments WEBENCH® Designer. Given the operating conditions of the MSP430 and the sensors that will need to be powered from this supply, the desired output will be 3.3 volts and 500 milliamps. The MSP430 is capable of running on less voltage and current but the sensors require more to operate. Figure 3.5.3.1 is the circuit that was designed according to the specifications that are required to supply the microcontroller and circuits.

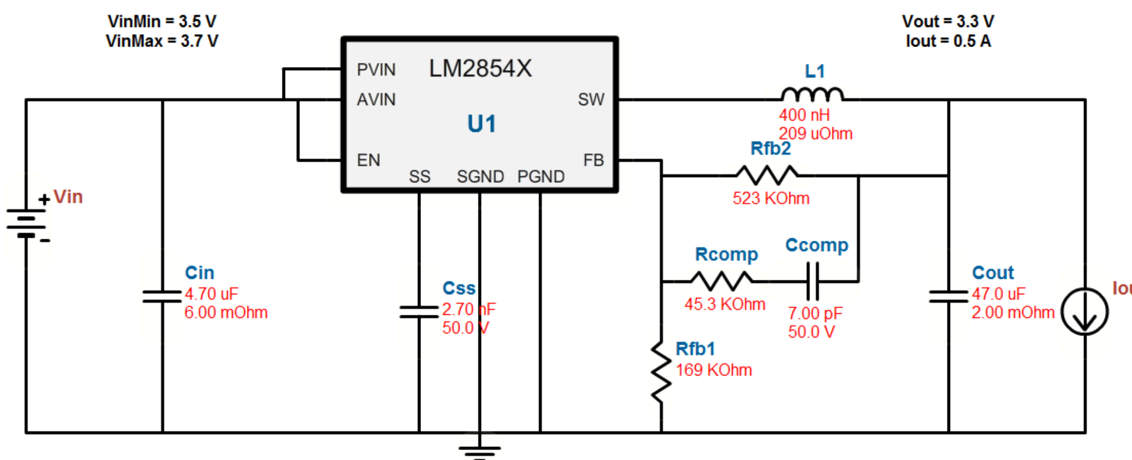


Figure 3.5.3.1 – Circuit diagram created using Texas Instruments WEBENCH® Designer

A variety of simulations were performed on this circuit to determine how it will perform under different operating conditions. Figure 3.5.3.2 shows the efficiency of the design while subject to different input voltages. It clearly shows that this design has a high efficiency for the designed operating conditions. Figure 3.5.3.3 graphically displays the duty cycle percent compared to the output current, the values displayed are what is expected for this particular design. The power output of this design is very low which will extend the life of the battery, which can be viewed in Figure 3.5.3.4.

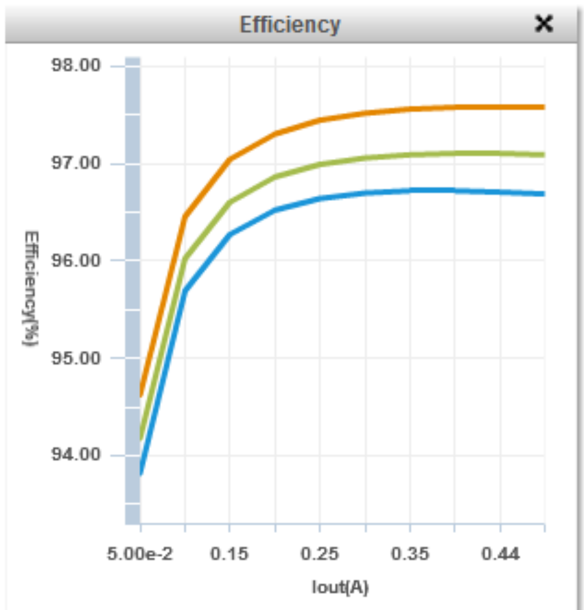


Figure 3.5.3.2 – Efficiency graph, the orange line represents Vin = 3.5V, the green line represents Vin = 3.6V, and the blue line represents Vin = 3.7V, created using Texas Instruments WEBENCH® Designer

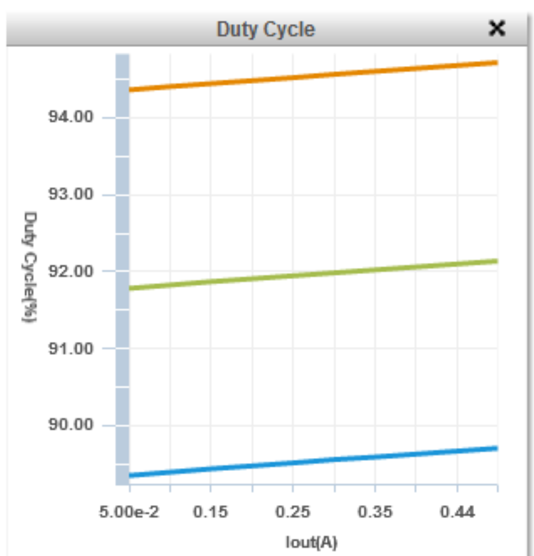


Figure 3.5.3.3 – Duty cycle graph, the orange line represents Vin = 3.5V, the green line represents Vin = 3.6V, and the blue line represents Vin = 3.7V, created using Texas Instruments WEBENCH® Designer

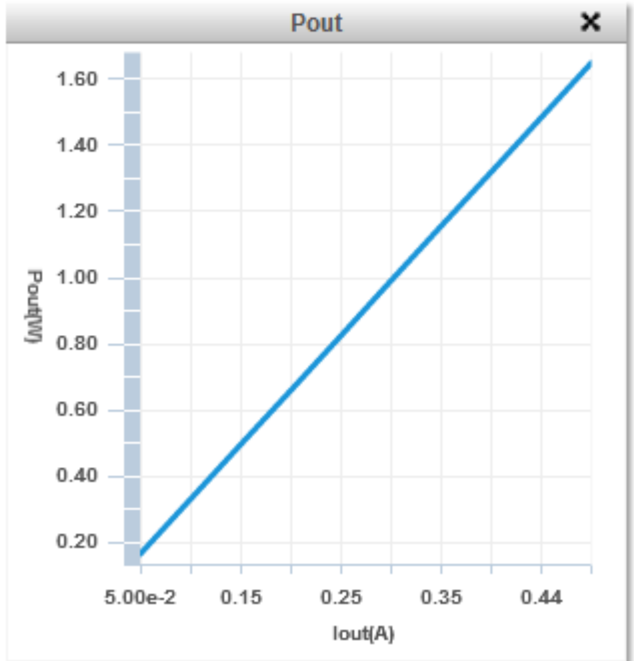


Figure 3.5.3.4 – Power out graph, created using Texas Instruments WEBENCH® Designer

The cost of materials to create this power supply design will be $2.65 in just parts alone. This cost will rise when a printed circuit board is ordered and populated. Ordering parts from the same website will reduce the cost of shipping, which normally tends to be significantly more than the price of the actual parts. When prototyping this design, it will be possible to get a sample of the integrated circuit that is used and all the other parts can be acquired for relatively low cost.

Part	Manufacturer	Part Number	Quantity	Price	Attribute 1 Name	Attribute 1 Value	Attribute 2 Name	Attribute 2 Value	Attribute 3 Name	Attribute 3 Value	Footprint
Ccomp	Yageo America	CC0805DRNP09BN7R0	1	$0.01	Cap	7pF	ESR	0Ohm	VDC	50V	805
Cin	Kemet	C0603C475K9PACTU	1	$0.02	Cap	4.7uF	ESR	6mOhm	VDC	6.3V	603
Cout	TDK	C3216X5R0J476M	1	$0.21	Cap	47uF	ESR	2mOhm	VDC	6.3V	1206
Css	Yageo America	CC0805KRX7R9BB272	1	$0.01	Cap	2.7nF	ESR	0Ohm	VDC	50V	805
L1	Coilcraft	SLC7530D-101MLB	1	$0.51	L	400nH	DCR	209uOhm	IDC	8A	SLC7530D
Rcomp	Vishay-Dale	CRCW080545K3FKEA	1	$0.01	Resistance	45.3KOhm	Tolerance	1%	Power	0.125W	805
Rfb1	Vishay-Dale	CRCW0805169KFKEA	1	$0.01	Resistance	169KOhm	Tolerance	1%	Power	0.125W	805
Rfb2	Vishay-Dale	CRCW0805523KFKEA	1	$0.01	Resistance	523KOhm	Tolerance	1%	Power	0.125W	805
U1	Texas Instruments	LM2854MH-1000/NOPB	1	$2.10							MXA16A

Figure 3.5.3.4 – Bill of materials for DC power supply, excel chart created using Texas Instruments WEBENCH® Designer

Another simulation of this circuit was performed to determine how it will perform at different frequencies. Figure 3.5.3.6 is a bode plot that has both the phase and the magnitude displayed. It is very informative to know how the circuit will perform under the operating conditions, which should be taken into account when the final design is selected.

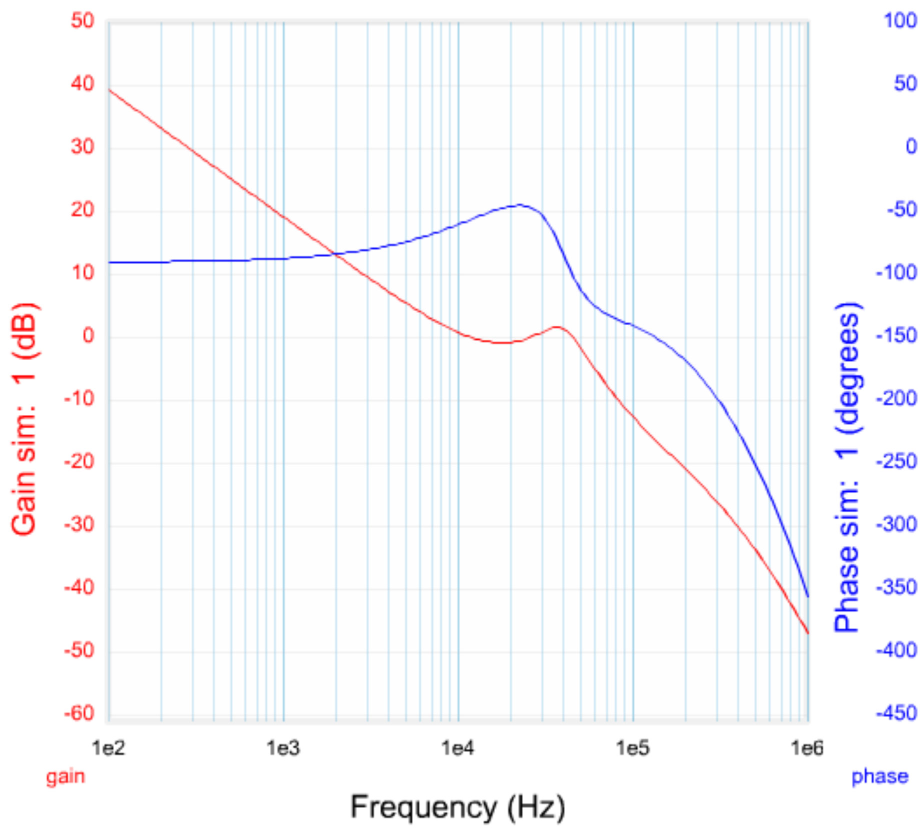


Figure 3.5.3.6 – Bode plot of gain and phase, created using Texas Instruments WEBENCH® Designer

3.6 Device Exploration

3.6.1 Microcontrollers

The selection of the microcontroller is critical to the success of the design. Each sensor will be controlled through the microcontroller and the power consumption of the overall system will be dictated by the microcontroller.

It is extremely important to select a microcontroller that can manage the power consumption of the portable devices to meet the design requirements. Not only will it need to meet the design requirements concerning power but it will also need to perform its main function. This is why a good balance between performance and power consumption will be necessary when selecting which microcontroller will be best for each particular function of the design.

3.6.1.1 Peripheral MCU

The peripheral microcontroller will be incorporated in the wireless device worn by the user. It will need to be powered for a long period of time. Thus, the highest priority for this microcontroller will be power consumption.

The peripheral microcontroller features for consideration are (highest priority =1, low priority=5):

1. Power Consumption
2. CPU Frequency
3. Flash Memory
4. Temperature
5. ADC Sample Rate

While ADC sample rate is important, very few signals from the body measured during sleep are above a few Hz. It is generally expected that most modern microcontrollers will be able to accommodate the ADC requirements of this project in terms of sampling rate. The overall number of general purpose input/output pins (GPIO) and how many are ADCs is a factor for consideration.

Evaluation boards are considered a plus because it simplifies testing the circuits used in this project. If a development board is successful in implementing the desired functions of this project, the associated microcontroller and circuits will then be designed as a PCB for the prototype. This does not mean microcontrollers that do not offer a development board are not worth consideration, however.

Atmel Atmega328 (Arduino Development Board)
The Atmel Atmega328 is an 8-bit RISC microcontroller. It has a max operating frequency of 20 MHz, 32 kB of flash memory that has read-while-write capabilities, 1 kB of EEPROM, 2 kB of SRAM, 32 general purpose working registers, and 23 general purpose I/O pins. This microcontroller has 1 analog comparator and 8 analog-to-digital channels. The ADC speed is about 15 ksps. The Atmega328 has a throughput of 1 MIPS per MHz, this means that it can get up to 20 MIPS at 20 MHz. At 20 MHz the Atmega328 operates at 4.5 to 5.5 volts. In active mode the Atmega328 uses 0.55 μA at 2 volts, in the idle mode it uses 0.9 μA at 1.8 volts, and in the off mode it uses 15 μA at 3 volts.

The Atmega328 is capable of entering into six different sleep modes: idle, ADC noise reduction, power-save, power-down, standby, and extended standby. These six sleep modes could be beneficial when trying to reduce power consumption. Figure 3.6.1.1.1 below shows the pinout for the Atmega328 thin quad flat package (TQFP), reprinted with permission from Atmel.

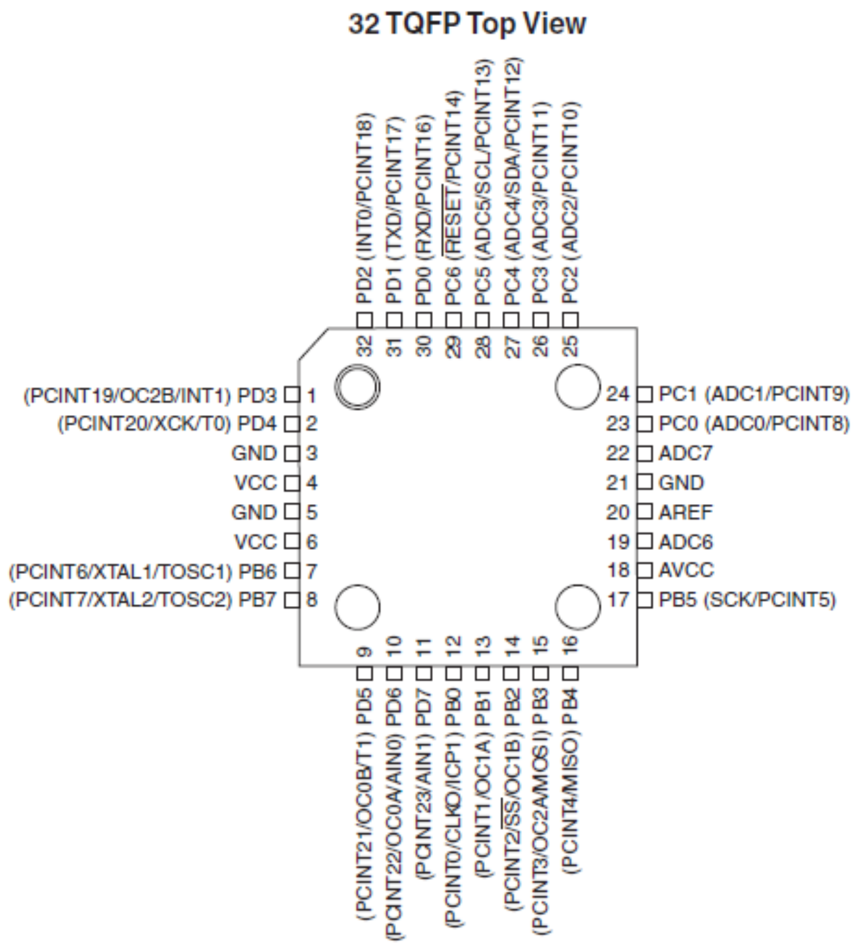


Figure 3.6.1.1.1 – Pinout for the Atmel Atmega328. Reprinted with permission from Atmel.

TI MSP430G2553 (Launchpad)

The Texas Instruments MSP430G2553 is a 16-bit microcontroller with a max operating frequency of 16 MHz. The MSP430G3553 has 16 kB of flash memory, 512 bytes of SRAM, and 24 general purpose I/O pins. This microcontroller has 8 analog-to-digital channels. The ADC speed is 200 ksps. The MSP430 operates at 1.8 to 3.6 volts. One of the key features of this microcontroller is the low power consumption. In active mode the MSP430 uses 230 μA/MHz at 2 volts, in standby mode it uses 0.5 μA at 2.2 volts, and in off mode it uses 0.1 μA.

This particular microcontroller from Texas Instruments has 5 lower power modes that are optimized to extend battery life in portable applications. The digital controlled oscillator lets the MSP430 wake up from low power mode to active mode in less than 1 μs. Newer versions offer ferroelectric RAM (FRAM), which offers even faster write speeds and lower power usage. Figure 3.6.1.1.2 below shows the pinout for the MSP430G2553, reproduced without alteration as allowed by Texas Instruments.

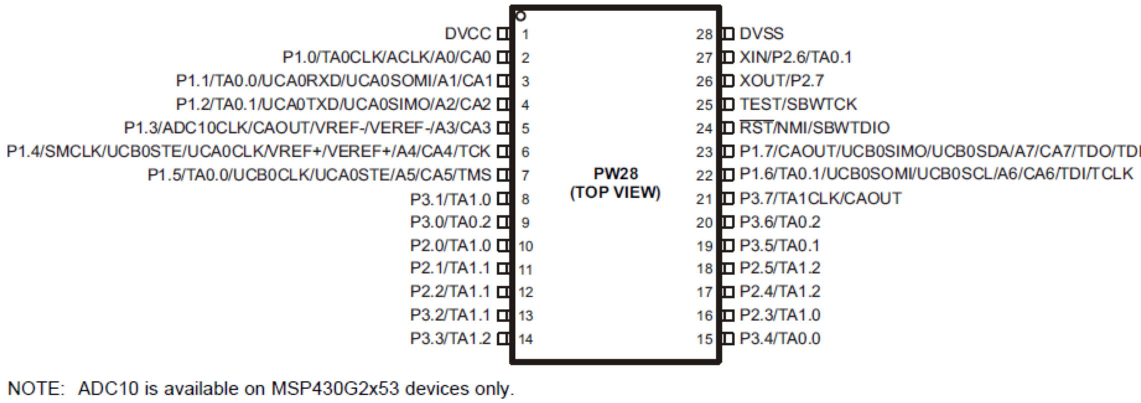


Figure 3.6.1.1.2 – Pinout of the TI MSP430G2553. Reproduced without alteration as allowed by Texas Instruments.

Microchip PIC16F720

The Microchip PIC16F720 is an 8-bit microcontroller with a max operating frequency of 16 MHz. The PIC16F720 has 3.5 kB of flash memory, 128 bytes of SRAM, and 18 general purpose I/O pins. This microcontroller has 12 analog-to-digital channels. The PIC16F720 operates at 1.8 to 5.5 volts. It has low power consumption. In active mode the PIC16F720 uses 134 µA/MHz at 1.8 volts. In standby mode it uses 8 µA at 1.8 volts.

Figure 3.6.1.1.3 below shows the quad-flat no-leads package of the PIC16F720, permitted under fair use by Microchip.

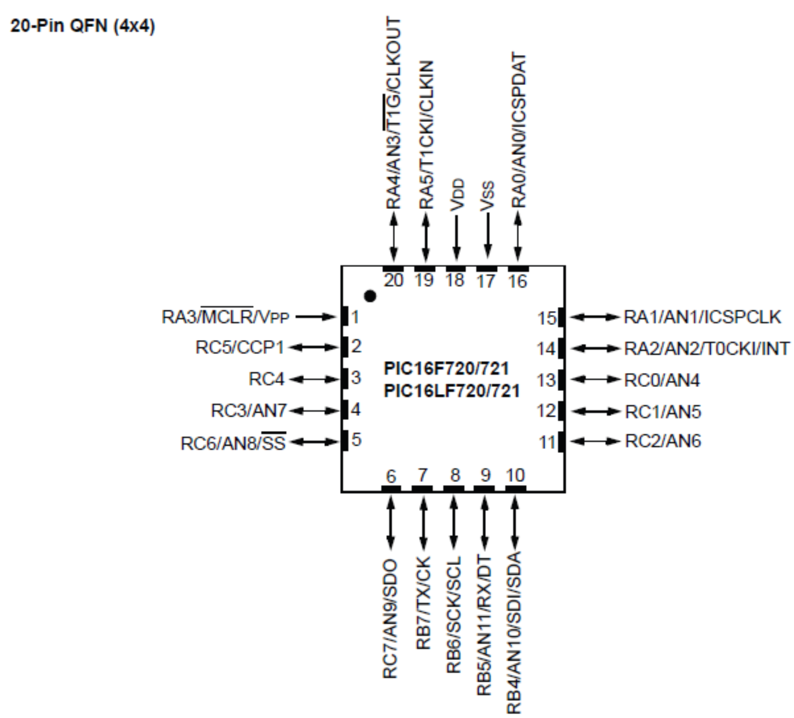


Figure 3.6.1.1.3 – Pin out of the Microchip PIC16F720. Permitted under fair use by Microchip.

The features of each microcontroller considered for the wearable device are summarized in Table 3.6.1.1.1 below.

	Atmega328	TI MSP430G2553	PIC16F720
Max Frequency	20 MHz	16 MHz	16 MHz
Flash	32 Kbytes	16 Kbytes	3.5 Kbytes
Data Unit Size	8 bits	16 bits	8 bit
SRAM	2 Kbytes	512 Bytes	128 Bytes
ADC Channels	8	8	12
ADC Sample Rate	15 ksps	200 ksps	n/a
Temperature	-40 – 85 ºc	-40 – 85 ºc	-40 – 125 ºc
Active Power Consumption	2v, 550μa	2.2v, 230μa	1.8v, 134μa
Idle Power Consumption	1.8v, 0.9μa	2.2v, 0.5μa	1.8v, 8μa

Table 3.6.1.1.1 – Comparisons of the peripheral microcontrollers

The Atmega328 uses the most power, but offers the most memory and has the fastest CPU. While the PIC16F720 has the lowest active power consumption, the MSP430 also has excellent active power consumption and much lower idle power. The PIC16F720 has too little flash memory for consideration. The MSP430 has the most well-rounded feature set for this application and will be used in the wearable devices for this project.

3.6.1.2 Base Station MCU

The base station microcontroller is the central component of this project. It will interpret sensor data sent from the peripherals to determine the user's stage of sleep and make decisions on when to wake the user. It must also be sufficiently powerful to perform some analytics of the user's data.

In order for this microcontroller to do precision arithmetic, it will need a Floating Point Unit (FPU). A Floating Point Unit is designed to carry out operations on floating points. Some basic operations are addition, subtraction, multiplication, division, and square root. Some processors can even do exponential or trigonometric calculations. But many older designs do not have hardware support for floating point calculations. The base station microcontroller will need different features than the peripheral microcontroller.

The base station microcontroller features for consideration are (highest priority =1, low priority=5):

1. Floating Point Unit
2. CPU Frequency
3. Flash Memory

4. SRAM
5. ADC Sample Rate

Microchip PIC32MX320F128H
The Microchip PIC32MX320F128H is a 32-bit microcontroller with a max operating frequency of 80 MHz. The PIC32MX320F128H has 128 kB of flash memory, 16 kB of SRAM, and 53 general purpose I/O pins. This microcontroller has 16 analog-to-digital channels. The ADC speed is 1000 ksps. The PIC32 operates at 2.3 to 3.6 volts. In active mode the PIC32 uses 75 mA at 2.3 volts and 80 MHz, in idle mode it uses 5 mA at 2.3 volts, and in off mode it uses 30 μA at 2.3 volts.

The pinout of the PIC32MX320F128H is shown below in Figure 3.6.1.2.1, permitted under fair use by Microchip.

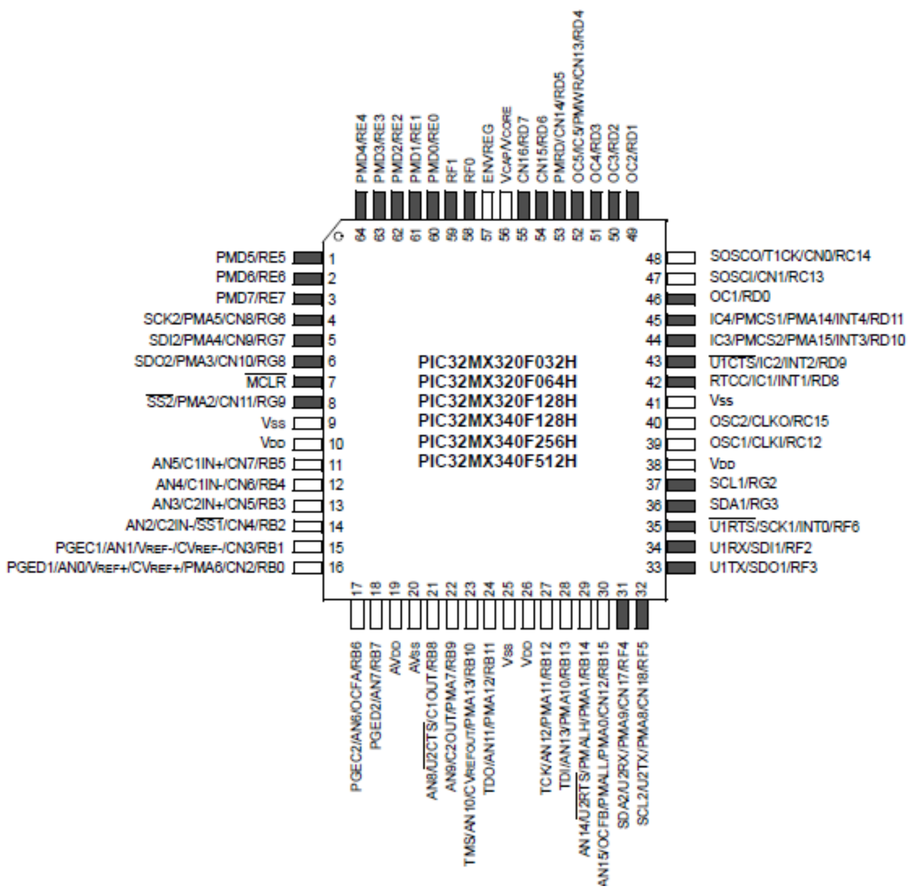


Figure 3.6.1.2.1 – Pinout of the Microchip PIC32MX320F128H. Permitted under fair use by Microchip.

Stellaris LM4F120H5QR
The Texas Instruments Stellaris ARM Cortex LM4F120H5QR is a 32-bit microcontroller with a max operating frequency of 80 MHz. The LM4F120H5QR has 256 kB of flash memory, 32 kB of SRAM, and 43 general purpose I/O pins with programmable control for GPIO interrupts and pad configuration. This microcontroller has 12 analog-to-digital channels. The ADC speed is about

1,000,000 samples per second. The LM4F120H5QR operates at 2.97 to 3.63 volts. In active mode the LM4F120H5QR uses 50 mA at 3.3 volts and in idle mode it uses 12 mA at 3.3 volts.

This microcontroller has a FPU (Floating point unit). The Floating point unit fully supports single-precision add, subtract, multiply, divide, multiply, and square root operations. There are 32-bit instructions for single-precision (C float) data-processing operations. It also has combined multiply and accumulate instructions for better precision.

The pinout for the Stellaris is shown below in Figure 3.6.1.2.2, reproduced without alteration as allowed by Texas Instruments.

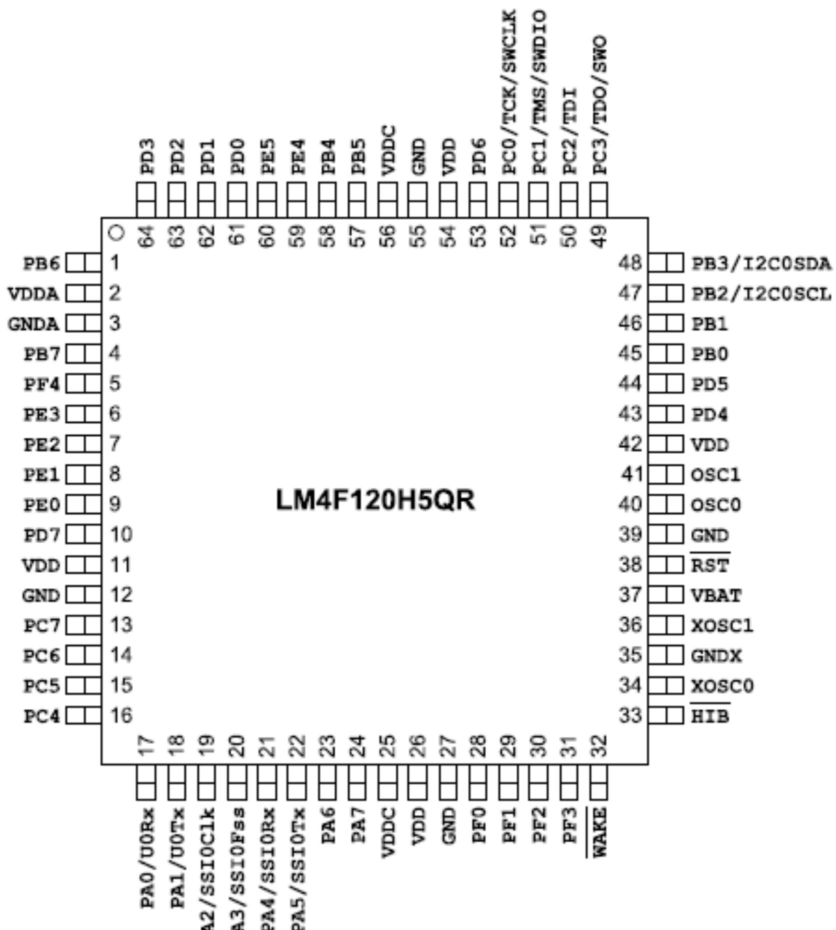


Figure 3.6.1.2.2 – Pinout of the Stellaris LM4F120H5QR. Reproduced without alteration as allowed by Texas Instruments.

TI TMS320F28027

The Texas Instruments Piccolo family TMS320F28027 is a 32-bit microcontroller with a max operating frequency of 60 MHz. The TMS320F28027 has 32 kB of flash memory, 6 kB of SRAM, and 22 general purpose I/O pins with programmable control for GPIO interrupts and pad configuration. This microcontroller has 6 analog-to-digital channels. The TMS320F28027 operates at 2.97 to 3.63 volts. In active mode the TMS320F28027 uses 90 mA at 3.3 volts and in idle mode it uses 18 mA at 3.3 volts.

The pinout for the Piccolo is shown below in Figure 3.6.1.2.3, reproduced without alteration as allowed by Texas Instruments.

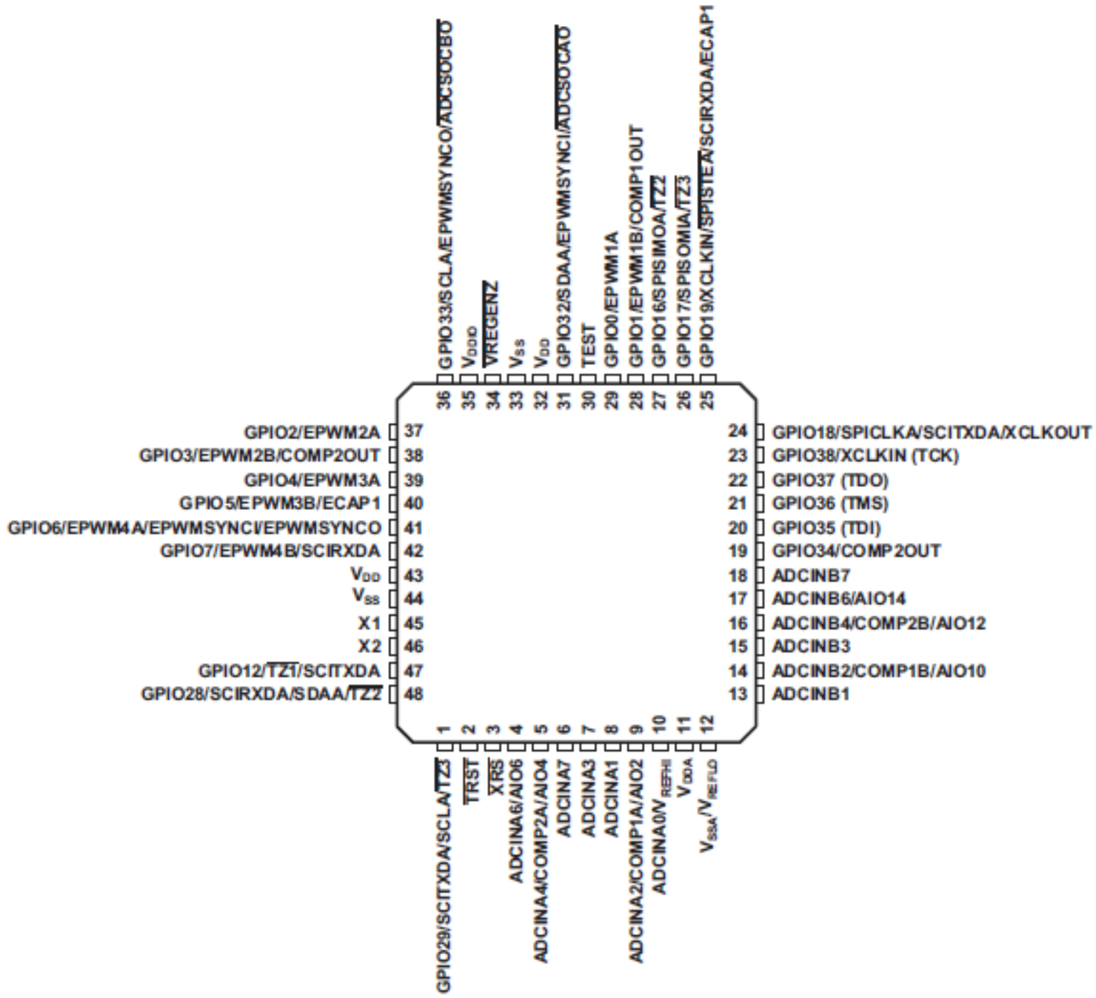


Figure 3.6.1.2.3 – Pinout of the TI TMS320F28027. Reproduced without alteration as allowed by Texas Instruments.

Atmel ATmega2560

The Atmel ATmega2560 is an 8-bit microcontroller with a max operating frequency of 16 MHz. The ATmega2560 has 256 kB of flash memory that has read-while-write capabilities, 4 kB of EEPROM, 8 kB of SRAM, 32 general purpose working registers, and 86 general purpose I/O pins. This microcontroller has 1 analog comparator and 16 analog-to-digital channels. The ADC speed is about 15 ksps. The ATmega2560has a throughput of 1 MIPS per MHz, this means that it can get up to 16 MIPS at 16 MHz. At 16 MHz the Atmega328 operates at 4.5 to 5.5 volts. In active mode the Atmega328 uses 0.55 mA at 2 volts, in idle mode it uses 15 μA at 3 volts, and in off mode it uses 0.9 μA at 1.8 volts.

The features of each microcontroller considered for the base station are summarized in Table 3.6.1.2.1 below.

	PIC32MX320F128H	**LM4F120H5QR**	**TMS320F28027**	**ATmega2560**
Max Frequency	80 MHz	80 MHz	60 MHz	16 MHz
Flash	128 Kbytes	256 Kbytes	32 Kbytes	256 Kbytes
Data Unit Size	32 bits	32 bits	32 bits	8 bits
SRAM	16 Kbytes	32 Kbytes	6 Kbytes	8 Kbytes
ADC Channels	16	12	6	16
ADC Sample Rate	1000 ksps	125ksps-1Msps	n/a	15 ksps
Active Power Consumption	2.3v, 75ma	3.3v, 50ma	3.3v, 90ma	2v, 0.8ma
Idle Power Consumption	2.3v, 5ma	3.3v, 12ma	3.3v, 18ma	3v, 15 μa

Table 3.6.1.2.1 – Comparisons of the base station microcontrollers

The primary consideration for the base unit microcontroller was sufficient power to process the data from the peripheral sensor devices. Only two of the above have the desired FPU for averaging large amounts of sensor data. Even though both have the same CPU frequency, the Stellaris has twice as much flash memory and SRAM as the PIC32. The active power consumption is also slightly better. The Stellaris also has a LaunchPad evaluation board for testing before the final PCB is made. The Stellaris is the best choice of the microcontrollers considered and will be used in the base unit for this project.

3.6.2 Sensors

3.6.2.1 Temperature

The system will make use of two types of temperature measurements for its overall functionality. The first is the measurement of body temperature, which may provide information about the current state of the user's circadian rhythm cycle. Body temperature measurements will also be helpful in determining transitions between different stages of sleep.

The second type of measurement to be utilized by the system is ambient room temperature. The ambient room temperature will provide context for the body temperature measurement. Changes in body temperature will be understood relative to the current ambient temperature, so that the system does not falsely correlate a change in temperature to a transition in sleep state or circadian rhythm.

Room temperature measurements are better suited for the base unit of the system while body temperature measurements are obviously better suited for a wearable device. It may also be possible to measure body temperature from the base unit using thermal imaging or another more sophisticated method, but that exceeds the budget and practical limitations of this project.

The thermometer for body temperature should have low power requirements, have high accuracy, be relatively small, and be able to measure body temperature with as little ambient thermal interference as possible. The thermometer for ambient temperature should also be accurate but is not as restricted in terms of physical dimensions. Neither thermometer will require a wide range of measurement, with measurements expected to fall between 15-30 degrees Celsius

Because the two temperature measurements will be taken in a much different manner, different sensors will be chosen for application-specific features. The following types of temperature sensing devices were considered: infrared thermometers, thermocouples, resistance temperature detectors (RTD's), and thermistor circuits.

Thermistors and RTD's both exploit the variability of resistance in materials with respect to temperature. The material used in resistance thermometers determines their temperature response. In general, the ceramic or polymer thermistors have a smaller temperature range but are faster and more sensitive within that range. RTD's, made of a pure metal, are usable for a wider temperature range and have long-term stability. RTD's can be made of different metals and the price varies accordingly. RTD's are better suited for industrial applications requiring high temperatures and stability. Since thermistors enjoy higher sensitivity within a limited temperature range and are less costly, they are a more suitable choice for this project.

Thermocouples take advantage of the difference in voltage between two conductors along the same temperature gradient due to the thermoelectric effect. The voltage at this junction is measured with a high input impedance circuit to minimize current draw from the thermocouple itself. There are many types of standard thermocouples, denoted by industry-standard letters according to materials, applicable range, and even whether they are magnetic or not. Like

RTD's, they are suitable for wide temperature ranges and industrial use. They are not as sensitive as thermistors, however.

Thermopiles are a series or parallel combination of multiple thermocouples. They therefore also generate a voltage proportional to a temperature gradient. Thermopiles may even be used for energy harvesting from ambient heat, and are a good fit for the low power requirements of this project. Thermopiles are incorporated in other temperature sensing devices.

Infrared thermometers exploit the thermal radiation emitted by all matter with a temperature above absolute zero, which is often in the infrared range. The devices explored use a lens to focus the emitted infrared radiation onto a thermopile junction, which then generates a measureable voltage corresponding to temperature. Because the reading is based upon emitted electromagnetic radiation, the sensor itself need not be in direct physical contact with the object being measured. This effectively makes them pyrometers, or non-contacting thermometers that measure surface temperature.

For the measurement of ambient temperature from the base unit, thermistors or thermocouple integrated circuits are the most suitable choices. They offer good precision and sensitivity in the temperature range between 0 and 100 degrees Celsius. They are also a better choice for ambient measurements than infrared thermometers, which focus emitted radiation within a limited field of view. Sensor placement on the base unit is desirable, since the measurement will be closer to the current room temperature than that measured on the wearable device close to a human body and often under warm blankets.

For the measurement of body temperature, infrared thermometers are a good option for this project. Many infrared medical thermometers are commercially available for both professional and home use, where measurements are taken from the forehead or inside the ear to approximate internal temperature. An infrared thermometer can be affixed to a wearable device inward-facing to the user's body. The body surface will be the source of the emitted radiation that is measured, and the device is therefore less susceptible to continual ambient temperature fluctuations such as the person moving in and out of blankets or laying on top of the device. The surface reading will not be the internal body temperature of the subject, but is expected to vary with core temperature anyway such that the exact core temperature is not important. Nonetheless, thoughtful placement of the sensor is an important consideration.

Ambient Temperature Sensor

The primary requirements for the ambient temperature sensor are accuracy and cost, with size and power requirements being less important since the sensor will be on the base unit. Accuracy within 1°C is desirable. A through-hole solution that may be exposed to external airflow is preferred to a surface-mount part for ease of integration with the base unit.

The LM35 series of sensors from National Semiconductor by Texas Instruments were considered and compared. The LM35 has packaging options that include a metal tab and metal can body, allowing for soldering to metal surfaces or heatsinks. The sensor leads are the dominant thermal path for the integrated circuit, such that the sensor must be isolated from the board and glued or soldered to the base unit to get as close to ambient temperature as possible. The LM35 is a thermocouple integrated circuit with low self-heating, low power requirements, and linear voltage output corresponding to temperature in Celsius. The integrated circuitry reduces the amount of external signal conditioning necessary.

Thermistors are also worth consideration due to their high sensitivity in the desired temperature range. A thermistor by itself has a resistance with a very nonlinear relationship to temperature, and therefore requires much signal conditioning and calibration. An integrated circuit that performs these tasks is convenient. Maxim Integrated Products manufactures a variety of Thermistor-to-Digital converters that provide this function while maintaining the desirable characteristics of the thermistor. The MAX6682 outputs a 10-bit + sign code for the temperature, with 0.125°C resolution. The datasheet specifies a nominal accuracy of 0.2°C between +10°C and +40°C, which is competitive with National Semiconductor's LM35.

The candidate devices are summarized in table 3.6.2.1.1 below.

Device	**LM35CAZ**	**LM35DT**	**LM35DZ**	**MAX6682**
Manufacturer	National Semi	National Semi	National Semi	Maxim
Accuracy	± 0.2°C	± 0.4°C	± 0.4°C	± 0.2°C
Output	Voltage	Voltage	Voltage	10-bit Digital
Supply Current	91.5 μA	91.5 μA	91.5 μA	21 μA (+ thermistor dissipation)
Supply Voltage Range	4 V to 30 V	4 V to 30 V	4 V to 30 V	3 V to 5.5 V
Operating Temperature Range	-40°C to +110°C	0°C to +100°C	0°C to +100°C	-55°C to +125°C
Package	TO-92-3 (Plastic Through-Hole)	TO-220 (Plastic with Metal Tab)	TO-92-3 (Plastic Through-Hole)	8-Pin μMAX (Surface-mount)
Dimensions (lxwxh)	5.0 x 4.0 x 5.0 mm	10.0 x 4.6 x 15 mm	5.0 x 4.0 x 5.0 mm	3.0 x 3.0 x 1.0 mm
Price	$5.60	$2.33	$1.57	$2.88 + $0.864 (IC + thermistor)

Table 3.6.2.1.1 – Summary of Ambient Temperature Sensors Considered

The MAX6682 is selected for its low supply voltage requirements (it can be powered from a 3.3 and 5 V supply), accuracy, digital output, price, and the fact that it interfaces with a thermistor, making thermal isolation from the board easier.

Body Temperature Sensor

The primary requirements for the body temperature sensor are sensitivity, low power requirements, size, and ability to isolate the measurement to only the surface of the body. Cost is a less critical factor since a reliable and sensitive device is crucial to providing a key function of the overall system: determining circadian rhythm and sleep cycle transitions. All of the sensors considered are infrared thermometers, which should meet these requirements.

The Melexis MLX90614 Infrared Thermometer has an accuracy of ± 0.5°C between 0 and 60°C, fully digital output over SMBus or PWM with a resolution of 0.02°C, and is offered in several application-specific variants. Of primary interest is the variant for medical applications, MLX90614DAA, which offers an accuracy of ± 0.1°C between 36 and 39°C (human body temperature) and ± 0.2°C between 32 and 42°C. The device also supports a sleep mode useful for low power consumption.

The Texas Instruments TMP006 is a small surface-mount infrared thermopile sensor. It is primarily intended for measuring the case temperature of portable electronics or other objects without physical contact. The TMP006 has digital output over an I2C bus, with several readable registers including a 16-bit object voltage thermopile register with resolution of 156.25 nV and a 14-bit local temperature register with a resolution of 0.03125°C. The TMP006's low power consumption makes it an attractive choice for the wearable device, and also has a configuration register for setting shutdown, reset, and continuous conversion options. While offering very fine temperature resolution, the typical object temperature error is a little high at ± 1 to 3°C.

The General Electric ZTP-115 is another infrared thermopile sensor. It is completely analog device with no compensation or signal conditioning. The sensor also includes an integrated thermistor for compensation of the thermopile signal. It is inexpensive for a sensor of this kind, but has extremely poor documentation to the point of being unusable for this project. There is no guaranteed measurement accuracy. However, because the device consists of only a thermopile and thermistor, the power requirements could be very low if the accompanying circuitry is well-designed. This sensor is used in experimental prototyping, but not the final design, due to its low cost and flexibility.

The body temperature sensor devices considered are summarized in table 3.6.2.1.2 below.

Device	MLX90614DAA	TMP006	ZTP-115
Manufacturer	Melexis	Texas Instruments	General Electric
Accuracy	± 0.2°C	± 1.5°C	N/A
Output	10-bit Digital	14-bit Digital	Voltage
Supply Current	2 mA	240 µA	None
Supply Voltage Range	2.6 V to 3.6 V	2.2 V to 5.5 V	None
Operating Temperature Range	+32°C to +42°C	-40°C to +125°C	-20°C to +100°C
Package	TO-39 (Metal Can Through-hole)	YZF Die-Size Ball Grid Array (Surface-Mount)	TO-5 (Metal Can Through-hole)
Dimensions (lxwxh)	9.1 x 9.1 x 4.1 mm	1.54 x 1.54 x 0.625 mm	9.25 x 9.25 x 3.6 mm
Price	$14.31	$3.78	$3.37

Table 3.6.2.1.2 – Summary of Body Temperature Sensors Considered

Although expensive, the accuracy, feature set, and ease-of-use offered by the Melexis MLX90614 make it the best choice for initial development of the wearable body temperature sensor.

3.6.2.2 Body Movement Sensor

The ability to measure body movement is a primary requirement of this project. It is an extremely helpful indicator when evaluating sleep. Commercial actigraphy devices such as Fitbit accomplish a great deal using only an accelerometer and a wireless connection: step counting, all-day activity monitoring, and sleep monitoring. Because actigraphy alone can provide a high degree of agreement with polysomnograms, the accelerometer or inertial measurement unit is a critical component of the sleep monitoring system. It is expected to greatly enhance the overall quality of the sleep evaluation data when used in conjunction with other body sensors.

Movements during sleep are expected to be subtle in some cases, so detecting very light movement will be helpful in differentiating stages of sleep as muscle movement declines from N1 to N3 and with the onset of paralysis in REM. The accelerometer or inertial measurement unit chosen must therefore have an appropriate level of sensitivity.

Accelerometers are sensors that measure only acceleration. This measurement does not necessarily indicate movement, however, since everything on the planet constantly experiences gravitational acceleration. Due to that fact, though, accelerometers are very useful in determining orientation with respect to the constant gravity. Accelerometers are available that measure acceleration in one, two, or three directions. The price of the accelerometer is directly correlated with the number of axes measured. The presence of triple axis accelerometers in nearly every new phone and tablet being manufactured has fortunately led to both lower prices and higher quality for triple axis accelerometers. Therefore, only triple axis accelerometers are considered for this project.

Common accelerometer technologies include a piezoelectric and capacitive variety. Unlike temperature measurement, where the underlying technology was a major consideration, the sensitivity and cost versus performance are the primary criteria for detecting body movement in this project. The other factors for consideration are power requirements, size, and packages available for testing and prototyping. The body movement sensor may be by itself in a wristband with no other sensors, so analog or digital output will both be considered without worrying about taking up ADC or digital pins.

In addition to accelerometers, gyroscopes are another option for measuring motion. Gyroscopes measure angular velocity and are therefore unaffected by gravity. Gyroscopes also come in one to three axis varieties, measuring roll, pitch, and yaw, although three axis gyroscopes are expensive. By themselves, gyroscopes do not offer any particular advantage over accelerometers for this project.

Inertial measurement units (IMUs) consist of an accelerometer, a gyroscope, and optionally a magnetometer. By combining the one to three axes of both the accelerometer and gyroscope, IMUs provide from two to six degrees of freedom with magnetometers adding up to three more. Six or more degrees of freedom in an IMU with appropriate sensitivity would provide the most detail on body motion for this project. The downside is the price of IMUs versus simple gyroscopes and accelerometers. The size and battery consumption may also be slightly larger, but power consumption is less of a concern if the IMU is separated from the other body sensors.

Searching for IMUs and accelerometers revealed a large price range, from a few dollars to a few thousand dollars. The range of many accelerometers is adjustable between ± 2 g, ± 4 g, and ± 8 g. The desired range for this project is between 1.5 and 4 g, with 1 g being the standard acceleration experienced standing on the surface of the earth and 3.5 g being like an intense rollercoaster ride.

One option that combines an accelerometer and gyroscope in a single IC is the InvenSense MPU-6050, which is one of a few such units that cost under $100.00. It requires an input voltage of 2.3-3.4 V, which is within range for the power supply of the wearable device. The output is digital 16-bits over I^2C, with ± 2, 4, 8, and 16 g accelerometer output, or ± 250, 500, 1000, and 2000 dps gyroscope output. If connected to a 3-axis magnetometer, a proprietary Digital Motion Processor (DMP) outputs special customizable data with 9 total degrees of freedom (DOF). With the DMP activated, the operating current is around 3.9 mA. If using only the accelerometer, the current usage is around 500 µA. The sensitivity for the gyroscope set at ± 250 dps is 131 LSB/(º/s) and the accelerometer set at ± 2 g is 16,384 LSB/g, which are the likely range settings for this project. There is also a digital temperature output of die temperature for measurement compensation.

A less expensive option for using only an accelerometer is the Analog Devices ADXL345 3-axis digital accelerometer. It also has ± 2, 4, 8, and 16 g digital output, but with 13-bit resolution at 16 g and 10-bit resolution at 2 g. The digital output is compatible with both I^2C and SPI, however. Supply voltage is from 2-3.6 V. The biggest benefit is the low power usage, with the supply current ranging from 10-140 μA during active measurement and a standby mode drawing only 0.1 μA with a wake-up time of 1.4 ms. Sensitivity is 256 LSB/g at ± 2 g, much lower than the MPU-6050.

An analog option is the Analog Devices ADXL335 3-axis accelerometer. It has a range of ± 3 g, suitable for this project. The supply voltage is from 1.8-3.6 V with typical current draw of 350 μA. The sensitivity is 300 mV/g at a supply voltage of 3.0 V. A possible advantage of analog is the option of using the on-chip analog-to-digital converter (ADC) or an external one with more precision. Ultimately the accuracy is limited by the word size of the microcontroller used. Another advantage is the possibility to perform analog signal processing on the accelerometer output to save microcontroller resources. Bandwidth is adjustable with external capacitors to prevent aliasing when using various ADCs.

Each option is suitable for this project. The candidate devices are summarized in table 3.6.2.2.1 below.

Device	**MPU-6050**	**ADXL345**	**ADXL335**
Manufacturer	InvenSense	Analog Devices	Analog Devices
Sensitivity	16,384 LSB/g	256 LSB/g	300 mV/g
Range	± 2, 4, 8, 16 g	± 2, 4, 8, 16 g	± 3 g
Axes	3 (up to 9 DOF)	3	3
Output	16-bit Digital I^2C	10-bit Digital I^2C/SPI	Voltage
Supply Current	500 μA to 3.9 mA	10 to 140 μA	350 μA
Supply Voltage Range	2.3 V to 3.4 V	2 V to 3.6 V	1.8 V to 3.6 V
Operating Temperature Range	-40°C to +105°C	-40°C to +85°C	-40°C to +85°C
Package	QFN surface mount	LGA surface mount	LFCSP surface mount
Dimensions (lxwxh)	4.0 x 4.0 x 0.9 mm	5.0 x 3.0 x 0.95 mm	4.0 x 4.0 x 1.45 mm
Price	$38.81	$6.44	$5.08
Features	DMP with magnetometer	Sleep Mode	Adjustable BW

Table 3.6.2.2.1 – Comparison of potential body movement sensors.

It is clear from Table 3.6.2.2.1 that the MPU-6050 has a large sensitivity advantage. While the sensitivity of the ADXL335 is also excellent, the addition of required analog-to-digital conversion and capacitors to adjust the bandwidth will even out the advantage in current draw. While 3.9 mA is certainly large compared to the incredible 140 µA draw of the ADXL345, assuming the actigraph unit for this project consists only of the IMU, MCU, and wireless transmitter, the draw on a 500+ mAh battery should easily be able to last through a night.

The package size for all devices is a concern. They are all extremely small, even for a surface mount device. The quad-flat no-leads package of the MPU-6050 in fact has no leads at all, so soldering will be difficult. The leadframe chip scale package of the ADXL335 is similar, and the land grid array of the ADXL345 will be easier soldered by adding a socket to the board.

The MPU-6050 is the prime choice, except for the price consideration versus the risk of faulty soldering that may destroy the IC. Fortunately, the $38.81 price tag is for the IC alone, the MPU-6050 is more commonly sold as a breakout package and is readily available from eBay for as little as $9.00. Such a breakout board was already acquired for this project to be used in prototyping. A photograph of the MPU-6050 breakout board owned by this group is shown in Figure 3.6.2.2.1 next to a dime and nickel for size perspective. The breakout board design itself is open hardware released under the Creative Commons Attribution Share-Alike 3.0 License [43].

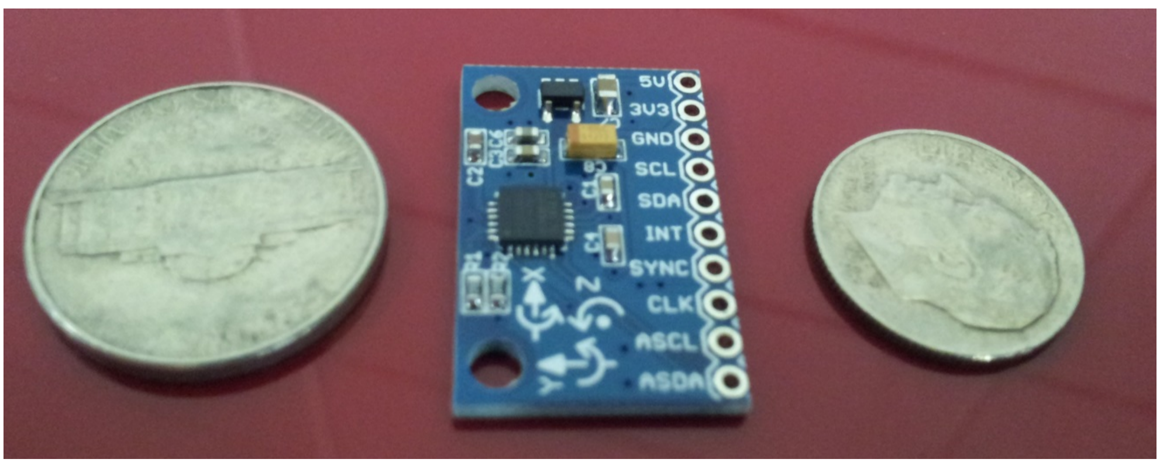


Figure 3.6.2.2.1 – MPU-6050 breakout board next to common U.S. currency for size perspective. Photograph and unit owned by GoodKnight.

Given the exceptional sensitivity, reasonable cost of $9.00, reasonable power usage, and feature set of the MPU-6050, it will be used in the sleep management system. As is made clear in the photograph, there should be no problems using the breakout board in a wristband, where it may be mounted with the already-drilled holes and soldered to a custom PCB. Additionally, if more sensitivity and accuracy is desired at a later time, a magnetometer may be interfaced with this unit.

3.6.2.3 Microphones

This project will make use of a microphone to detect snoring, which is a possible sign of sleep apnea and an indicator or poor sleep quality. To detect snoring, the microphone itself does not need to be of extraordinary quality. It needs to be able to detect the snoring itself, and signal processing on the sound can then be performed. There are various microphone technologies, including capacitive, condenser, piezoelectric, and even laser. The underlying technology is not critical to this particular task, but the majority of cheap, small, and readily available microphones are electret microphones.

For ease of placement, omnidirectional microphones are desirable. Various locations may be suitable, but the microphone is likely to be muffled under blankets if placed for instance on a wristband. Snoring sounds are likely to reach the base station, although the forehead is an acceptable location [44]. The sensor may be placed in a headband.

The frequency range of the microphone should be sufficient to capture the snoring. Snoring is expected to take place under 3 kHz, with a bandpass filter from 20 Hz to 3 kHz recommended [44]. Note that if the signal is to be processed digitally, according to Nyquist-Shannon sampling theorem an ADC with a sampling rate of at least 6 kHz will be required. The majority of snoring will be under 500 Hz [44].

Price, ease of use, directivity, and frequency response are the primary considerations in microphone selection for this project. There are many microphones available, but using an online electronics vendor and selecting a minimum frequency response of 20 Hz yielded a couple of low-cost options compared in Table 3.6.2.3.1.

Device	AOM-4544P-2-R	TOM-1545P-R
Manufacturer	Projects Unlimited	Projects Unlimited
Directivity	Omnidirectional	Omnidirectional
Supply Voltage Min	1.5 VDC	2.0 VDC
Supply Voltage Max	10 VDC	10 VDC
Frequency Response Min	20 Hz	20 Hz
Frequency Response Max	20 kHz	19 kHz
Sensitivity	-44 ± 2 dB	-45 ± 3 dB
Current Consumption (max)	0.5 mA	0.5 mA
Impedance	2.2 kΩ	2.2 kΩ
Signal-to-Noise Ratio (min)	60 dB	60 dB
Dimensions (diameter x height)	9.7 x 4.5 mm	4.0 x 1.5 mm
Price	$0.853	$1.90

Table 3.6.2.3.1 – Candidate Microphone Devices for Snoring Detection

The AOM-4544P-2-R is an overall better microphone, with higher sensitivity, lower supply voltage requirements, wider frequency response, and lower price. The tradeoff is a slightly larger size, although still very small and readily incorporated into a headband or the base station. Additionally, the AOM has 5 mm leads versus 2.8 mm leads on the TOM, which will make testing easier. The AOM-4544P-2-R will be used in this project.

3.6.2.4 Heart Rate

Detecting heart rate is one of the project’s basic requirements. Heart rate is physiological indicator in several stages of sleep; it gradually falls from N1 to N3 with respiration and suddenly rises during REM. The use of traditional ECG is not suitable for this project due to the comfort requirement. Stethophones and Piezoelectric sensors were similarly found to be inconvenient and difficult to implement.

Pulse oximetry is a good way to determine heart rate with commonly available resources such as infrared LEDs and photodiodes. Sensor placement is also more flexible than the other options mentioned, with the forehead, wrist, and fingertips being good locations. Additionally, the pulse oximetry is scalable from simple reflectance oximetry capable of determining heart rate to transmittance oximetry giving more detailed information about blood oxygenation.

Since several sensors are suitable for positioning on the forehead in a headband, the component selection and heart rate sensor design will be made assuming forehead placement. The primary components for consideration are light emitting diodes and photodiodes. Most standard infrared LEDs should work, with the photodiode, phototransistor, or photoresistor being the controlling component from which measurements are taken.

An appropriate circuit may be built around most photosensitive elements, though. An interesting consideration is isolating the infrared light emitted from the photosensitive element, such that the only infrared light detected is that reflected or transmitted through the skin. Ideally both elements and the surrounding skin would be shielded from ambient light. Luckily, such packaged combinations are already sold, with the typical intended application being proximity sensing.

All of the parts are very similar, consisting of an infrared LED closely positioned to a photosensitive element separated by an obstruction such that only reflection will allow the LED light to reach the photosensitive element. The devices found are contrasted in Table 3.6.2.4.1.

Device	HCL1395-002	QRE1113	TCND5000	TCRT1000
Manufacturer	Honeywell	Fairchild Semiconductor	Vishay	Vishay
Photosensitive Element	Phototransistor	Phototransistor	Photodiode	Phototransistor
LED Forward Current (max)	50 mA	50 mA	100 mA	50 mA
LED Wavelength	N/A	940 nm	940 mm	950 mm
Typical Output Current (coupled)	0.6 mA	0.4 mA	0.15 µA	0.5 mA
Operating Temperature	-40 to +85 °C	-40 to +85 °C	-40 to +85 °C	-40 to +85 °C
Package	Through-hole	Through-hole	Surface Mount	Through-hole
Dimensions (lxwxh)	4.45 X 2.21 x 5.72 mm	3.4 x 2.7 x 1.6 mm	6 x 4.3 x 3.75 mm	7 x 4 x 2.5 mm
Price	$2.24	$0.93	$1.86	$0.803
Feature	IR-transmissive encapsulant		Daylight Blocking Filter	Daylight Blocking Filter

Table 3.6.2.4.1 – Components for Heart Rate Detection

All devices are inexpensive. For the sake of testing, all may be purchased. The non-infrared blocking filters on the Vishay and Honeywell sensors make them appealing. Given the nearly identical specs of the Fairchild QRE1113, HCL1395, and TCRT1000, the TCRT1000 has the best features for the price. They may be used interchangeably in a circuit. The TCRT1000 is the largest of all the sensors but still acceptably small. It is anticipated that the TCRT1000 will be used in the final design.

Given the unique nature of the sensor, containing an IR LED and phototransistor in a single package, a helpful visualization is shown in Figure 3.6.2.4.1 courtesy of Vishay Intertechnology. Some additional shielding in the form of a foam barrier may be added around the package such that, when interfaced with the surface of the skin, light is prevented from entering the sensing area.

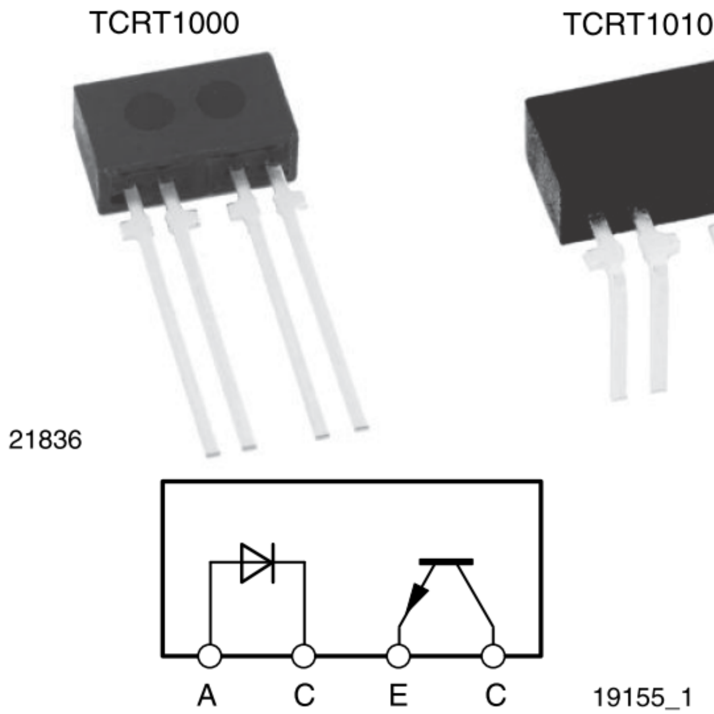


Figure 3.6.2.4.1 – TCRT1000 and TCRT1010 packages and equivalent circuit courtesy of Vishay Intertechnology.

3.6.2.5 Barometer

A barometer is used to measure atmospheric pressure; it does this by measuring the pressure exerted by the atmosphere above it. The barometer can be used to detect short term changes in weather and can estimate changes in altitude. A barometer can be used to find the actual altitude given the current ground-level barometric pressure.

Since this design will focus on providing information about the user's sleeping habits, it would be useful to also provide information on his or her surroundings while they are sleeping. Through reading the barometric pressure, it would be possible to determine if the weather was different than normal. This would allow the user to determine if his or her sleep was affected by the weather or local room climate. If the user understands how his or her sleep is impacted under different weather conditions, they may adjust his or her sleep and room climate accordingly.

MPL115A2T1 - IC, PRESS SENSOR, I2C DIGITAL BAROMETER, LGA-8
by FREESCALE SEMICONDUCTOR
The MPL115A2 is the only barometer that will be considered for this design. This particular sensor has two power modes. The multiple power modes are essential for our design to extend the battery life of the peripheral. The active mode has a current consumption of 5 μA and the shutdown mode has a current consumption of 1 μA. The data sheet for this sensor provides examples on how to utilize the raw sensor output and convert it into absolute pressure using the compensation algorithm.

Product Information:

- Operating pressure range: 50 kPa to 115 kPa
- Accuracy: ±1 kPa
- Overpressure: 1000 kPa
- Supply current: 5 μA
- Supply voltage range: 2.375 V to 5.5 V
- Operating temperature range: -40°C to +105°C
- Dimensions: 5.0 mm by 3.0 mm by 1.2 mm

Price: $1.99 *(for a quantity of 1)*

3.6.3 Transmitters

Wireless transmitters are required for data flow within the system. Without reliable transmitters, the system will not be able to propagate commands down the architecture and it will not be able to report data back to the user. Therefore, without proper wireless transmitters, the data is not guaranteed.

Low power consumption is again an important feature to be considered. Lower power consumption of the transmitter means that the peripherals will be able to meet the 8-hour functional requirement. Additionally, if power requirements are low within a peripheral design, it grants the option of downsizing the size of the peripheral module and using cheaper, smaller batteries.

Lastly, any wireless transmitter that contains guaranteed data delivery will receive special consideration. A GoodKnight system without a reliable wireless network could cause faults and malfunctioning of the main algorithm driving the product. For instance, if the peripheral reads vital data which hints that the user should be awakened and it does not get delivered, the system could miss the small window altogether.

Considering these sought-after features in a wireless transmitter, there are a few eligible modules that are examined. Priority is given to essential specifications including power consumption, range, module size, and operating temperatures.

3.6.3.1 RN-42 Bluetooth Radio

The RN-42 module is a low-powered, Class 2 Bluetooth radio developed by Roving Networks. Since the RN-42 is Class 2 Bluetooth, it means that this device can transmit and receive data at a longer distance compared to the RN-41 Class 1 Bluetooth Radio. In addition, the RN-42 radio is compatible with Bluetooth versions 2.1 +EDR, 2.0, 1.2, and 1.1. It contains multiple configurable power modes that allow the engineer to choose the appropriate power profile for a given application. The RN-42 uses about 26 µA in sleep mode, 25 mA in standby/idle mode, and 30 mA in normal mode. It also has a low-power sniff mode using 8 mA.

When this device uses an onboard stack it can only send and receive data at a rate of 300 Kilobits Per Second (Kbps). Without the onboard stack, it can sustain a data rate of 1.5 Megabits Per Second (Mbps) with occasional bursts at 3 Mbps.

Noticeably, the RN-42 has some special features like secure communications with 128-bit encryptions and auto-discovery/pairing. The secure communications keep user sleep data safe from unauthorized entities. The auto-paring feature allows the user to automatically connect to a peripheral without having to search for the device to pair with it. Lastly, due to the error correction feature, the RN-42 also guarantees packet delivery; hence, allowing more reliable connections.

Table 3.6.3.1.1, shown below, summarizes the features of the RN-42 Bluetooth Radio module. Figure 3.6.3.1 shows the general pin layout for the module.

Bluetooth Version	2.1 + EDR, 2.0, 1.2, 1.1
Frequency Band	2.412 – 2.484 GHz
Data Rate	Onboard Stack: 300 Kbps, Normal: 1.5 Mbps, 3Mbps burst
Voltage Supplied	3.3v ± 10%
Power Consumption	Standby/Idle: 25mA Normal: 30mA Low Power Sniff: 8mA Sleep: 26µA
Temperature	-40C to +85 ºC
Antenna	PCB trace
Size	13.4 x 25.8 x 2 mm

Table 3.6.3.1.1 – Summarizes the RN-42 Bluetooth radio specifications.

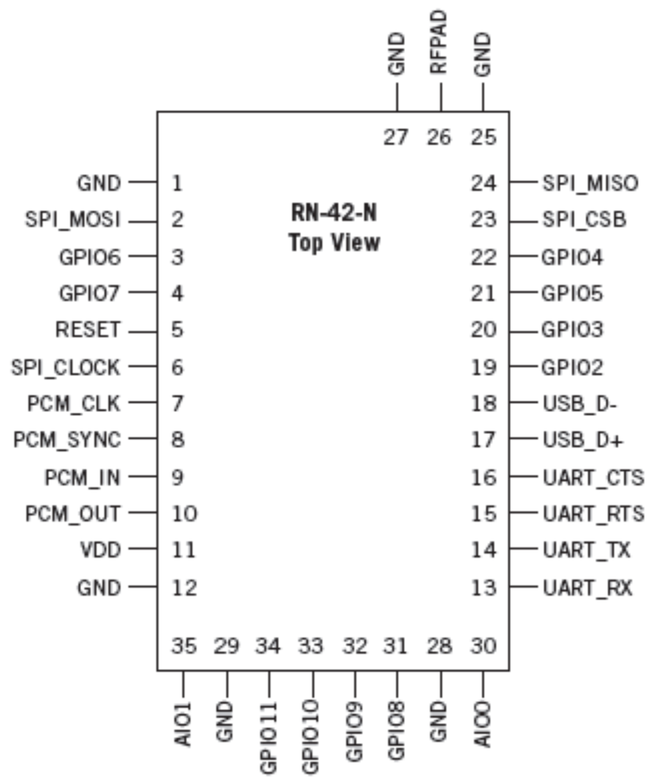


Figure 3.6.3.1 – RN-42 Bluetooth radio pin layout. Reprinted with permission from Roving Networks.

3.6.3.2 CC2541 Low-Energy Bluetooth Module

The CC2541 Boosterpack® is a Bluetooth low-energy module and proprietary system-on-chip (SoC) developed by Texas Instruments. A SoC is an integrated circuit that integrates many components of a computer into a single chip. The CC2541 combines the performance of a RF transceiver with an 8051 microcontroller. The CC2541 is recommended for applications where low power consumption is needed. It has multiple power consumption modes. In active-mode, the CC2541 uses 17.9 mA when receiving data and 18.2 mA when transmitting data. In power mode one it uses 270 µA. In power mode two, it uses 1 µA. And in power mode 3, it uses 0.5 µA. Moreover, in order to further lower power consumption, there are short transition times between power modes.

Since the CC2541 is a SoC, it contains 128-256 kB of programmable flash memory and 8 kB of RAM. The CC2541 also has a HW I^2C interface, battery monitor, temperature sensor, twenty-three General-Purpose I/O Pins and two I/O pins that have LED capabilities.

Table 3.6.3.2, shown below, summarizes the specifications of the CC2541 Boosterpack® Bluetooth module. Also, Figure 3.6.3.2 shows the pin layout for the module reproduced without alteration as allowed by Texas Instruments.

Bluetooth Version	Bluetooth low energy 4.0
Frequency Band	2.402 – 2.480 GHz
Data Rate	1 Mbps
Voltage Supplied	2 to 3.6 V
Power Consumption	• Active-Mode RX Down to: 17.9mA • Active-Mode TX (0 dBm): 18.2mA • Power Mode 1 (4-µs Wake-Up): 270µA • Power Mode 2 (Sleep Timer On): 1µA • Power Mode 3 (External Interrupts): 0.5µA
Temperature	-40 to +125 ºC
Antenna	Differential
Size	6 × 6 mm

Table 3.6.3.2 – Lists the specifications CC2541 Boosterpack® module.

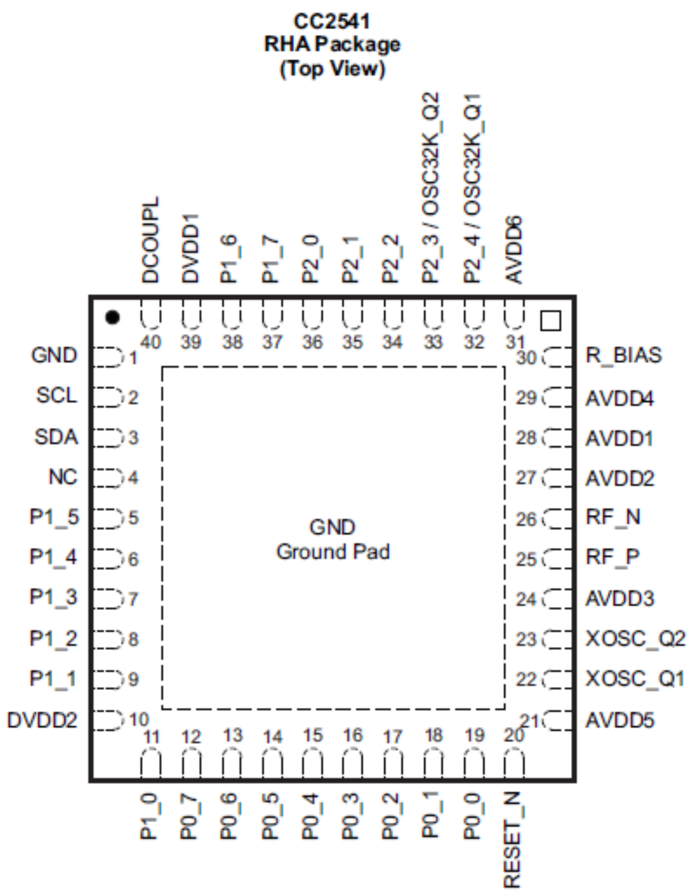


Figure 3.6.3.2 – Pin layout for the CC2541 module. Reproduced without alteration as allowed by Texas Instruments.

3.6.3.3 CC2560-PAN1325 Bluetooth Boosterpack® Module

A Boosterpack® is a form factor for the add-on modules to the Texas Instruments' Launchpad® evaluation boards. They allow engineers to rapid prototype with the evaluation boards by facilitating the connections between a third-party board and a Launchpad® evaluation board. The CC2560-PAN1325 module is a Class 2 Host Controlled Interface module. By using Panasonic's PAN1325 and Texas Instruments' CC2560, output power capabilities are increased. Since the device is a Host Controlled Interface (HCI), it supports three and four-wire UART with data rates up to 4 Mbps. The CC2560-PAN1325 has multiple power modes for improved power consumption. In shutdown mode, this device uses 1 µA, in sleep mode it uses 40 µA, in active mode it uses 1 mA, and in full throughput mode it uses 40 mA.

Table 3.6.3.3.1, shown below, summarizes the specifications of the CC2560-PAN1325 Bluetooth module.

Bluetooth Version	Bluetooth 2.1 + EDR
Frequency Band	2.4 GHz
Data Rate	Up to 2.1 Mbps
Voltage Supplied	1.7 to 4.8 V
Power Consumption	○ Shutdown mode: 1µA ○ Sleep mode: 40 µA ○ Active mode: 1ma ○ Transmit full throughput: 40mA
Temperature	-20 to + 70 ºC
Antenna	Embedded
Size	9 x 9.5 x 1.8 mm

Table 3.6.3.3.1 - Specifications of the CC2560-PAN1325

Selection

Because of the RN-42 Bluetooth module's special features like guaranteed packet delivery, the module is the best transmitter for the GoodKnight system. The system will benefit from guaranteed packet delivery due to the decreased complexity of retransmitting undelivered data. In addition, the RN-42 module establishes a secure connection, protecting the data from any malevolent sources attempting to corrupt data or any anomalies that could occur with multiple connections established. Lastly, the RN-42 also contains an auto-discovery feature. This feature could facilitate the process of connecting a peripheral to the system and thereby make the process user-friendly.

3.6.4 Alarm Clock

The alarm clock is a very important aspect of the project. Given the importance of the alarm to the overall functioning of the design project, certain factors must be considered such as what are the basic requirements needed to create an alarm. The alarm should include an audible alarm, an alarm to physically alert the user such as vibration, and it will need to be smart. Smart means capable of waking the user based upon certain customizable indicators, such as stage of sleep, how long the user has been asleep, and even whether the sun has risen or not.

3.6.4.1 Buzzer

The system will make use of a buzzer to act as an audible alarm. This buzzer will need to produce a tone that is capable of waking someone in any stage of sleep. Most of the buzzers available are capable of producing a wide range of frequencies.

Buzzers are produced in two main categories: the electromagnetic type and the piezoelectric type. When selecting which buzzer will work as the audible alarm, it is necessary to determine which type will work best for this design first.

Both of these types work by using electronic components to convert an input voltage into an appropriate oscillating signal that drives a metal sounder diaphragm. This metal sounder diaphragm then physically flexes up and down producing air pressure waves that the human ear can interpret as sound. It is possible to generate different tones by applying different voltages to the buzzer.

The electromechanical buzzer is able to obtain low frequencies. They typically are small in size. When size is a factor, it is the best choice of the two types. This type of buzzer has many drawbacks associated with it. The drawbacks include mechanical wear, electrical noise, lower sound output, and large power consumption. It is also important to consider the operating life due to the mechanical operating characteristics of this type of buzzer. The electromechanical alarm has an electrical contact inside that keeps opening and closing which typically has a high failure rate.

The piezoelectric buzzer is superior in many ways to the electromechanical type. It does not have any mechanical devices that move, and this will extend the life of the buzzer since there is no mechanical wear on the device. They are capable of operating in a much wider variety of environments. This type of buzzer draws very little current making it suitable for a battery-powered application.

Of these two types of buzzers only the piezoelectric buzzer type will be considered when selecting parts. This is because of the electrical noise and the high power consumption of the electromechanical type. An electromechanical design can draw up to ten times the current of the piezoelectric variety. Electrical noise will definitely make designing the alarm much more challenging since it will require greater attention to detail when considering how each part is impacted by the noise introduced. Alarms that use piezoelectric technology draw less current, are capable of louder sound levels, and do not generate magnetic fields.

When creating the alarm sound it will use pulsing tones. A pulsing tone is more easily distinguished compared to constant tones. When people hear a pulsing tone it will typically convey more urgency to a person compared to a constant tone. To create a pulsing audible alarm it will be necessary to create extra electronic circuitry and software code.

To be an effective audible alarm it should be at least 10 decibels louder than the ambient background noise. This is so it can be easily heard. It is possible to measure the actual ambient noise level of the room and the design will attempt to do this using the microphone.

Most people can only distinguish a sound level change only when it increases or decreases by 3 decibels. When the sound level changes by 10 decibels, the person who is listening would say that it is twice as loud as before. When generating the sound that will be the alarm it will be necessary to take into account how the human ear works to generate an alarm to wake the user.

MULTICOMP - MCKP1206R1-4720 - BUZZER, PIEZO, 115DB
by Multicomp
The MCKP1206R1-4720 is a small piezoelectric buzzer that packs quite a punch. The buzzer supports a wide range of frequencies that will allow for a variety of tones to be produced.

Product information:

- Impedance: 32 ohm
- Sensitivity: 115 dB
- Frequency response: 300 Hz – 3.4 kHz
- External diameter: 6 mm
- External height: 12 mm

Price: $1.23 *(for a quantity of 1)*

PRO SIGNAL - ABI-001-RC – BUZZER
by PRO SIGNAL
The ABI-001-RC provides a little more detail in the specification sheet regarding operating current and voltage. This buzzer has a built-in oscillating circuit, which will save time in the development phase. The specification sheet indicates that it has low power consumption.

Product information:

- Rated voltage: 12 VDC
- Operating voltage: 3 – 16 VDC
- Rated current: 7 mA
- Sound output: 80 dB

- Resonant frequency: 4000 ± 500 Hz
- Operating temperature: -20°C to +70°C
- Weight: 1 g

Price: $2.23 *(for a quantity of 1)*

MULTICOMP - MCKPI-G4510L-4013 - PIEZO BUZZER
by Multicomp
The MCKPI-G4510L-4013 also provides more detail than the first buzzer listed. This buzzer has similar specifications to the ABI-001-RC except that this buzzer produces continuous tones. It may be beneficial to have a continuous tone and create a tune using a microcontroller, which is why this buzzer was also considered.

Product information:

- Rated voltage: 12 VDC
- Operating voltage: 3 – 16 VDC
- Max rated current: 35 mA
- Sound output: 100 dB
- Resonant frequency: 3200 ± 500 Hz
- Tone nature: Continuous
- Operating temperature: -20°C to +60°C
- Weight: 21 g

Price: $1.81 *(for a quantity of 1)*

3.6.4.2 Vibrator

The physical alert will be created using a vibration motor. The idea with the physical alert is to provide stimulation to the user that would awaken them from a light sleep. It will provide a gentle vibration to the user to gradually wake them up. A small vibration motor is all that would be necessary for this design.

When researching vibration motors, the initial search included all the different types on the market such as encapsulated, enclosed, coin, linear resonant actuators, and long life brushless. Determining which types would be useful for our design was relatively simple since we mainly were interested in the motors that had no exposed moving parts. So for our design we will focus on encapsulated, enclosed, and coin vibration motors.

The encapsulated vibrating motor design has some advantages that will be considered in the final decision. They feature a water-resistant casing that is resistant against water, dust, and dirt. It is possible to further seal the motor to make it full water proof if needed with only a small amount of epoxy. Another aspect of their design is that they provide a larger vibration force compared to the coin vibration motors.

The enclosed vibration motors offers a stronger vibration. The enclosed casing allows it to be resistant against dust and dirt. Unlike the encapsulated motor, this is not water resistant. These enclosed motors feature a lengthened case, allowing the eccentric mass to be fitted to the motor shaft within the case.

The coin vibration motors are compact and convenient to use. The small footprint of the coin vibration motor is a significant advantage when considering our design. It is important for the final design to be small enough that it is not a burden to the user when they are trying to sleep.

Pico Vibe 7mm Vibration Motor - 25mm Type (306-108)
by Precision Microdrives
The Pico Vibe 7mm Vibration Motor is the smaller of the two encapsulated motors that will be considered. This particular vibration motor is light weight and small in size. It operates within the temperature range that is specified for this project. The low operation current will extend the time the device operates on a single battery charge.

Product information:

- Unit weight: 3.9 g
- Operating temperature: -20°C to +60°C
- Max mechanical noise: 45 dB
- Max start current: 115 mA
- Max operating voltage: 1.8 V
- Max operating current: 53 mA
- Rated speed: 11,000 rpm +/- 2,200 rpm
- Typical power consumption: 66 mW
- Typical vibration amplitude: 0.93 G
- Typical operating current: 44 mA
- Typical start current: 115 mA
- Typical start voltage: 0.45 V

Price: $7.83 *(for a quantity of 1)*

Pico Vibe 10mm Vibration Motor - 2.7mm Type (310-103)
by Precision Microdrives
This motor has a compact size, an easy self-adhesive mounting method, and an enclosed shaftless design. This type of vibration motor is generally used to provide vibration in cell phones. This is the smallest vibration motor that will be considered and is the lightest in weight.

Product information:

- Unit weight: 1 g
- Operating temperature: -20°C to +70°C
- Max mechanical noise: 50 dB
- Max start current: 90 mA

- Max operating voltage: 3.6 V
- Max operating current: 90 mA
- Rated speed: 13,500 rpm +/- 3,000 rpm
- Typical power consumption: 156 mW
- Typical vibration amplitude: 0.9 G
- Typical operating current: 52 mA
- Typical start current: 90 mA
- Typical start voltage: 1 V

Price: $6.71 *(for a quantity of 1)*

Uni Vibe 12mm Vibration Motor - 20mm Type (312-100)
by Precision Microdrives
The Pico Vibe 12mm Vibration Motor is the larger of the two encapsulated motors that will be considered. This encapsulated motor is the largest that will be considered and will draw the most power. It will be considered because of the stronger vibration amplitude.

Product information:

- Unit weight: 8.7 g
- Operating temperature: -10°C to +50°C
- Max mechanical noise: 60 dB
- Max start current: 430 mA
- Max operating voltage: 3.6 V
- Max operating current: 125 mA
- Rated speed: 12,600 rpm +/- 1,260 rpm
- Typical power consumption: 183 mW
- Typical vibration amplitude: 0.8 G
- Typical normalized amplitude 2 G
- Typical operating current: 61 mA
- Typical start current: 430 mA
- Typical start voltage: 0.9 V

Price: $8.63 (for a quantity of 1)

3.6.4.3 Smart Alarm

The smart alarm component of this project will wake the user up at the optimal time in the morning. Not only will it wake the user at the optimal time, but it will attempt to keep them awake.

Waking the user at an optimal time is critical to the goal of the project. To have a smart alarm it will need to interact with the other sensors and gather data to determine when would be the optimal time to wake the user. The optimal time to wake the user is determined using a window of time that the user sets. In this window of time, the alarm will only sound if it detects that the user is in a light stage of sleep. It could be possible for the alarm to wake the user slightly outside of this window if it determines that the user will not have an optimal time during the predefined window of time they set up.

To keep the user awake after the alarm has successfully woken them up, the base unit will have the user perform a certain task that would require either mental or physical effort to complete. By performing this task, the user would have a hard time falling back to sleep and will experience reduced sleep inertia [45]. Exposure to light in the morning is also known to fight sleep inertia and help wake the user, so interfacing with lights at a later time is a possibility [46].

The interactive element of the alarm will be designed to function from the base station. It is possible to do the smart alarm element with software or hardware for this project. The progress of the either the software or the hardware will determine what the smart alarm will look like in the final design, but at least one interactive element will definitely be included in the prototype. The hardware method would be along the lines of shooting a ball out of the base station and requiring the user to place it back into the receptacle on the base station to turn the alarm off. It is not only limited to a ball but could potentially be a fast moving toy car that has a buzzer on it that would still need to be returned to the base to turn it off. The software method would involve doing a simple puzzle on the touch screen of the base station. A simple puzzle could include many things such as solving a simple algebra problem or completing a game of tic-tac-toe. The wearable accelerometer could be used to force the user to jump up and down until a sufficient amount of activity is detected to shut off the alarm. None of these tasks would be difficult but they all would require the user to perform a task that is outside the normal morning routine, stimulating them enough to stay awake.

4.0 Project Hardware and Software Design Details

4.1 Project Block Diagrams

When beginning the initial design efforts, it is highly beneficial to design the system abstractly. For the hardware portion, the way modules are going to be transferring data and how they are going to be powered must be considered. For software, this means considering how modules are going to be designed so the system is scalable, debuggable, and efficient.

4.1.1 Hardware Block Diagrams

By simplifying the hardware into block entities, it lessens the overflow of information and shows the module interactions abstractly. Figure 4.1.1.1 exemplifies the hardware implementation for the base station in a block diagram. It demonstrates how the microcontroller is the main interfacing unit amongst all the hardware modules. In addition, Figure 4.1.1.2 shows a block diagram for Peripheral 1 and Figure 4.1.1.3 shows the block diagram for Peripheral 2.

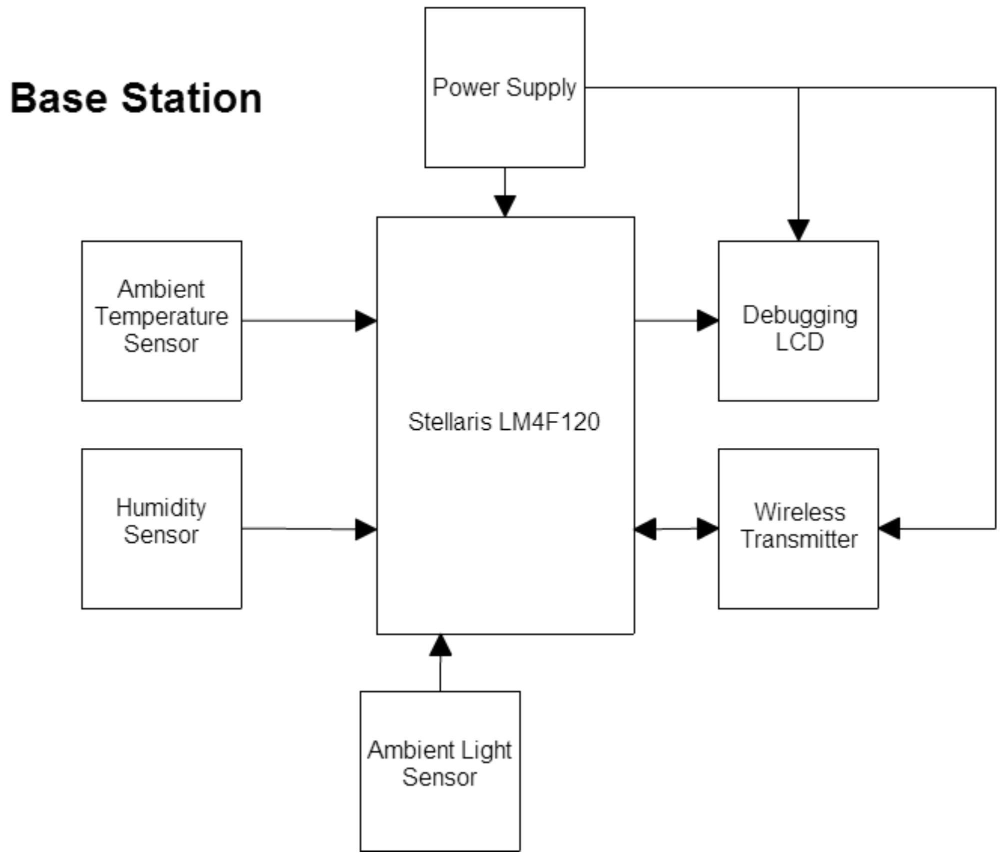


Figure 4.1.1.1 – Hardware block diagram for the base station

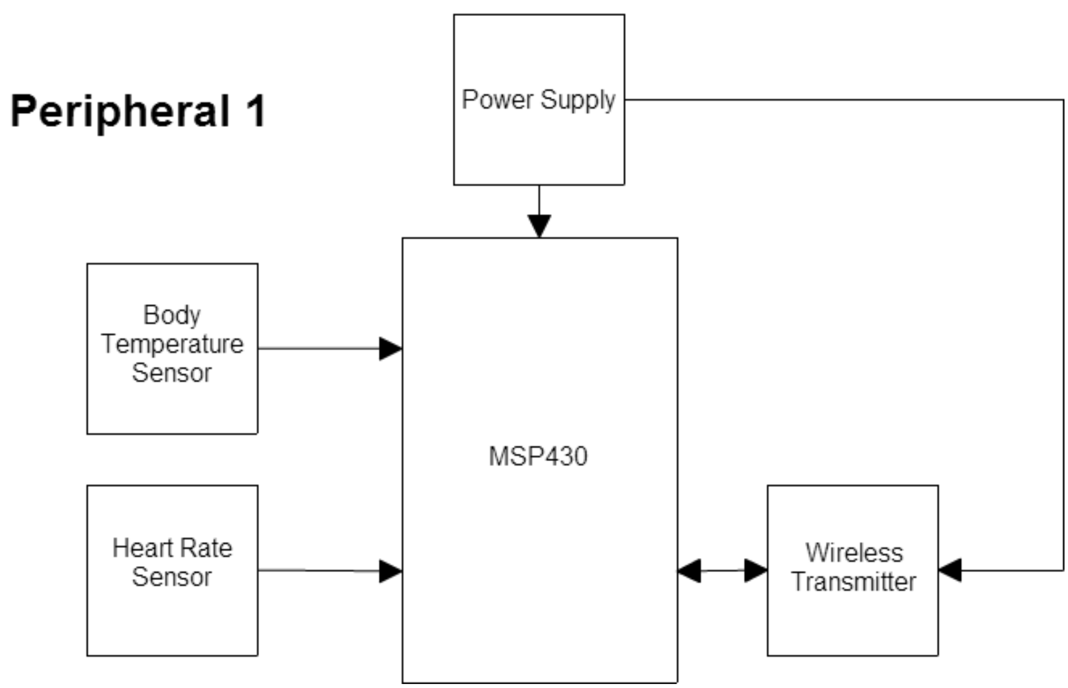


Figure 4.1.1.2 – Block diagram for peripheral 1

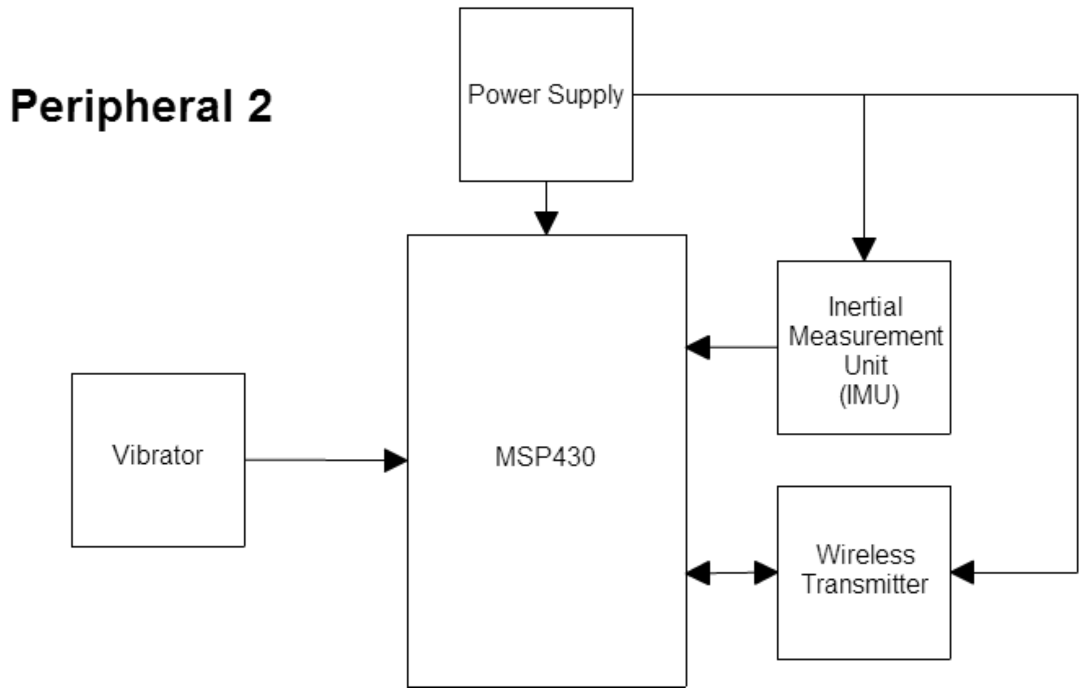


Figure 4.1.1.3 – Block diagram for peripheral 2

4.1.2 Software Block Diagrams

Software block diagrams portray the layered architecture of a major software release and help show the relationships of the modules and their compositions (including other sub-components). For this project, Figure 4.1.2.1 shows how the software architecture is designed.

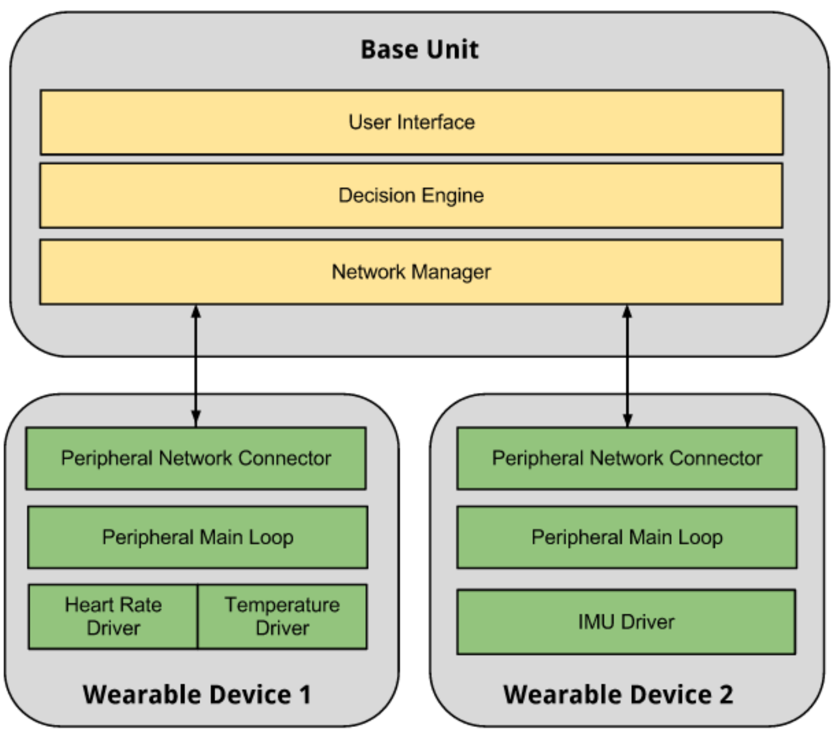


Figure 4.1.2.1 – Software architecture block diagram for the system.

More importantly, some critical modules need further design details. For example, the base unit's Network Manager module should implement a scalable messaging system to guarantee that all the acquired data receives proper processing and therefore leverage the scalibity of the messaging framework. Figure 4.1.2.2 below describes the messaging system using Unified Modeling Language (UML).

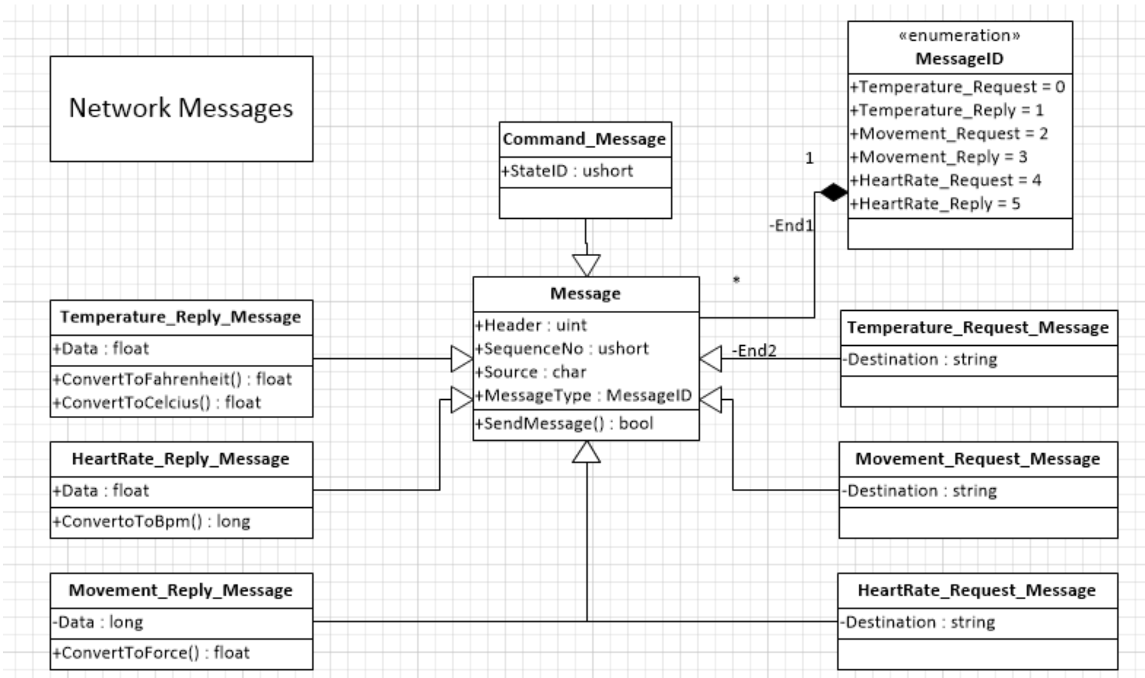


Figure 4.1.2.2 – Scalable design for the network messages to be used in the Network Manager module.

Another important module is the Decision Engine module as shown the software block diagram in Figure 4.1.2.1. This module is critical to handling the received messages from the peripherals and launching their appropriate interrupts. As a result, a sequence diagram was created in order to depict these timespan relationships. Figure 4.1.2.3 shows the sequence diagram designed.

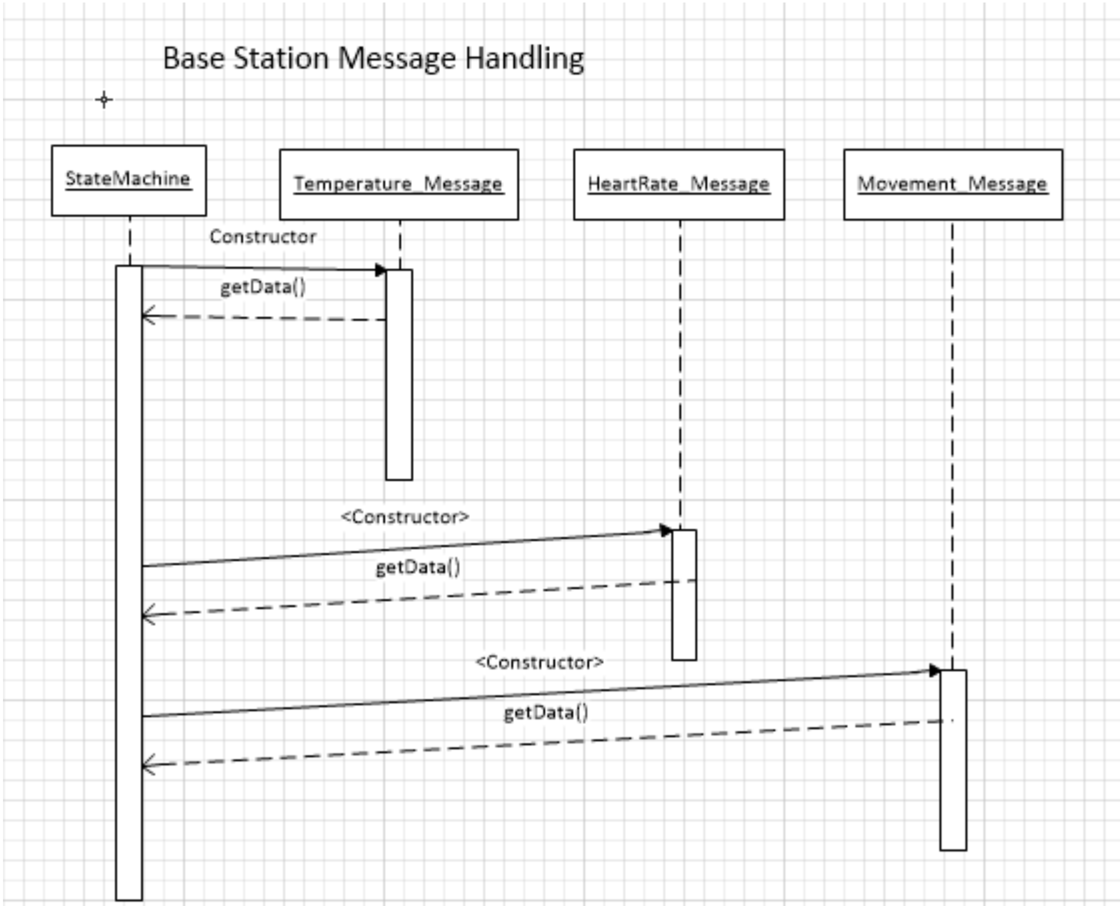


Figure 4.1.2.3 – Sequence Diagram for the timespan relationships to be implemented within the base unit's Decision Engine module.

4.2 Wearable Device Hardware Subsystems

4.2.1 Body Temperature

Melexis MLX90614 was chosen for body temperature measurement. The sensor measures the temperature of an object in its field of view without contact required. The output is a digital signal over SMBus or PWM. All interfacing with the microcontroller is digital over SMBus, which is compatible with I^2C in most cases [47]. However, certain calculations and checks must be made to ensure compatibility. Those considerations will be made while testing the hardware. For now, the SMBus is connected to the SDA and SCL I^2C capable pins of the MSP430. The device is then powered with the +3.3 V regulator source. Note that the SDA and SCL lines of both SMBus and I^2C require pull-up resistors.

A generalized schematic of this circuit made in CadSoft Eagle is shown below in Figure 4.2.1.1.

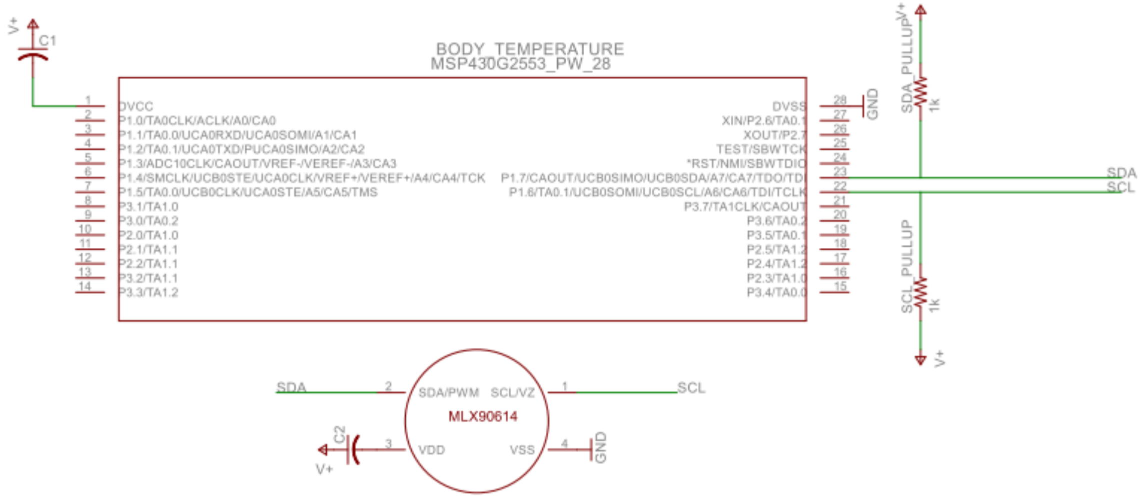


Figure 4.2.1.1 – Melexis MLX90614 interfaced with the MSP430.

The physical placement of the sensor is expected to be in the headband along with a few other sensors. The MLX90614 will face downward from the PCB to the forehead, either lightly contacting the head or slightly separated for comfort (full contact is not required for the infrared temperature sensor).

4.2.2 DC Power Supply

The research conducted in section 3.5.3 outlines the various elements that will be required to construct the DC power supply. The final design of the DC power supply will be decided based on the research presented in section 3.5.3.

The power supply may be created using the components researched in section 3.5.3. These components will be integrated together to create the DC power supply, which will consist of a polymer lithium ion battery, LiPo charger, and the designed circuit topology that will deliver the power from the battery. The designed power supply will meet the desired power requirements of all the sensors and microcontrollers for the portable devices.

This same power supply design will be used for all the portable devices. The design will be reused because each portable device will still have the same power requirements. This is because they will function using the same microcontroller and the sensors selected all operate within the designed operating conditions supplied by the power supply.

Given that the peripherals are using a LiPo battery, which is common in many portable devices such as cellular phones, there may be a widely available solution to regulate the voltage of the battery. In fact, much like the readily available charger, such power management solutions do exist. One such example is the Texas Instruments TPS650250 Power Management IC for Li-Ion Powered Systems.

The IC can take an input voltage of 0 to 7 volts and output up to 1.6 A at 3.3 V with 97% efficiency. This is suitable for the 3.7 V, 860 mAh LiPo battery chosen for the peripheral devices. The power management IC will help protect the sensors and other components in the wearable device, while offering a likely cheaper, safer, and more efficient alternative to a DC power supply designed from scratch. The cost is $4.38, and the part will likely be used in the final design.

Using this power supply design it will be possible to run the portable devices for the duration of the whole night. It was calculated that with the battery fully charged, the portable devices could run constantly for almost the whole night with the sensors constantly on assuming a conservative 500 mAh from the battery. With the microcontroller running in low power mode and disabling the sensors when they are not being using, it is estimated that this design will meet the basic requirement of lasting a full night on a single charge. The alternative is to simply purchase a slightly more expensive LiPo battery with a greater mAh capacity.

4.2.3 Heart Rate Monitor

A proximity sensor was chosen to attempt reflectance pulse oximetry. The part consists of both an infrared LED and an NPN phototransistor combined in a single package. It is not an integrated design; the pins from the LED and phototransistor are accessible the same as two separate components. They are simply placed conveniently together.

The reflected infrared light should bias the base of the phototransistor, enabling a flow of current from the collector to emitter proportional to the incident light. An undetermined amount of signal processing will need to be performed, including a low-pass filter of around 5 Hz, since the human pulse is never expected to exceed 200 beats per minute, which correlates 3.3 beats per second. Artifacts and noise are expected from the physical movement of the person.

There are some signal conditioning ICs, such as the Analog Devices AD8232 ECG heart rate frontend, that may be used creatively to acquire heart rate. Feeding the phototransistor current to the AD8232 from a current-to-voltage converter may be one way to accomplish this. However, the AD8232 is intended for at least two leads from an ECG. The frontend will likely complicate the process.

Instead, the approach is to feed the signal through a current-to-voltage converter, then through a 5 Hz low-pass filter, then through a narrowband notch filter to eliminate the ever-present 60 Hz noise, then through an active DC servo filter to remove any DC component of the signal, and then through a variable-gain amplifier. The variable-gain amplifier is there for testing purposes and also to adjust the gain, perhaps digitally, should the signal suddenly become too weak or too strong as the person shifts about during the night. The basic block diagram for this process is shown in Figure 4.2.3.1.

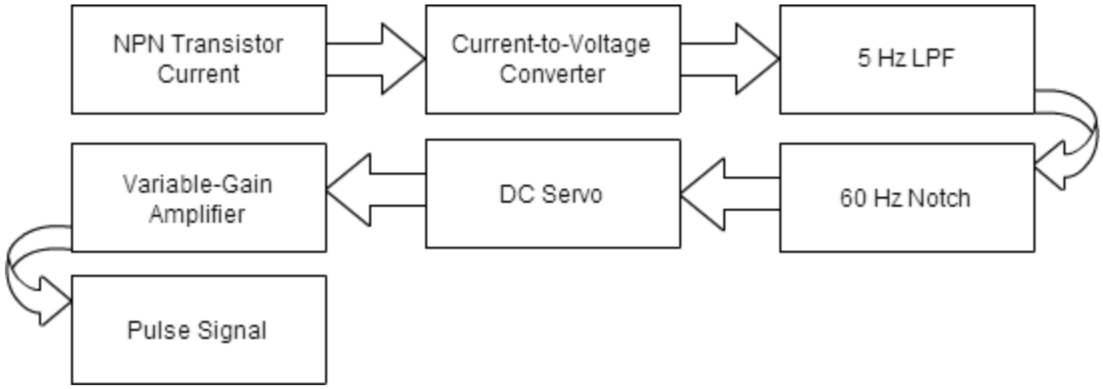


Figure 4.2.3.1 – Signal conditioning for heart rate sensor.

The circuit from the LED to the current-to-voltage converter is shown in Figure 4.2.3.2. After that, the signal will be filtered and rectified before being fed to the microcontroller's ADC.

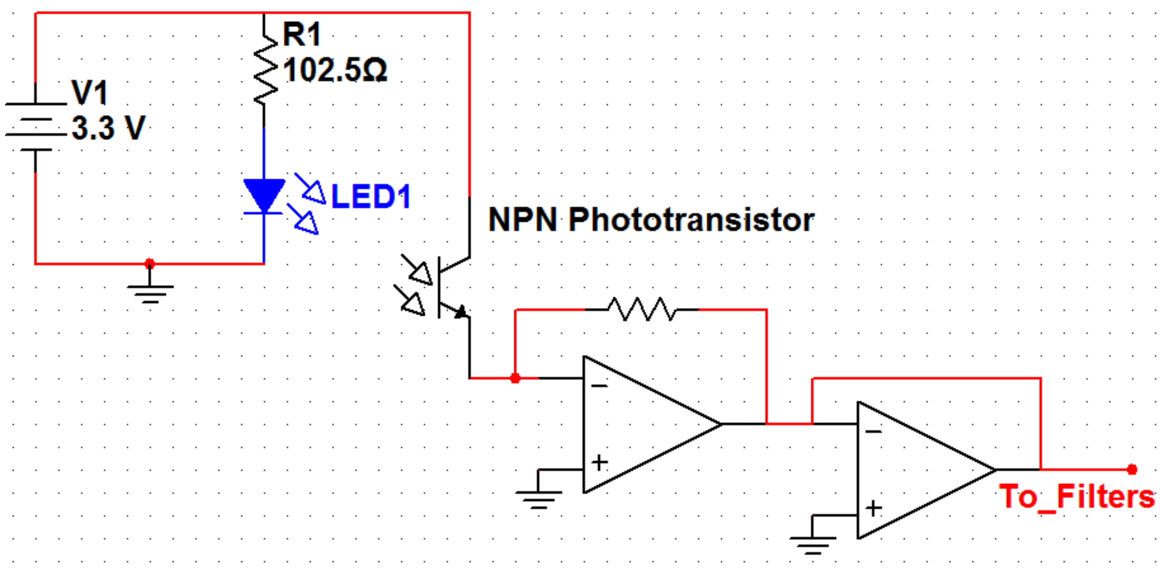


Figure 4.2.3.2 – Initial portion of the heart rate circuit. The reflected IR LED biases the base of the phototransistor, allowing current to flow through the transistor to the current-to-voltage converter and then through the inverter.

The remainder of the signal conditioning may be performed using analog or digital techniques. Once the microcontroller obtains a pulse count, it will be sent to the base station via the Bluetooth transmitter module.

4.2.4 Microphone

The AOM-4544P-2-R will be the microphone used to detect snoring. It was an overall better microphone in terms of sensitivity, low voltage requirements, wider frequency response, and low price.

The circuit in Figure 4.2.4.1 uses a low-pass filter along with an instrumentation amplifier. The low-pass filter will limit the frequencies to a range of 0 Hz – 300 Hz; this is because the highest peaks of intensity regarding snoring occur in that frequency range. The signal from the microphone will need to be amplified to be read by the microcontroller so the instrumentation amplifier has a high gain to increase the signal.

The Bode plot in Figure 4.2.4.2 shows that the low-pass filter for this design has a cutoff frequency of 300 Hz. The third order low-pass filter that was designed allows the magnitude to reach zero exactly one decade after the cutoff frequency. The phase response is shown in Figure 4.2.4.3.

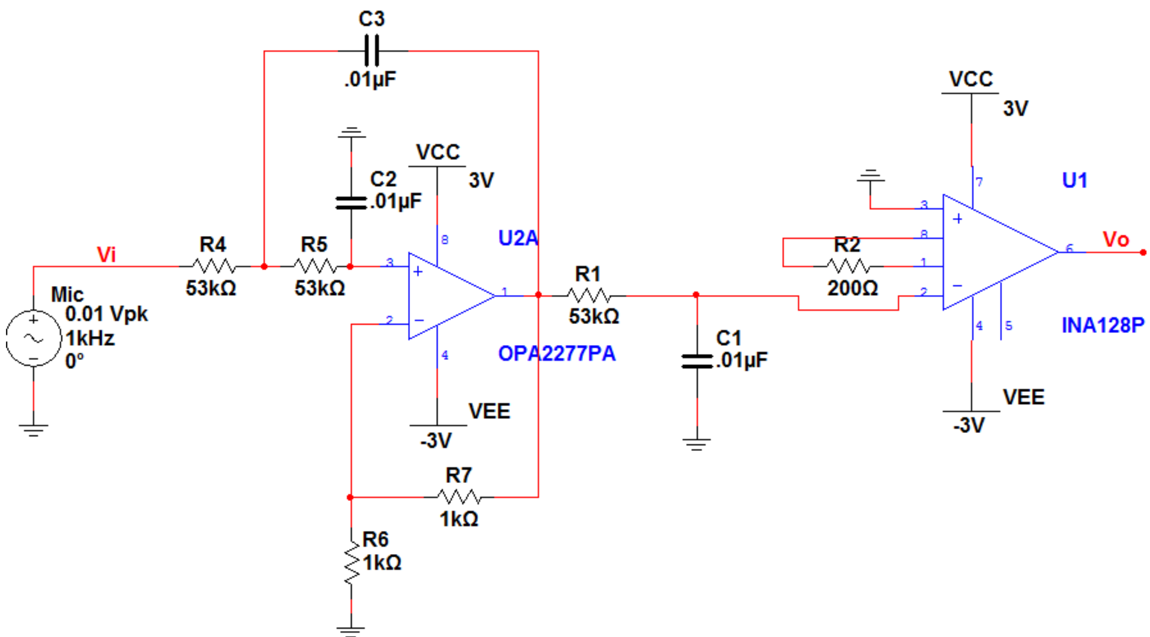


Figure 4.2.4.1 – Microphone Schematic

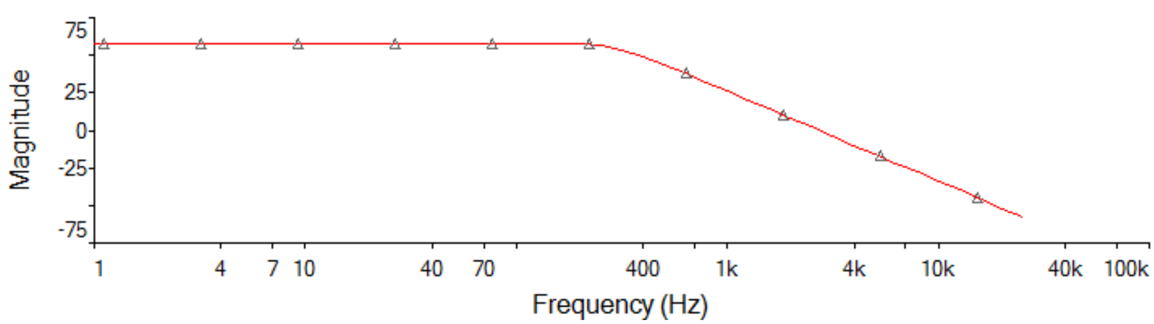


Figure 4.2.4.2 – Microphone Bode Magnitude Plot

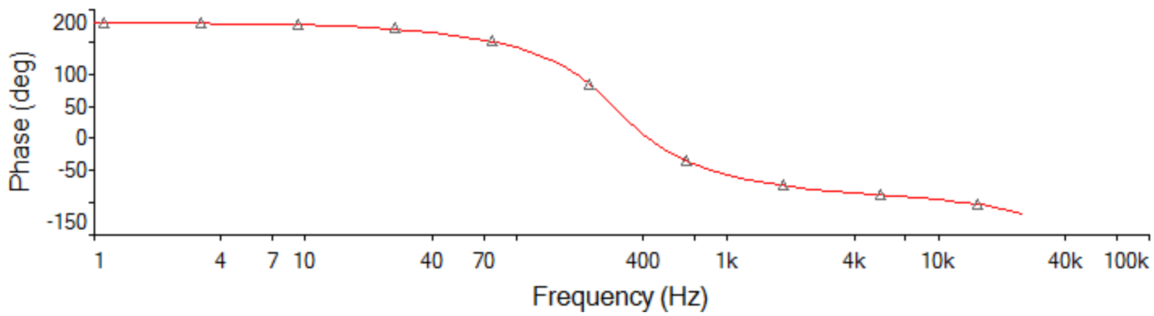


Figure 4.2.4.3 – Microphone Bode Phase Plot

Following the low-pass filter, the signal will be passed through a full-wave rectifier to prevent negative voltage on the ADCs. Alternatively, the negative supply of the operational amplifiers may be grounded such that the output is between 0 and 3.3 volts.

There are a few potential strategies for detecting the snoring with the microcontroller. One is to periodically read the signal through the ADC for a certain interval of time. Averaging the readings should be a good indicator of whether or not snoring took place during the measured interval.

Instead of constantly using the ADC over a certain interval of time, some resources might be saved using the peak detector circuit pictured in Figure 4.2.4.4. 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 microcontroller will then apply voltage to the gate of the MOSFET to drain the capacitor so that new snoring peaks may accumulate. This may not be as detailed as averaging many values, so both methods will be tested.

4.2.5 Movement

The MPU-6050 IMU was chosen as the body movement sensor to be used as an actigraph unit. Because of the IMU's rich feature set and the fact that a breakout module is being used, the only circuit required is the I^2C interface with the microcontroller as pictured in Figure 4.2.5.1. The breakout module is open hardware released under the Creative Commons Attribution Share-Alike 3.0 License, originally designed by Joel Bartlett [43]. It may be modified freely as required by this project.

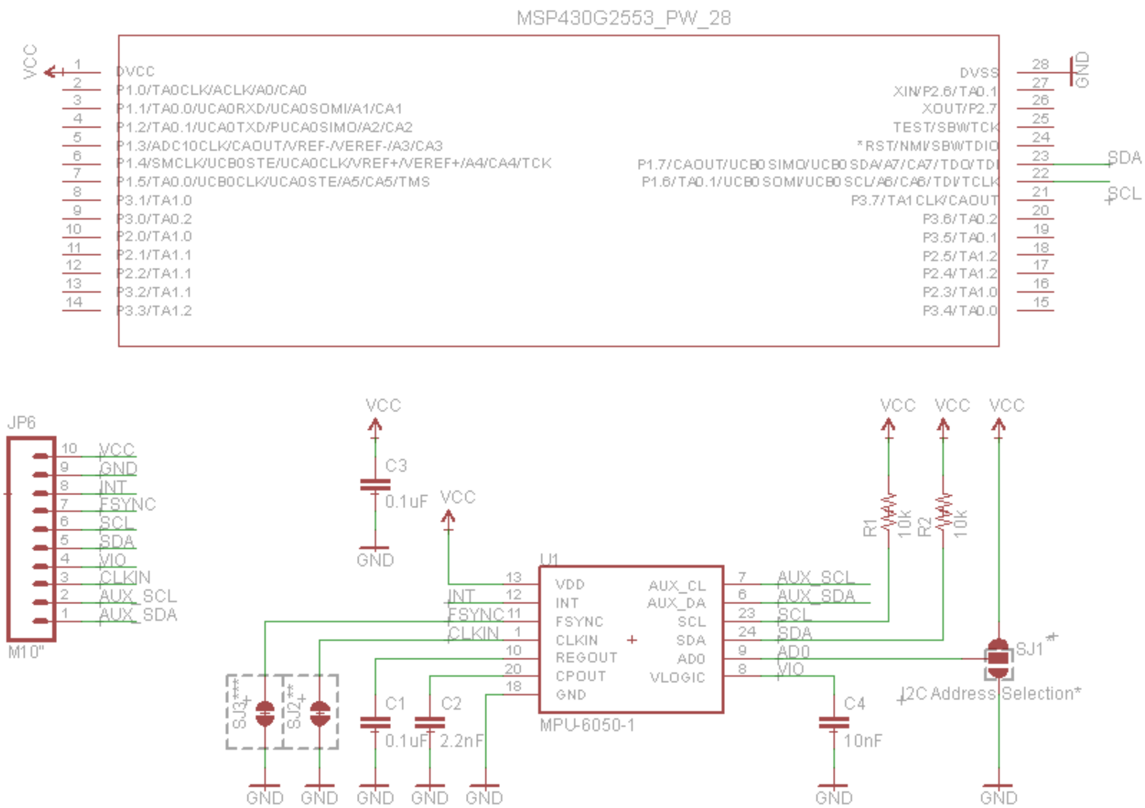


Figure 4.2.5.1 – MPU-6050 connected to MSP430 via I^{2}C. Open hardware released under the Creative Commons Attribution Share-Alike 3.0 License, originally designed by Joel Bartlett [43].

The module will be connected to a separate PCB for the wristband with the available screw holes. The microcontroller will report the values read from the IMU over Bluetooth to the base station. The wristband will constitute an actigraph unit.

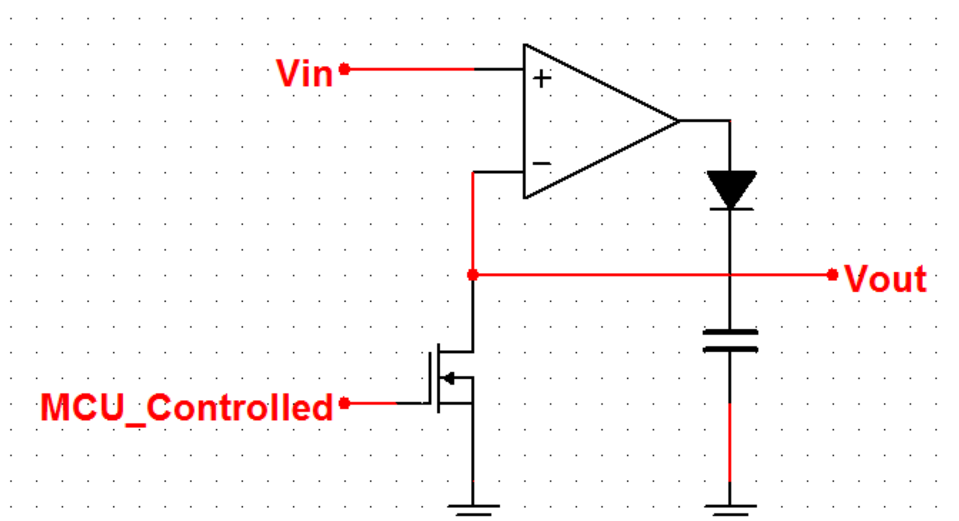


Figure 4.2.4.4 – Peak Detector Circuit to indicate highest degree of snoring in a given time interval.

Another strategy is to use a comparator. Once the snoring breaches a certain threshold, the comparator can output a high to the microcontroller, which will count the number of such instances in a given interval. The number of times the comparator is activated over a period of time should correlate to the level of snoring during that interval.

4.2.6 Vibrator

The Pico Vibe 10mm vibration motor will be used in portable device to provide a small vibration to the user. This motor was selected because it was the smallest vibration motor that was considered and has the lowest weight.

This type of vibration motor is commonly found in cell phones, which provide a strong enough vibration to alert someone when they receive a phone call. Because this particular type of vibration motor has been used in cell phones it indicates that it should also be able to act as an alarm to wake the user in the morning.

The connection between the vibration motor and the microcontroller will be connected as shown in Figure 4.2.6.1. It is not very complicated to connect this motor to the microcontroller so it will be very easy to test during the prototyping phase of this project.

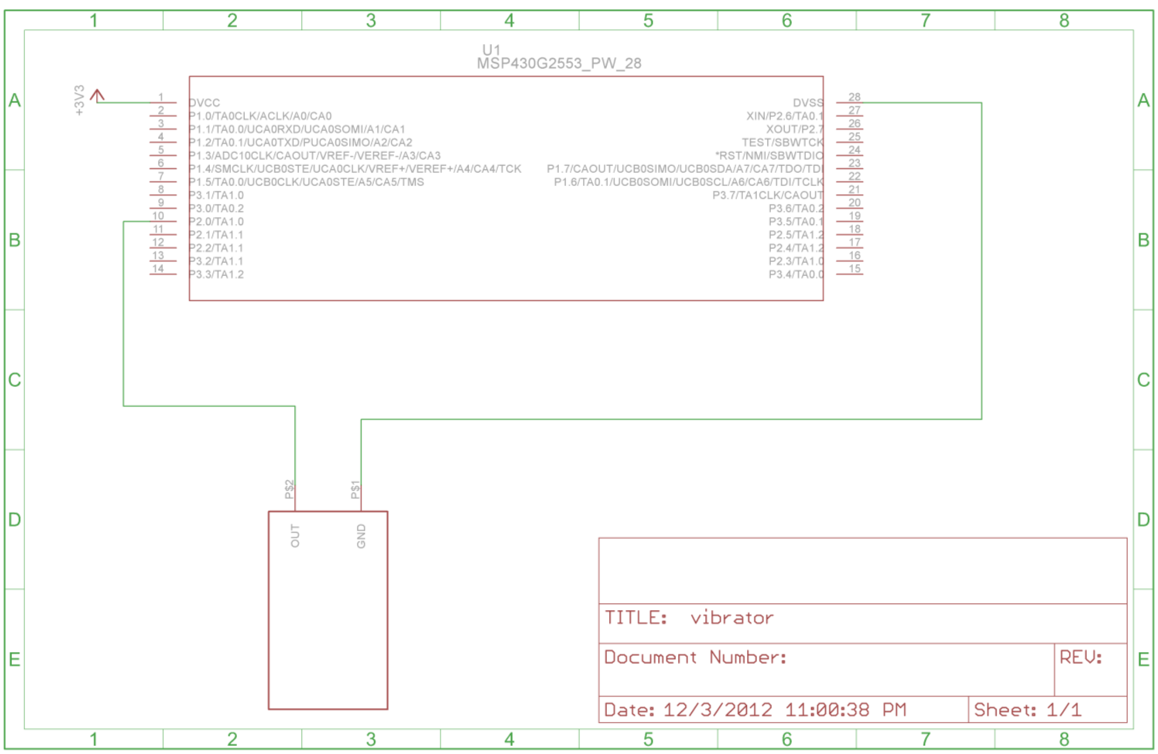


Figure 4.2.6.1 – Pico Vibe 10mm vibration motor connected to MSP430 microcontroller

The only thing to note is that the signal sent from the microcontroller must be a pulse. Vibrators typically do not respond to DC. The vibration intensity is therefore customizable according to the PWM sent from the microcontroller.

4.2.7 Wireless Communication

The wireless communication device that will be used on the peripheral is the RN-42. As seen in section 3.6.3, the RN-42 was chosen because it had extra features like secured communication, auto-discovery/pairing, and guaranteed packet delivery. Once the peripheral is powered on, the auto-pairing feature will allow the user to automatically pair the peripheral with the base station. As shown in figure 4.2.7.1, a red LED is connected to pin 5 on the RN-42 and a green LED is connected to pin 2 on the RN-42. When the RN-42 on the peripheral is powered up, the red LED will continue to blink until it is paired with the base station. Once the peripheral is paired with the base station the green LED will light up.

The most important pins in Figure 4.2.7.1 are the PWR, GND, Rx, Tx, CTS and RTS pins. The table 4.2.7.1 shows the details of each pin.

RN-42 Pin	**Pin Details**
PWR	Power: 3 volts
GND	Ground
Tx	Used to transmit from the RN-42 serial output
Rx	Used to receive into the RN-42 serial input
CTS	Clear-To-Send into the RN-42. This pin is used for hardware flow control. If it is not used connect this pin to the RTS pin.
RTS	Ready-To-Send into the RN-42. This pin is used for hardware flow control. If it is not used connect this pin to the CTS pin.

Table 4.2.7.1 – Pinout details for the RN-42

In this design, the CTS (Clear to Send) and RTS (Ready/Request to Send) pins will not be used. These two pins are supposed to alert the transmitter and receiver of each other's state. This is just overhead. The peripheral would consume more power trying to send an additional Clear to Send and Ready to Send packet to the base station. By default, the RN-42 has CTS/RTS enabled. To disable this feature, the CTS pin is connected to the RTS pin as shown in Figure 4.2.7.1, otherwise the device will not work properly.

The most complex part of this design is connecting the Tx (Transmit) pins and the Rx (Receive) pins. The Tx pin on the RN-42 has to be connected to the Rx pin of the MSP430 and the Rx pin on the RN-42 has to be connected to the Tx pin of the MSP430. Basically, the RN-42 will transmit data from the Tx pin and send it to the Rx pin of the MSP430, indicating that the MSP430 is receiving data.

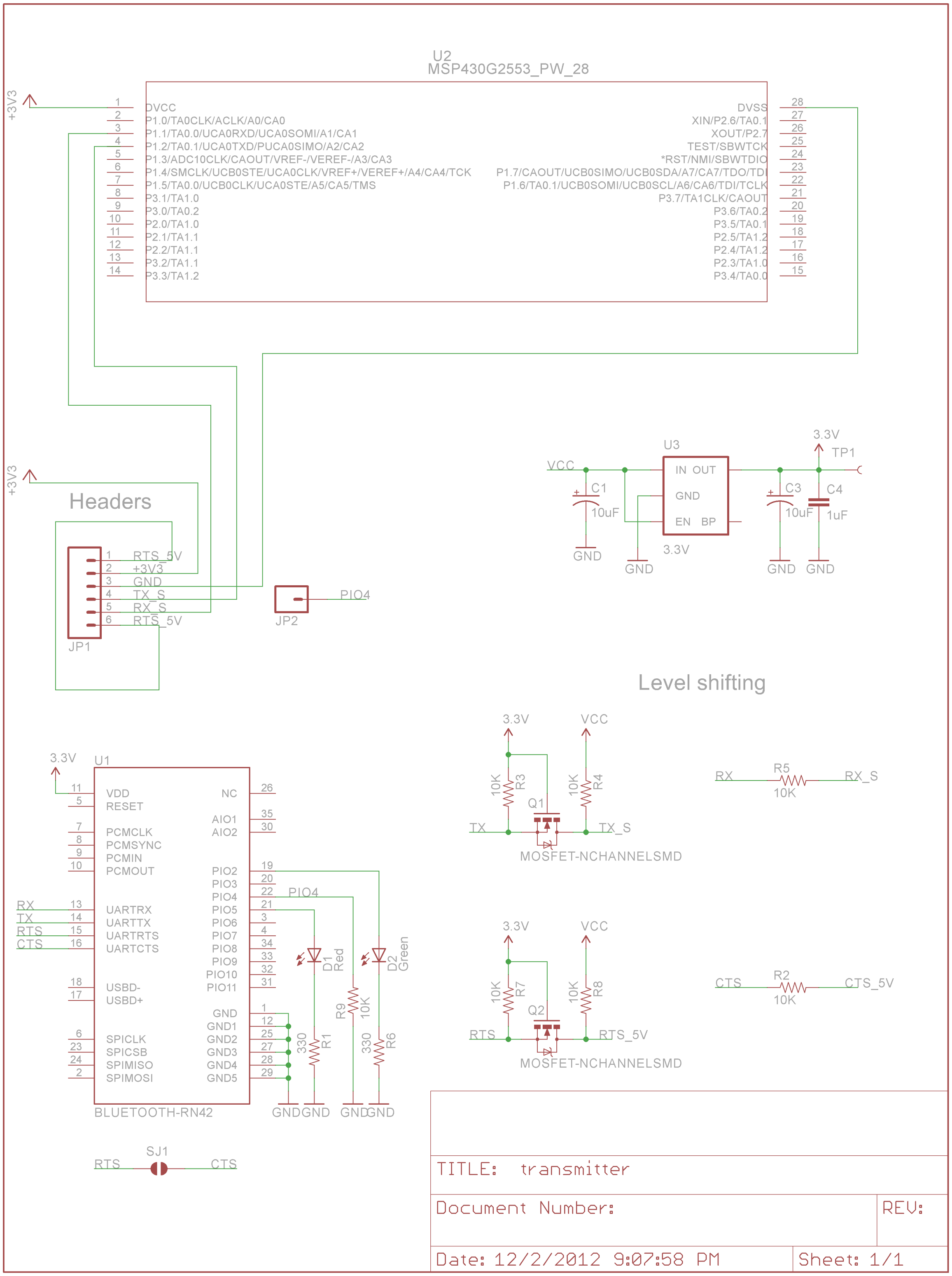


Figure 4.2.7.1 – Schematic of the RN-42 connected to the MSP430

4.3 Base Unit Hardware Subsystems

4.3.1 AC Power Supply

Powering the base station will require a reliable power supply. That is why a commercial product was selected for this task. Not only will it provide a reliable amount of power to the base station, but it will be safer for the user.

It was determined in section 3.5.2 that the designed AC power supply would have been costly to produce and it is unclear how safe the final result would have been. This was a deciding factor when making the final selection for the power supply. This contributed to the selection of a commercial product instead of a designed power supply.

The commercial product that was selected to power the base station was the 5 volt USB wall charger. It is the cheapest solution available and meets the power requirements of the base station. This was also selected because the microcontroller is already powered through a USB cable which will allow for the least amount of modification to the design of the microcontroller's eagle files.

Also, USB is extremely convenient for the end user. Many surge protectors and outlets now offer a direct USB connection, and most users will likely have many USB wall chargers readily available in the event that the original is lost.

4.3.2 Ambient Light

For this project, the photocell was chosen to detect ambient light. They are very low powered, cheap, small and easy to use. Photocells are resistors that change their values depending on the amount of light shining on the cell. The photocell is very inaccurate for precise ambient lighting. For this project the photocell will only need to detect if it is dark in the room or light in the room.

Photocells change resistance when exposed to light. When it is dark in the room, the photocell's resistance will increase. When the light level increases in the room, the resistance will decrease. Table 4.3.2.1 shows what happens to the resistance and current of the photocell in different light settings. To find the voltage and current across the resistor, the value of the pull-down resistor, the resistance of the photocell at a particular light setting, and the amount of voltage supplied will need to be known. Once that is determined, the Equation 4.3.2.1 can be used.

$$V_{Rpull} = VCC\left[\left(R_{pull}\right)/\left(R_{pull} + Photocell\right)\right]$$

Equation 4.3.2.1 – Voltage across the resistor

In Equation 4.3.2.1 V_{Rpull} is the voltage across the resistor, V_{CC} is the voltage supplied, R_{pull} is the value of the pull-down resistor, and photocell is the resistance value of the photocell. Once V_{Rpull} is calculated it is multiplied by R_{pull} to find the current through the photocell.

Light Settings	Photocell resistance	Pull Down Resistor (R_{pull})	Current thru Photocell + R_{pull}	Voltage across Resistor (V_{Rpull})
Moonlit night	70 KΩ	1 KΩ	.007 mA	0.1 V
Dark room	10 KΩ	1 KΩ	.045 mA	0.5 V
Bright room	1.5 KΩ	1 KΩ	.2 mA	2.0 V
Overcast day	300 Ω	1 KΩ	.38 mA	3.8 V
Full daylight	100 Ω	1 KΩ	.45 mA	4.5 V

Table 4.3.2.1 – The illuminance, the photocell resistance, the current through the photocell and resistor, and the voltage across the resistor for some of the different light settings.

As shown in Figure 4.3.2.1, the photocell is connected to the power on the microcontroller and the other side is connected to a 1 kΩ pull-down resistor which is connected to ground. The analog pin of the microcontroller is then connected between the photocell and pull down resistor. Another part of that circuit has an LED that will help determine how bright or dark it is in the room. The LED is grounded and connected to a resistor which is connected to the Stellaris's PA6 pin.

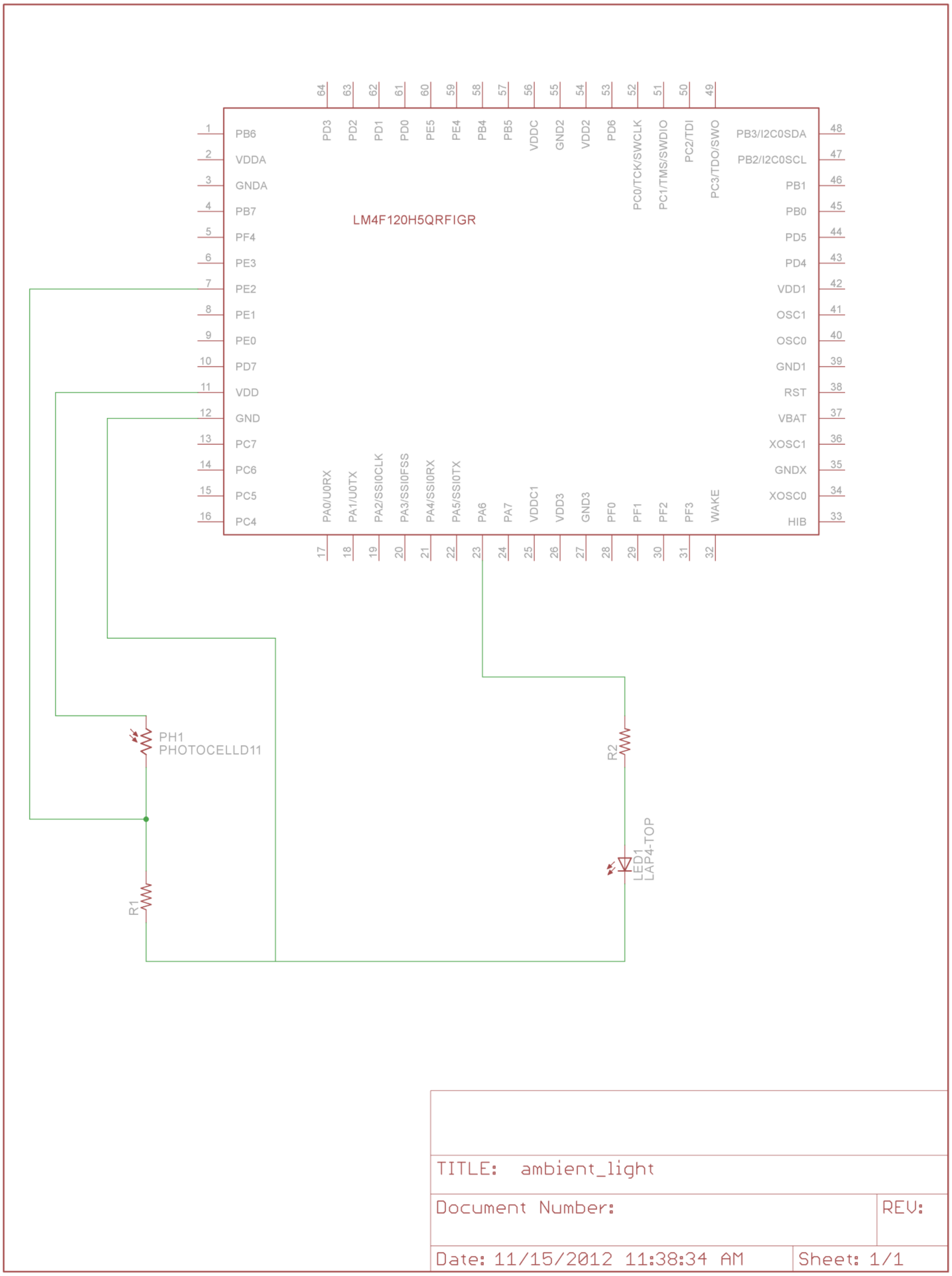


Figure 4.3.2.1 – Ambient light circuit connected to the Stellaris

4.3.3 Ambient Temperature

The MAX6682 thermistor-to-digital IC temperature sensor was selected because of the desired underlying thermistor technology, accuracy, and price for performance. It also conveniently outputs an 11-bit (10-bit + sign) digital value over Serial Peripheral Interface Bus (SPI). The accuracy is within 0.2 °C. A 10K thermistor and an external resistor (selectable based upon the desired temperature range) are selected.

Once the external thermistor and resistor are connected, the IC is powered from the 3.3 volt supply using a bypass capacitor for protection. The IC is interfaced with the microcontroller over SPI by connecting the MAX6672's CS', SCLK, and SO pins to the I/O, SCLK, and MISO pins of the microcontroller.

For the temperature range 0 to 70 °C, the external resistance value needed is 5110 Ω. The datasheet recommends a couple of standard thermistors, of which the Vishay-Dale 1M1002 is chosen. The circuit from the datasheet is shown in Figure 4.3.3.1, copyright of Maxim Integrated Products and reproduced for noncommercial use. This will be the same circuit used in the design, since it is the way the device is intended to be used.

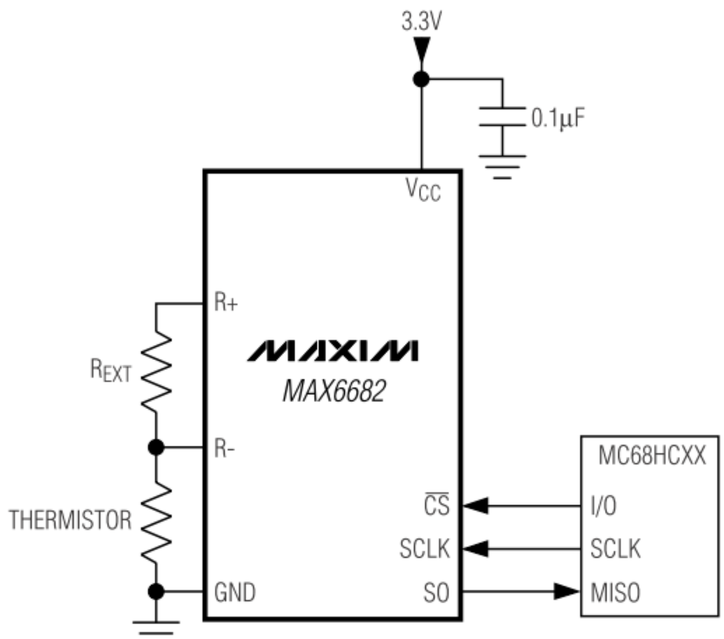


Figure 4.3.3.1 – Typical Operating Circuit for the MAX6682. Copyright of Maxim Integrated Products and reproduced for noncommercial use.

The other consideration is the SPI connection to the Stellaris. The Stellaris uses Synchronous Serial Interface (SSI). Compatibility with three-wire SPI is possible when the SSIFss pin is held low with a pull-down resistor. Referencing back to Figure 3.6.1.2.2, SSI occupies pins 19-22 on the Stellaris. The SCLK, SO, and CS' pin of the MAX6682 will be connected to pin 19 SSIOClk, pin 21 SSIORx, and pin 22 SSIOTx of the Stellaris respectively. Pin 20 SSIFss will be connected to a grounded 1 or 10 kΩ pull-down resistor.

The final consideration is sensor placement in the base unit. It is desirable that the thermistor be exposed to the open air of the room that the user is sleeping in.

There may be a small opening or vent in the base unit to accommodate the temperature measurement.

4.3.4 Buzzer

The buzzer that will be used in this project is the MULTICOMP - MCKP1206R1-4720 piezoelectric type buzzer. The MCKP1206R1-4720 has a wide range of frequencies that will allow for a variety of tones to be produced. This feature can give the designer the ability to manipulate the sound to a very pleasant tone or a very annoying tone for the deep sleepers. As seen in section 3.6.4.1, there were many buzzers to choose from. This buzzer was the most power efficient. It only consumed about 10 mW. The power consumption for the MULTICOMP - MCKPI-G4510L-4013 was about 420 mW and the power consumption for the PRO SIGNAL - ABI-001-RC was about 84 mW. The sound output for the MCKP1206R1-4720 is the loudest, which is rated at 115 dB. It also has the smallest dimensions compared to the rest of the buzzers.

As shown in Figure 4.3.4.1, there are only two pins to connect to the microcontroller to get the piezoelectric buzzer to work.

1. Connect the positive side of the piezoelectric buzzer to pin PB7 on the Stellaris microcontroller.
2. Then connect the piezoelectric buzzer negative side to GND (Ground) on the Stellaris Microcontroller.

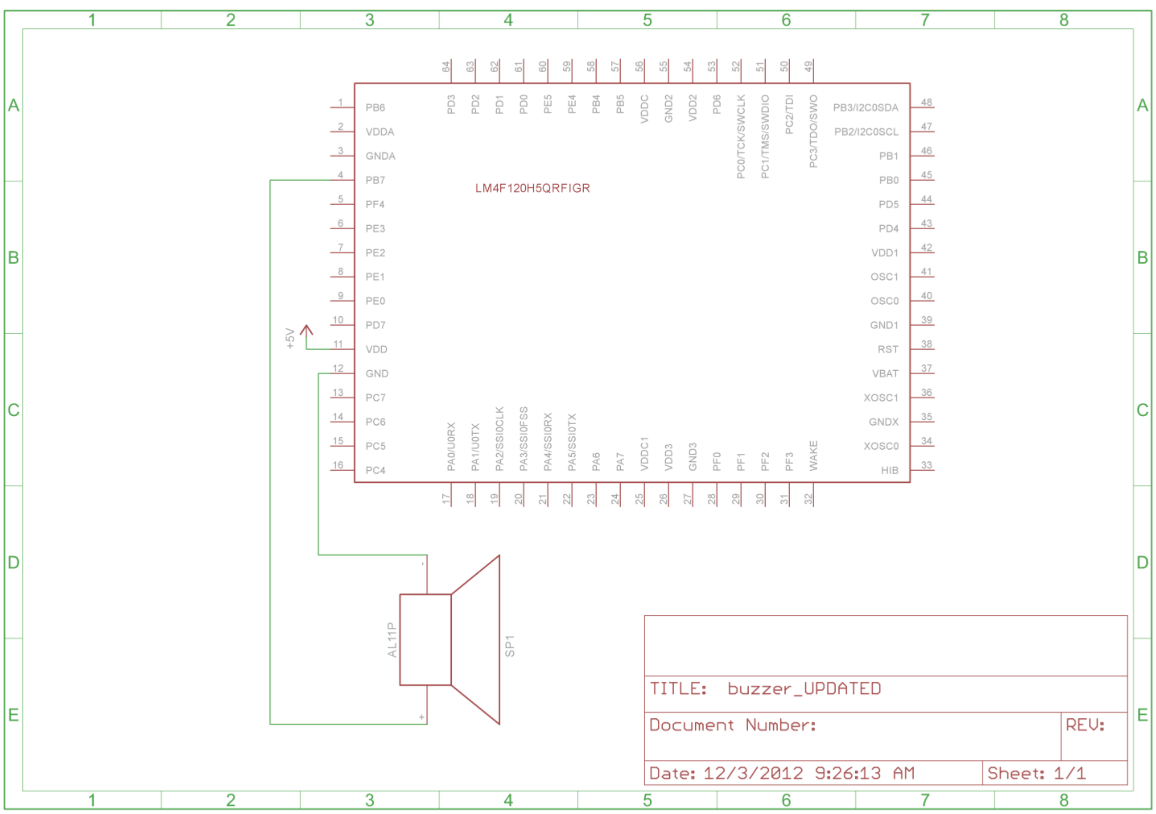


Figure 4.3.4.1 – Schematic connecting the buzzer to the Stellaris microcontroller

4.3.5 Enclosure

The purpose of the base station's enclosure is mostly to satisfy non-functional requirements. It improves visual aesthetics to the base station and protects the hardware from outside forces. In addition, it contains a diagonal slot for the user's device to sit on. It should have the necessary dimensions to fit any size tablets or smart phones. Ideally, the user's device should be held in place by the angle, friction, and weight of the device.

The enclosure contains three USB ports on the top-rear. These ports are meant to be used for charging the peripheral devices using USB A/male to Micro USB/male cables. Figure 4.3.5.1 shows a concept enclosure design for the base station.

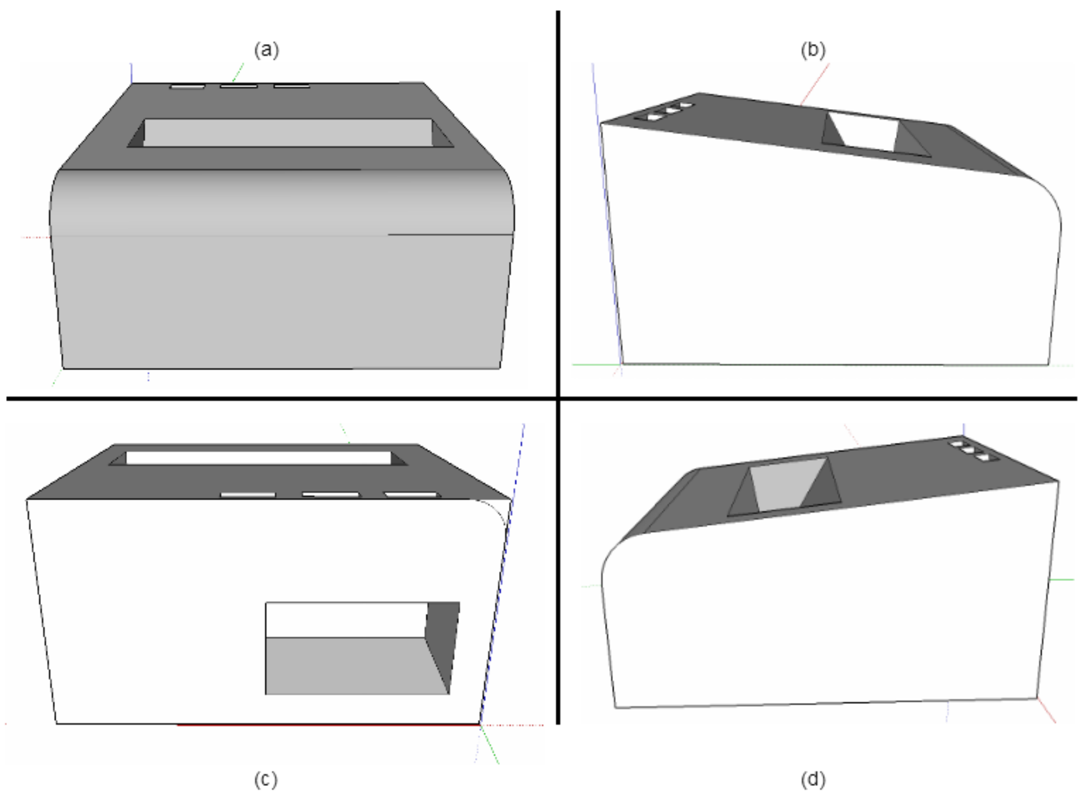


Figure 4.3.5.1 – Concept design for the base station's enclosure. (a) Front-View (b) Left-Side View (c) Back View (d) Right-Side View

4.3.6 Wireless Communication

The wireless communication device used on the base station will be the RN-42 (Roving Network-42), which is the same Bluetooth device used on the peripherals. As seen in section 3.6.3, the RN-42 was chosen because it had extra features like secured communication, auto-discovery/pairing, and guaranteed packet delivery.

In order to connect the RN-42 to the Stellaris microcontroller additional circuitry was needed. As shown in Figure 4.3.6.2, the RN-42 will need a level shifting circuit to connect to the Stellaris microcontroller. This is because the RN-42 supply voltage ranges from 3.0-3.6 volts and the Stellaris microcontroller will use 5 volts. Connecting the Bluetooth device to the Stellaris will eventually overstress the Bluetooth device and it may lead to device failure. This design uses a MOSFET to help determine a digital one from the RN-42 to the Stellaris microcontroller. In Figure 4.3.6.1, the 3.3 volt (RN-42) will transmit into the 5 volt (Stellaris). To transmit a digital zero, the MOSFET becomes grounded and the Tx pin will see 0 volts. For the 3.3V to transmit a digital one, the MOSFET will become HIGH and the TX pin will acquire 5 volts through resistor 3.

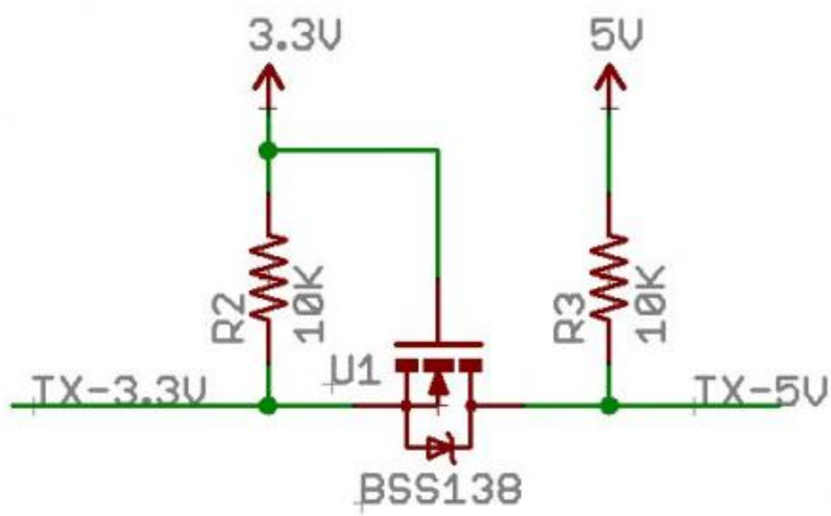


Figure 4.3.6.1 – The level shifting circuit used by the Bluetooth device and base unit

This circuit design is intended for connecting a low-voltage device to a high-voltage device. To interface with this circuit, connect the RN-42 to the left side of the level-shifting circuit and the Stellaris to the right side of the circuit. The diode in the MOSFET will be forward biased if the Stellaris is connected to the left side of the circuit and the RN-42 to the other side.

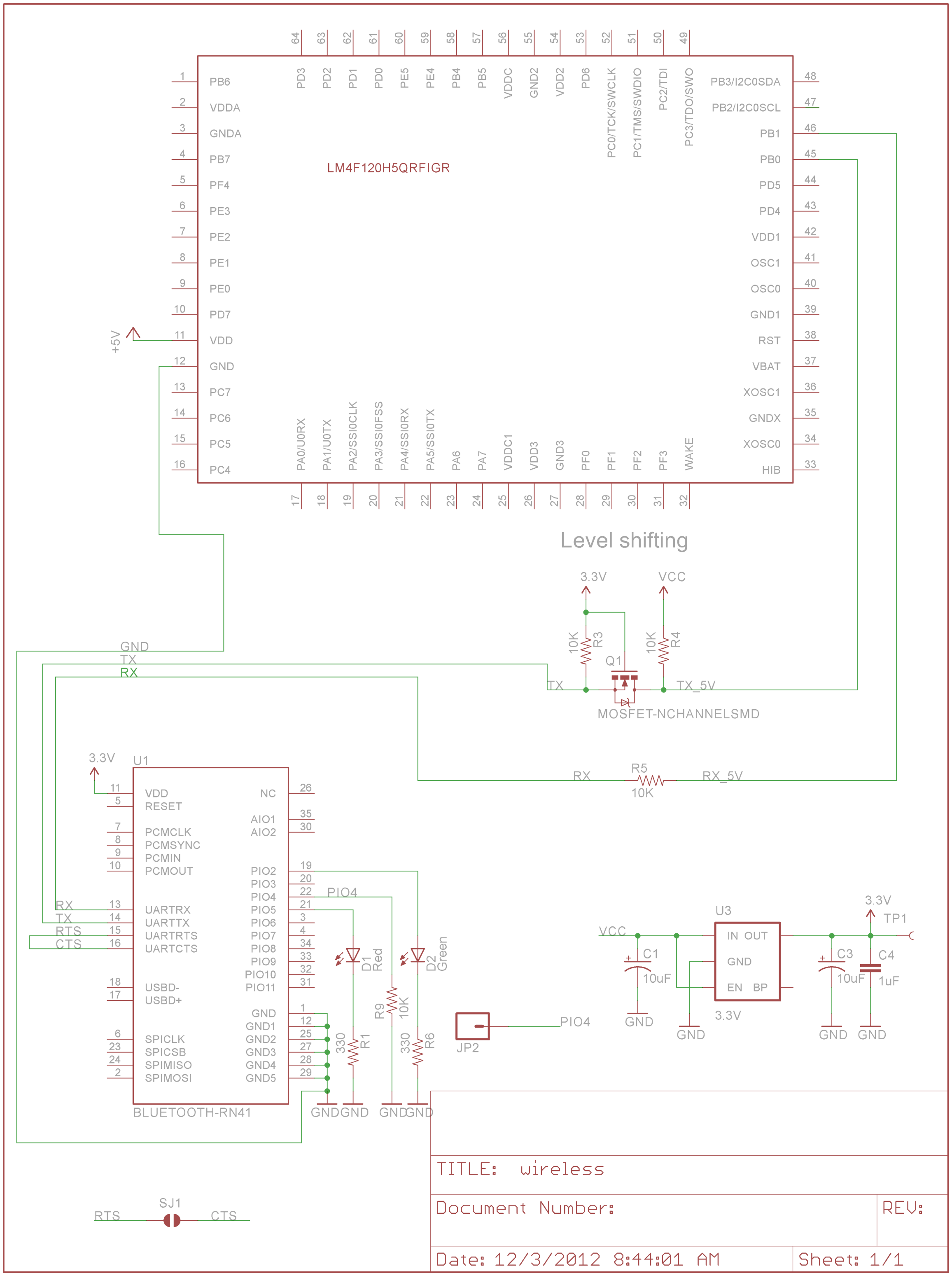


Figure 4.3.6.2 – Schematic of the RN-42 connected to the Stellaris

4.4 Software Design

Unlike hardware, software is much more scalable, malleable, and modular, causing less design risks in many occasions. Typical risks include extraordinary costs that might surface when there is a faulty hardware design. When there is a faulty software design, also known as a “bug," software can be updated with “hotfixes,” “firmware,” and regular “updates.” On the other hand, whenever hardware fails, the design is rigid so a new updated hardware designed has to be produced in order to address the issue.

4.4.1 Graphical User Interface

The Graphical User Interface (GUI) needs to be as intuitive and user-friendly as possible. These goals are classified as non-functional requirements. These requirements are important to the success of the application because it will smooth the interaction between the system and the end-user. If these non-functional requirements are not met, some inevitable consequences could arise and jeopardize the quality of the system.

If the user interface has a bland color scheme, some user controls (e.g. buttons, scrollbars, labels) might not be easy to recognize; hereby, harming the conception of quality for the system. In addition, if the overall presentation of the data is too crowded, it could perplex the user. In retrospect, if an application has a good color scheme, fluid animations, and an intuitive layout, it could help the user interact with the system fluidly while portraying quality.

The picture in Figure 4.4.1.0.1 shows a concept design of what the GoodKnight GUI might look like on a touchscreen tablet.

Figure 4.4.1.0.1 – Concept design of app hosted by a tablet.
***Background image provided by Jessie Eastland aka Robert DeMeo (Own work) [CC-BY-SA-3.0 (http://creativecommons.org/licenses/by-sa/3.0)], via Wikimedia Commons obtained from http://commons.wikimedia.org/wiki/File%3AActual_Sunset.jpg**

4.4.1.1 Application Aesthetics

The application will no doubt have to be appealing in order to be user friendly. However, visually appealing does not necessarily have to be revolutionary, complex, or flashy; instead, it could be minimalistic, clean, simple, and seamless. Within the Android APIs, buttons, text-boxes, labels, titles, and graphs are designed to be dragged and dropped into the application layout without being redesigned. Similarly, Windows 8 APIs provide the same functionality for the components in its Rapid Application Development (RAD) environment within Visual Studio IDE. However, the only drawback to using the "Mono for Android" framework is that the graphical user controls will have to be designed in the target's IDE. Specifically, once an application is built for a Windows 8 device, the backend can then be ported into Android using "Mono for Android." However, the front-end, i.e. the user interface, would have to be redesigned in Android's IDE environment and each graphical user control would have to be linked to the back-end. Figure 4.4.1.1.1, shown below, shows the development pipeline using the platform development environments compared against the development pipeline using "Mono for Android."

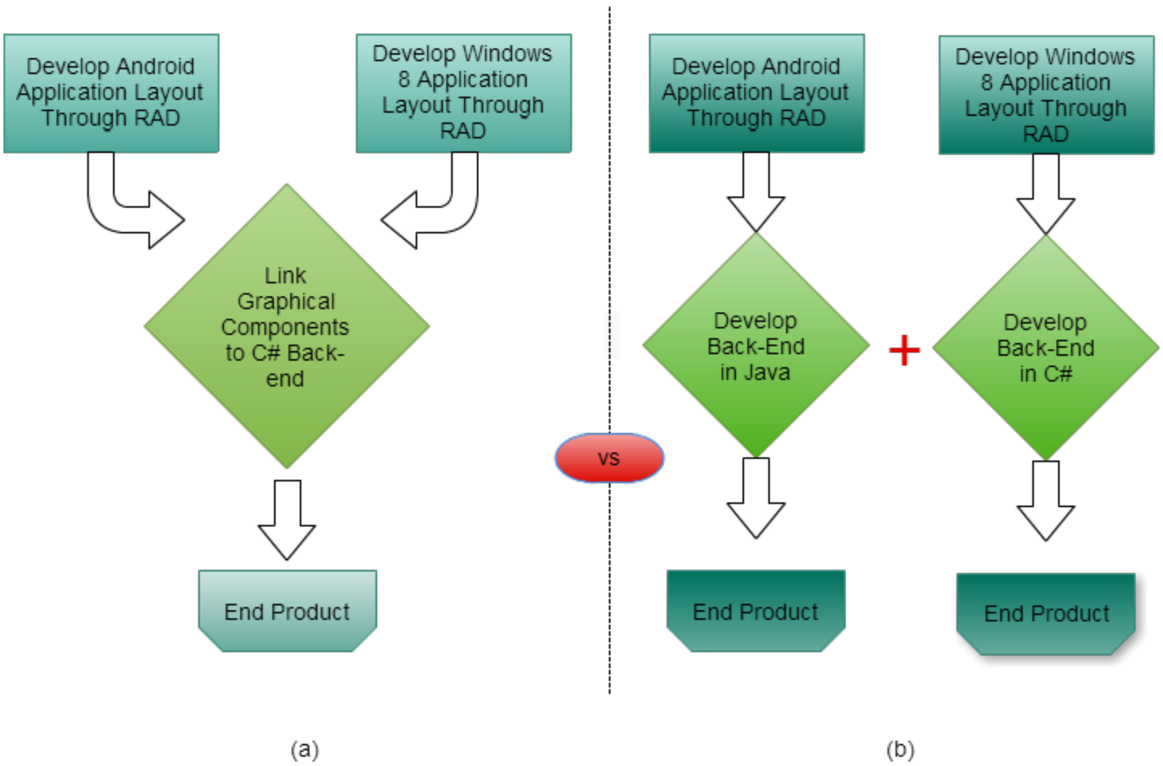


Figure 4.4.1.1.1 – (a) Shows the application development pipeline using Mono for Android (b) Shows the application development pipeline by using the platforms' corresponding development environments.

4.4.1.2 Data Visualization

Once the system detects REM sleep and determines it is a good time to wake the user, the system should be ready to present the acquired data collected throughout the night. Moreover, when the user wakes up, he or she should have the option to see a representation on how, why, and when the system collected data based on his or her temperature, the ambient temperature, his or her movement, and the ambient lighting.

In this case, the system would plot data using a series of graphs and diagrams to help the user understand the data. The most important graph shown will be the hypnogram, a graph that is used to plot a person's sleep cycles as a function of time. This implicitly explains to the user why the system made a decision to trigger the alarm.

Hypnogram

A hypnogram is plotted by interpreting brain activity data collected from an electroencephalogram (EEG). However, in this project, the system must interpret temperature and movement data to infer the brain activity. As our research shows, there is almost a direct relationship between the temperature, movement, and brain activity at least to the extent that sleep stages are concerned.

In most cases, when the brain activity goes up, body temperature and movement go down. Likewise, when brain activity goes down, temperature and movement go up. When sleeping, people usually move less while in the REM stage and therefore reach their lowest temperatures of the night provided the ambient temperature is lower than the body temperature.

The hypnogram used in this project would be developed from the combination of data acquired from the thermometers and the Inertial Measurement Unit (IMU). Hence, by trial and error, an iterative algorithm can be developed to determine when the user is transitioning between sleep stages. In addition, the diagram graphical control could show when the system chose to alert the user. Figure 4.4.2.2.1 provides a concept look at how the hypnogram could appear in a smart device application.

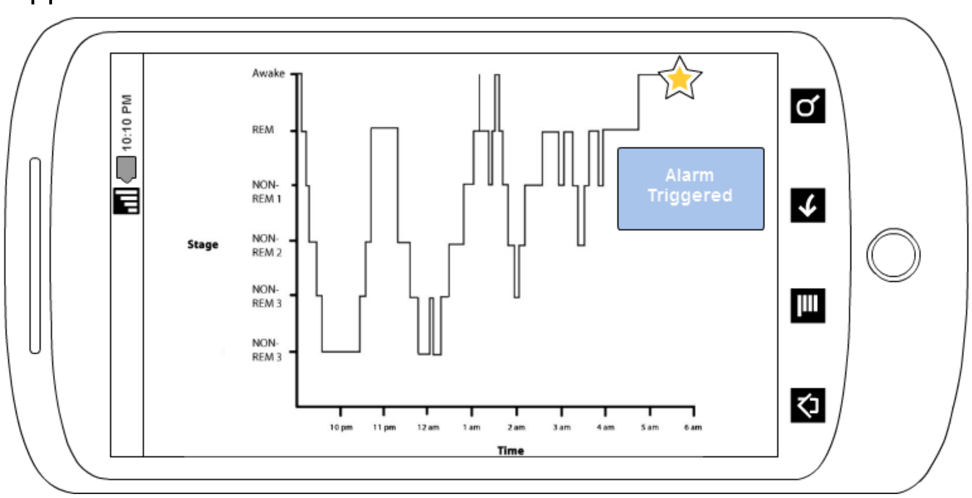


Figure 4.4.1.2.1 – Shows how the implemented hypnogram might look like hosted by an Android application. Hypnogram obtained from http://en.wikipedia.org/wiki/File:HYPNOGRAM_created_by_Natasha_k.jpg and whose original author is Natasha K (id: Tash510). This hypnogram image is also published under the Creative Commons Attribution-Share Alike 3.0 Unported license.

4.4.2 Monitoring Algorithm

As our research states, the best time to wake someone up in order to have a higher state of energy and awareness is immediately after he or she finishes the REM stage. REM stage is typically when a person dreams and, therefore, has a higher state of consciousness due to the higher brain activity. In addition, there can be times within a REM sleep stage that a person's brain activity levels are highly similar to the levels of a fully awakened person. This is why a brief period of wakefulness from REM could also be an optimal time for the user to be woken up by the system.

In essence, the monitoring algorithm should track what stage of the sleep the user is in. Hereafter, it constantly checks weather it is a good time to wake the user based on the time frame that he chose to wake up. Therefore, in most cases, the user will be awakened right after finishing a REM sleep stage. For example, if the user wants to wake up no later than 7 a.m., then if he or she finishes REM sleep at 6:30 a.m., the algorithm should determine that 6:30 a.m. is the best time to wake the user and trigger the alarm. If the algorithm chose to wait any longer, by the time that he or she cycled back to a REM sleep stage it could have been past the time he or she wanted to be awakened.

The following pseudo code shows how the monitoring algorithm should determine whether it's a good time to wake the user.

```
Boolean function IsOptimumTime()
{
      If remaining time is less than 90 minutes
      Else return false;

      //Rem 1
      If imu data is close to 0 and temperature is close to
ambient
            Previous Stage = Sleep stage;
            Sleep stage = 1;
      //Awake or NREM1
      Else if imu data is close to highest and temp is close to
ambient
            If previous stage is REM
                  Previous stage = Sleep stage;
                  Sleep stage = awake;
            Else
                  Previous stage = sleep stage;
                  Sleep stage = NREM1;

      //Determine whether it is a good time to alarm. Hence if
Awake or falling from REM to NREM1
      If Sleep Stage is awake
```

```
            Return true;
        Else if Previous stage is REM and Sleep stage is NREM1
            Return true;
        Else return false;
}
```

4.4.3 System State Machine

For consistency, the system software has to follow a state machine paradigm. Because of the layered architecture, certain modules need to be able to keep track of system states based on messages, signals, and interrupts. For example, if the user launches an event through the user interface to start monitoring his or her sleep, the user interface's back-end needs to communicate wirelessly via Bluetooth to the base station. The base station will receive this message and orchestrate the initialization of all the peripherals connected to the network. Hereafter, it will poll for data from each peripheral. When a peripheral replies, it will process the raw data and archive it. Every few cycles, the peripheral will relay the processed information to the user interface. In addition to this ongoing cycle, there needs to be a way of halting the monitoring loop and respond to interrupts predefined in the system.

Figure 4.4.4.1 exemplifies how the system state machine would be implemented if the user interface were to be implemented as an application for a tablet and the base station (a.k.a. Dock) were to be a Stellaris® LM4F120 based board. Note, this state machine does not exemplify how the Monitoring Algorithm is implemented. Instead, Figure 4.4.4.2 shows how the Monitoring Algorithm would be implemented within said state machine.

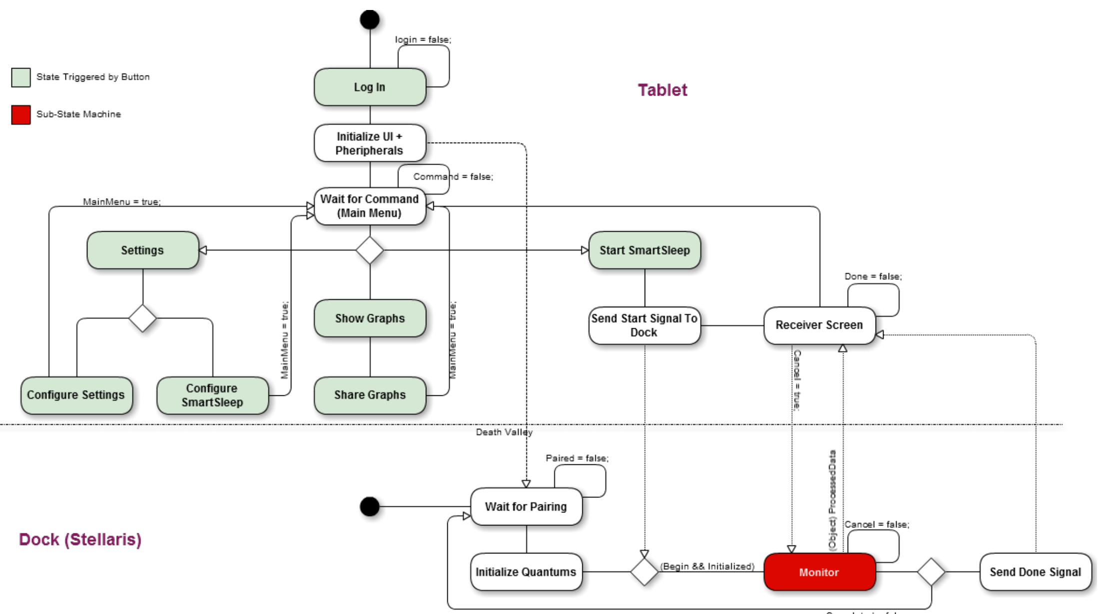


Figure 4.4.3.1 - Main state diagram for the UI, in this case a tablet and Base Station (aka Dock) interactions. NOTE: The Monitor State is a sub-state machine that is also referred to as the Monitoring Algorithm.

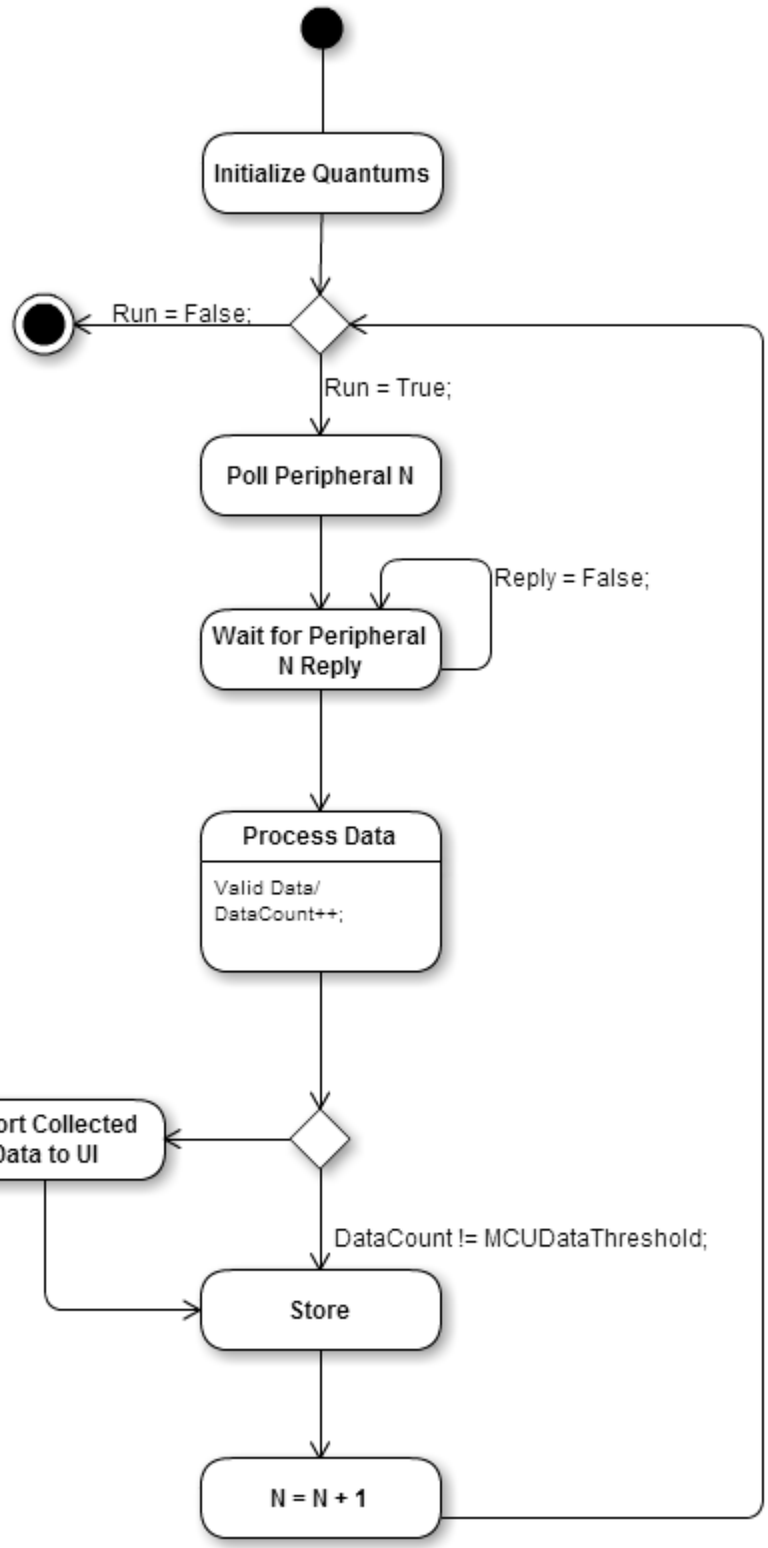


Figure 4.4.3.2 - Monitoring State Machine implemented in the base unit.

5.1 Printed Circuit Board

5.1.1 Board Layout

The layout for the printed circuit boards will be created using the CadSoft EAGLE PCB design software. A free version of this software is available to use. It is a single user license that enables all of the features of the EAGLE standard edition but has certain limitations such as six single layers, 160x100mm routing area, and access to all three modules of the software.

The single user license that is available will be good enough for the needs of this design. All of the designed printed circuit boards will have small dimensions so the size limitations of the single user license will not be an issue.

5.1.2 Board Fabrication

There are numerous companies that are able to fabricate PCBs. All options will be considered when it is necessary to make the transition from a breadboard and testing phase to a final prototype. Companies such as 4PCB will offer discounts to students that reduce the cost of producing a single PCB, which would normally be costly. Occasionally some of the companies will do this service for free, this is a very rare occurrence but has been known to happen.

When getting the PCB fabricated it will also need to be populated. Having the boards populated by a third party is an option because the final prototype is expected to be mostly surface-mount parts to keep the peripherals small. It will still be possible to solder the parts using already available soldering irons, solder paste, and a hot plate. Those items are therefore not included in the bill of materials.

The cost of fabricating the PCB has been included in the bill of materials.

5.2 Project Prototype Testing

In order to assure quality within this project, the system will have to be thoroughly tested. Also, in order to have a thorough and efficient testing plan, the team will have to follow some testing methodologies used in the industry.

In the first stage of the testing, each module will be unit tested. Unit testing is a method in which each module, class, or hardware device is tested to make sure that it handles all possible cases of functionality. For example, if the base station is receiving data from a peripheral in the form of a packet, how would it handle the data received if the connection to the peripheral were to be lost?

In the second stage of testing, successfully tested modules that have passed the unit testing will be integrated with each other. Likewise, modules integrated with other modules will be retested to confirm a successful integration, this is often referred to as regression testing. Integration testing also isolates problems produced from integrating software with software, hardware with software, and hardware with hardware.

Finally, once all modules were integrated together, a final system testing will be performed using a method called system testing. System testing is a method which involves using the product as the user intends to. It is a highly inefficient form of testing when it is performed as the sole method of testing; however, when it is used in combination with other testing methodologies, it is a highly effective form of testing that resembles the concept of "polishing" the final product.

5.2.1 Hardware

Hardware will be one of the most critical and essential parts of this project. The success of the hardware modules will dictate the quality of the final product. Imagine the scenario where a peripheral fails and stops working. The user would have no choice but to replace the peripheral with a new working peripheral in order to solve the problem. A design mistake in the hardware modules will eliminate quality and reliability. For instance, if someone were to buy a new tablet from an electronics store and the tablet stops working unexpectedly, he or she would have to replace it. The customer could not repair it otherwise. Unless there is a technician for tablets, it could not be done. Even if the customer chooses to use the warranty on this tablet, most manufacturers will send them a new one since problems could take weeks to solve. A design flaw or malfunctioning of a component in hardware are very costly and pose a financial risk.

To begin with, critical hardware components, such as DC-DC converters, should be unit tested to confirm their reliability. These unit tests will be performed with instruments including: oscilloscopes, multi-meters, function generators, logic analyzers, etc. These unit tests should also confirm the module meets functional requirements and operation standards imposed on the system.

Secondly, the completed hardware modules will need to be unit tested. Each major sensor within each peripheral needs to work as intended. For example, the IMU within the wrist-strap peripheral would be tested for:

- Steady state – no movement
- Abrupt state – unexpected, jerky movement
- Deliberate state – slow steady movement as intended
- Fault state – behavior after physical shock

On some occasions, after the hardware module is tested, it will also undergo a stress test. Stress testing will involve placing the hardware under the roughest of circumstances to assess how it will react and behave. This method of testing will help resolve any ad-hoc issues with the hardware that might harm the user, issues that might hinder the lifetime of the system, and issues that might cause other components to fail.

5.2.1.1 Unit Test – Peripheral 1 Temperature Sensor

Table 5.2.1.1.1 details how the unit test should confirm that the temperature sensor can successfully obtain temperatures in standard operating circumstances and in ad-hoc situations.

Step	Procedure/Inputs	Expected Results
1. **Determine Accuracy**	Obtain reading from low temperatures (50 °F) Obtain reading from room temperatures (68 °F) Obtain reading from high temperatures (90 °F)	± 1 °F compared to control*
2. **Determine Behavior in Ad Hoc Situations**	Obtain reading after sensor being submerged in bed sheets. Obtain readings in a humid environment.	± 1 °F compared to control*

Table 5.2.1.1.1 – Shows the steps to be performed for a unit test on peripheral 1 for the temperature sensor. *Control: Personal-use, digital thermometer.

5.2.1.2 Unit Test – Peripheral 1 IMU

Table 5.2.1.2.1 details how the unit test should confirm that the IMU responds correctly to standard operating situations and ad-hoc situations.

Step	Procedure/Inputs	Expected Results
1. **Determine Accuracy**	Obtain reading from no displacement. Obtain reading from slow, deliberate movement. Obtain reading from fast, jerky movement.	20% error against control*
2. **Determine Behavior in Ad Hoc Situations**	Obtain readings after receiving physical shock. Obtain readings in a moist environment. Obtain readings in a hot environment.	Still functional after procedures.

Table 5.2.1.2.1 – Shows the steps to be performed for a unit test on peripheral 1 for the IMU. *Control: Third-party High-Precision IMU

5.2.1.3 Unit Test – Peripheral 1 Heart Rate Monitor

Table 5.2.1.3.1 details how the unit test should confirm that the heart rate monitor meets the functional requirements. The monitor should obtain semi-accurate readings from a person.

Step	Procedure/Inputs	Expected Results
1. Determine Accuracy	Obtain reading from no heart rate. (disconnected) Obtain reading from resting state. Obtain reading from high heart rate. (170 bpm)	20% error against control*
2. Determine Behavior in Ad Hoc Situations	Obtain readings after being actively disconnected. Obtain readings from extreme heart rates.	High-risk flag is set.

Table 5.2.1.3.1 – Shows the steps to be performed for a unit test on peripheral 1 for the Heart Rate monitor. *Control: TBD

5.2.1.4 Unit Test – Peripheral 1 & 2 Power Supply

Table 5.2.1.4.1 details how the unit test should confirm that the power requirements for the predicted power intake of all the components within the peripheral are met. In addition, confirm that enough power can be supplied to all the components for at least 8 hours.

Step	Procedure/Inputs	Expected Results
1. Functional Test	Apply a load equivalent to the peripheral's load.	Battery should supply enough power for 8 hours. Battery should not overheat.
2. Operating Temperatures	While step 1 is being performed, obtain temperatures from the power supply.	Power supply should meet operating temperature requirements.

Table 5.2.1.4.1 – Shows the unit test for peripheral 1 & 2 regarding the power supply.

5.2.1.5 Unit Test – Peripheral 1 & 2 Wireless Transmitter

Table 5.2.1.5.1 details how the units test should confirm that the wireless transmitter can transmit/receive packets wirelessly.

Step	Procedure/Input	Expected Results
1. **Send**	Send packet to a receiver. If receiver does not receive packet, retransmit the packet. Retransmit up to 3 times.	Receiver should receive packet.
2. **Receive**	Transmit a packet to the transmitter.	Component should receive packet.

Table 5.2.1.5.1 – Shows the steps to perform of a unit test on the wireless transmitters on peripherals 1 & 2.

5.2.1.6 Integration Test – Integration of components for each peripheral

Table 5.2.1.6.1 details how the unit test should confirm that the components, major sensors, and the microcontroller within the peripheral were successfully integrated.

Step	Procedure/Input	Expected Results
1. **Single power integration**	Connect power supply to a single component at a time	Each component should be powered.
2. **Full power integration**	Connect all the components to the power supply	All components should be powered.
3. **Algorithm test**	Perform a functional test on the peripheral.	Collect data from each component, form a new packet, and send the packet through the wireless transmitter.
4. **Functional test**	Run the completed peripheral for 8 hours.	Data should be collected, processed, and sent for 8 hours straight without loss of power or faults.

Table 5.2.1.6.1 – Shows the integration test composed of unit tests for each peripheral.

5.2.2 User Interface

The user interface module will undergo a mixture of non-functional and functional tests. Functional tests are tests that check that the software meets functional requirements, i.e. functionality that defines what a system should accomplish. Non-functional tests are tests that mainly check for the quality of the system. In this project, the user-interface will undergo functional tests to confirm that its back-end meets functional requirements. On the other hand, non-functional tests will confirm that the user interface is easy-to-use and contains good visual aesthetics.

5.2.2.1 Functional Test

Table 5.2.2.1.1 details how a functional test should confirm that the user interface's back-end pairs up with Bluetooth devices and that it closely follows the main state machine.

Step	Procedure/Input	Expected Result
1. **Test User Login**	Create a new account as a new user and attempt to log in.	User should be able to log in.
2. **Test Connectivity with Dock**	Create a unit test to confirm that the tablet can pair up with the dock through Bluetooth.	The tablet and dock should pair up.
3. **Start system**	Use the debugging LCD to print out a statement that the system has started if the user selects start from the UI.	The debugging LCD should confirm that the system was started.
4. **User configures settings**	If the user chooses to change the system settings, the settings should be traced through the debugger to confirm that they have been updated.	The system settings should have been updated.
5. **System is started**	Use the debugging LCD to print incoming data from the peripherals while in "monitoring" state.	Dock should go into "Monitor" state.
6. **System is stopped**	Use the debugging LCD to inform that the system has been halted whether it was stopped by the user or by a fault.	The system should stop.

Table 5.2.2.1.1 – Shows the steps to perform for a user-interface functional test.

5.2.2.2 Non-Functional Test

This non-functional test should quantify the quality of the user interface; hence, user controls used in the application should appear glitch-free, reliable, and the overall layout is intuitive and easy to use. Table 5.2.2.2.1 lists the details for the non-functional test.

Step	Procedure/Input	Expected Result
1. Controls (e.g. Buttons, scrollbars, checkboxes)	Log in as the user and check whether the user-controls respond accordingly to clicks, hovers, and resizing.	User-controls should work as expected and intended.
2. Layout adjustment	Flip tablet to landscape view.	Layout should change to landscape view.
3. Data presentation	Input the data control with fake data to see how it's plotted by the control.	The fake data should be plotted as a hypnogram.
4. Intuitiveness	Have a first-time user try to use the app and provide feedback on his troubles.	First-time user should intuitively use the app.

Table 5.2.2.2.1 – Shows the steps to perform for a user-interface non-functional test.

5.2.3 Wireless Communication

The communication protocols between the base station and the peripherals are imperative. Without a successful communication between the two entities, information will not be able to be delivered to the user and commands will not be propagated down through the system architecture. As a result, this communication pipeline will undergo a series of regression tests that will include: unit tests, functional tests, and stress tests.

Unlike the previous modules, stress testing will be highly significant in the wireless communication portion of the project. By stress testing the network, the team will be able to assess the throughput and the threshold of the information being transmitted back and forth.

5.2.3.1 Unit Test – Peripherals 1 & 2

Table 5.2.3.1.1 details how the unit test should confirm the ability for the peripherals to communicate wirelessly with a device resembling the base station.

Step	Procedure/Input	Expected Result
1. Throughput Test	Program the peripheral to send as many packets as possible through the network. If sending queue becomes very large. Stop, decrease the rate at which packets are sent.	Peripheral should not be able to send packets without any time between transmissions. The peripheral should have enough time to transmit the packet before moving on to the next one.
2. High-Throughput Reception Test	Program the peripheral to listen to incoming packets from a device. Have the testing device send as many packets as possible.	The peripheral should receive some of the packets. If some packets were lost, reattempt the test with a slower throughput from the other device.

Table 5.2.3.1.1 – Shows the steps for a unit test on the wireless communication (software) of peripherals 1 & 2.

5.2.3.2 Unit Test – Base Station

Table 5.2.3.2.1 details how unit test should confirm the ability of the base station to communicate wirelessly to devices resembling the peripherals.

Step	Procedure/Input	Expected Result
1. Throughput Test	Program the base station to send as many packets as possible through the network. If sending queue becomes very large. Stop, decrease the rate at which packets are sent.	Base station should not be able to send packets without any time between transmissions. The peripheral should have enough time to transmit the packet before moving on to the next one.
2. High-Throughput Reception Test	Program the base station to listen to incoming packets from a device. Have the testing device send as many packets as possible.	The base station should receive some of the packets. If some packets were lost, reattempt the test with a slower throughput from the other device.

Table 5.2.3.2.1 – Shows the steps for a unit test on the wireless connection for the base station.

5.2.3.3 Functional Test – GoodKnight Network

This functional test should confirm the reliability of command messages delivered from the base station to a device resembling a peripheral. In addition, it should confirm the appropriate response the peripheral undertakes.

Step	Procedure/Input	Expected Result
1. Command Transmission Test	Send a command to the peripheral from the base station (e.g. start measuring, stop measuring, data request)	Base station should transmit the command to the peripheral. Peripheral should reply accordingly to the command.
2. Data Reply Test	Make the base station poll for data from the peripheral.	The peripheral should reply with appropriate data.

Table 5.2.3.3.1 – Shows the steps for a functional test on the system's network.

5.2.3.4 Stress Test – GoodKnight Network

This stress test analyses the threshold and throughput of the network. This test also inherently determines the reliability of the network.

Step	Procedure/Input	Expected Result
1. High Command Traffic	Program the base station to send as many commands as possible. If the peripheral loses commands, then lower the throughput.	Peripheral should handle a large number of commands from the base station. Test should determine the number of maximum commands it can handle.
2. High Data-Reply Traffic	Have numerous peripherals reply with data to the base station.	Observe how many data-replies the base station can handle.

Table 5.2.3.4.1 – Shows the steps for a stress test on the system's wireless network.

5.2.4 Integration

Once the main parts of the project are tested, i.e. the hardware, the user-interface, and the wireless communication, they are ready to be integrated and receive a final system test. This portion of testing will be the last safety-net before the bugs are caught before being released out to the public.

The method of testing used will be regression testing. Hence, previous unit tests will be performed again. Once the regression testing is done, it will be followed by a system test; hence, the system will be used just as how the end-user would use it.

5.2.4.1 Regression Testing

After integrating all the modules, this regression test should catch any bugs or runtime errors not previously detected during previous tests.

Step	Procedure/Input	Expected Result
1. Integrate All Parts	Integrate the hardware with wireless modules. Hereafter, integrate the wireless modules with the user interface.	-
2. Functional Test - Hardware	Perform main functional test on hardware components.	Same result as previous functional tests performed on the hardware.
3. Functional Test – User Interface	Perform main functional test on software modules.	Same result as previous functional tests performed on the user-interface.
4. Functional Test – Wireless Communications	Perform main functional test on software modules.	Same result as previous functional tests performed on the communications.

Table 5.2.4.1.1 – Shows the steps for a system regression test.

5.2.4.2 System Test

This system test should confirm that the system meets all the system's functional and non-functional requirements. Section 2.3 lists all the requirements established for the project.

Step	Procedure/Input	Expected Result
1. **Download and Start Application**	Download app from Android/Windows store. Start the application.	Application should download from the store. User should be able to use it.
2. **Make a New Account**	Sign up to make a new GoodKnight account.	Account should be created and user should be able to log in.
3. **Recover Password**	Click on the recover password option. Input user validation information to try to recover password.	Email should be sent to the user with new password.
4. **Monitoring Test**	User should try to start the smart alarm previous to going to sleep.	The user should be able to choose the settings he/she would like. The system should begin monitoring.
5. **Alarm Test**	-	The system should sounds its buzzer when the user finished his REM stage and it's close to the time that he/she wanted to wake up.
6. **User Data Test**	User should click to see the data collected. Hypnogram and the temperature & movement graph.	All the diagnostics that the user requests should be plotted and displayed accordingly.
7. **Longevity Test**	If the system did not run for at least 8 hours, let it run until it has been 8 hours.	The system should not lose power, fault, or unexpectedly shut down.

Table 5.2.4.2.1 – Shows the steps for a full system test.

6.0 Administrative Content

6.1 Milestone Discussion

Project management is a key aspect of any successful project. This project will be broken down into achievable milestones that will span two semesters. With the project broken down into milestones it will be more manageable to complete, without overwhelming any of the team members.

The timelines will take into account extra time that will need to be allocated for problems that may arise during the development phases. The hardware timelines will have less flexibility concerning exceeding the specified deadline for completion. This is because the software timeline will lag behind the hardware.

The timeline associated with software will be staggered to allow for coding to be completed on each hardware element as it is completed.

Each milestone in the project will be given between one and two weeks to be completed. Some of the later milestones will build from these previous milestones. This short time frame is to keep the group focused on each milestone.

Through weekly meetings discussing progress, the group plans to stay on target for each milestone. If necessary the group will extend the milestone for elements that encounter any unexpected difficulty. Extending a milestone is not an ideal scenario so it will be done in only special circumstances.

6.1.1 Senior Design I

During the first semester of Senior Design, research and testing will be the main focus. This is done so that the group can learn the material that is necessary to complete each milestone.

Research will take a considerable amount of time during the first semester. This is done so that the group can become familiar with the options that are available to complete the different objects. It is important to research each part to determine if it will fit into the design specifications. Not only will the parts be researched in this stage of the project but also the different sub system that make up the complete design. The group is doing this to completely understand what needs to be done for each section and determine how much time will need to be allocated to complete it.

Table 6.1.1.1 was created to display the milestones for the group during the first semester. This table will list the different elements of the projects in each stage of the design process and give a time frame on when it should be started and completed.

		Dates										
		1-Oct	8-Oct	15-Oct	22-Oct	29-Oct	5-Nov	12-Nov	19-Nov	26-Nov	3-Dec	10-Dec
Research	Pulse Oximeter	■	■	■	■	■	■					
	Body Temperature	■	■	■	■	■	■					
	Movement	■	■	■	■	■	■					
	Microphone	■	■	■	■	■	■					
	Vibration	■	■	■	■	■	■					
	Wireless Communication	■	■	■	■	■	■					
	DC Power Supply	■	■	■	■	■	■					
	AC Power Supply	■	■	■	■	■	■					
	Temperature	■	■	■	■	■	■					
	Buzzer	■	■	■	■	■	■					
	Alarm	■	■	■	■	■	■					
	Display Interface	■	■	■	■	■	■					
	Microcontrollers	■	■	■	■	■	■					
Prototype	Pulse Oximeter	■	■	■								
	Body Temperature				■	■						
	Movement						■	■				
	Microphone	■	■									
	Vibration						■	■				
	Wireless Communication	■	■									
	DC Power Supply								■	■	■	■
	AC Power Supply								■	■	■	■
	Temperature				■	■						
	Buzzer						■	■				
	Alarm						■	■				
	Display Interface	■	■	■	■							
	Microcontrollers	■	■	■	■	■	■	■				

Table 6.1.1.1 – Senior Design I Milestones

6.1.2 Senior Design II

During the second semester of Senior Design the focus will be on finishing the prototyping, integrate the prototypes, design software, order materials, and design PCBs.

Finishing the hardware prototypes will be a priority in the first couple weeks so that the software development can begin. Once the prototyping stage is complete it will be important to start ordering parts for the final PCBs as soon as possible.

Ordering materials in a timely manner will be important. With most the online retailers for electric parts the cheapest parts come from outside the country, this will add to the time it takes for the parts to arrive. That is why that it is necessary to do so soon after completing the prototyping stage.

Table 6.1.2.1 was created to display the milestones for the group during the second semester. This table lists the different elements of the projects in each stage of the design process and gives a time frame on when it should be started and completed.

		Dates								
		1-Jan	15-Jan	29-Jan	12-Feb	26-Feb	12-Mar	26-Mar	9-Apr	23-Apr
Improve Designs	Pulse Oximeter	■								
	Body Temperature	■								
	Movement	■								
	Microphone	■								
	Vibration	■								
	Wireless Communication	■								
	DC Power Supply	■								
	AC Power Supply	■								
	Temperature	■								
	Buzzer	■								
	Alarm	■								
Test	Pulse Oximeter		■							
	Body Temperature			■						
	Movement			■						
	Microphone			■						
	Vibration			■						
	Wireless Communication		■							
	DC Power Supply		■							
	AC Power Supply		■							
	Temperature		■							
	Buzzer				■					
	Alarm				■					
	Display Interface					■				
	Microcontrollers	■								
	Wearable Device						■	■		
	Base Station						■	■		
Order Parts	Printed Circuit Board (PCB)								■	
	Parts for PCB	■								
	Base Enclosure	■								
	Wearable Enclosure	■								
	Microcontrollers	■								
	Perforated Boards	■								
	Parts for Perforated Boards	■								
Software	Pulse Oximeter			■						
	Body Temperature				■					
	Movement				■					
	Microphone				■					
	Vibration				■					
	Wireless Communication			■						
	Temperature			■						
	Buzzer					■				
	Alarm					■				
	Display Interface	■	■	■	■					
	Wearable Device						■	■	■	■
	Base Station						■	■	■	■

Table 6.1.2.1 – Senior Design II Milestones

6.2 Budget and Finance

Although many components were discussed towards usage and implementation in the project, there are other costs involved in the development, prototyping, and fabrication of the system. Therefore, in order to have these costs reflected on the project's budget, they were included as part of the Bill of Materials. Table 6.2.1.1 shows the Bill of Materials, the pre-planned costs given the project's budget.

Many items may not appear in the final prototype. Please note: incidentals such as resistors, capacitors, and other small negligible prototyping components are not included.

Other required test bench equipment such as oscilloscopes, function generators, and power supplies are made available from the University of Central Florida. Software Licensing fees and the cost of fabricating PCBs are also included. The overall budget is expected to remain below $1,000.00, even with forthcoming incidentals. This is because the project is as yet unsponsored, although sponsorship during Senior Design II is not out of the question.

6.2.1 Bill of Materials

Part	Part #	Manufacturer	Unit Price	Quantity	Cost
10K Thermistor	1M1002	Vishay-Dale	$ 1.01	1	$ 1.01
850mA/H LiPo battery	63048	UNIONFORTUNE	$ 8.95	1	$ 8.95
Accelerometer, 3-Axis	MMA8453QT	Freescale	$ 1.46	1	$ 1.46
Accelerometer, 3-Axis	MMA7660FCR1	Freescale	$ 1.18	1	$ 1.18
Ambient Light Sensor (Analog)	APDS-9008-020	Avago	$ 0.75	2	$ 1.50
Barometer	MPL115A2T1	Freescale	$ 1.99	1	$ 1.99
Buzzer	ABI-001-RC	PRO SIGNAL	$ 2.23	1	$ 2.23
Buzzer	MCKPI-G4510L-4013	Multicomp	$ 1.81	1	$ 1.81
Buzzer	MCKP1206R1-4720	Multicomp	$ 1.23	2	$ 2.46
Heart Rate Monitor Frontend	AD8232ACPZ-WP	ANALOG DEVICES	$ 2.89	2	$ 5.78
Humidity and Temperature Sensor	RHT03	MaxDetect	$ 9.95	2	$ 19.90
Humidity Sensor	HCH-1000-002	Honeywell	$ 3.20	2	$ 6.40
Humidity Sensor	HIH-5031-001	Honeywell	$ 13.00	1	$ 13.00
IMU (Accel + Gyro)	MPU-6050	InvenSense	$ 9.47	1	$ 9.47
Infrared Light-to-Voltage Sensor	TSL262R-LF	TAOS	$ 2.71	2	$ 5.42
Infrared Temperature Sensor	ZTP-115	GE	$ 4.01	2	$ 8.02
Infrared Temperature Sensor	MLX90614DAA	Melexis	$ 14.31	1	$ 14.31
Infrared Temperature Sensor	TMP006AIYZFR	Texas Instruments	$ 3.40	1	$ 3.40
Jumper Wires 12" F/F	PRT-09389	Generic Chinese	$ 4.50	1	$ 4.50
Licensing Fee - Mono for Android	N/A	Xamarin	$ 80.00	1	$ 80.00
Licensing Fee - RadControls	N/A	Telerik	$ 199.00	1	$ 199.00
LiPo Charger Basic	MCP73831/2	Microchip	$ 9.95	1	$ 9.95
LiPo DC-DC Supply	TPS650250RHBT	Texas Instruments	$ 4.38	1	$ 4.38
LiPo DC-DC Supply	TPS650250RHBT	Texas Instruments	$ 4.38	1	$ 4.38
Microphone	MCKPCM-60H50-40DB-4805	Multicomp	$ 0.15	2	$ 0.30
Microphone	AOM-4544P-2-R	Projects Unlimited	$ 0.85	1	$ 0.85
Microphone	ABM-707-RC	Pro Signal	$ 1.11	2	$ 2.22
Module Bluetooth v2.1+EDR	RN-42	Microchip	$ 19.14	2	$ 38.28
MSP430 Launchpad	MSP-EXP430G2	Texas Instruments	$ 4.30	3	$ 12.90
Optical Reflective Sensor	TCRT1000	Vishay	$ 0.80	1	$ 0.80
Optical Reflective Sensor	TCND5000	Vishay	$ 2.48	2	$ 4.96
PCB Fabrication	All Boards	4PCB Advanced Circu	$ 33.00	3	$ 99.00
Perforated Board - Round 2"	PRT-08810	SparkFun Electronics	$ 2.95	1	$ 2.95
Photocell	GL5528	Generic Chinese	$ 1.50	10	$ 15.00
Phototransistor	TEMT6200FX01	Vishay	$ 0.59	1	$ 0.59
Stellaris Lauchpad	LM4F120	Texas Instruments	$ 15.00	3	$ 45.00
Thermistor-to-Digital Converter	MAX6682	Maxim	$ 2.88	1	$ 2.88
TouchScreen	LP101WX1	LG Electronics	$ 170.00	1	$ 170.00
Vibration Motor	310-103	Precision Microdrives	$ 6.71	1	$ 6.71
Vibration Motor	Precision Microdrives	ROB-08449	$ 4.95	1	$ 4.95
Wall Charger - 5V USB 1A	TOL-11456	Generic Chinese	$ 3.95	1	$ 3.95
Total					**$821.85**

Table 6.2.1.1 – Bill of Materials 1

7.0 Project Summary and Conclusions

The overall design plan of the system has been completed at this point with all the parts selected for the prototyping phase. Once the parts are ordered it will be a matter of verifying, testing, and elaborating on the designs explored here for each subsystem. Properly functioning subsystems will provide the tools necessary to realize the design plan. They will be integrated into an operational sleep management system.

This sleep management system has plenty of room to grow into a more complex system. By following the timeline created in the milestone section of this report, it will be possible to incorporate some of the mentioned features that can add polish to the system.

Appendices

Appendix A: Copyright Permissions

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Merken, Leo <Leo.Merken@atmel.com> 5:54 PM (5 hours ago)

to me

Dear Mr. Bharrat,

Your inquiry below was forwarded to me for response. If I understand the situation correctly, you are designing a system for a school project, are considering using Atmel products in the design, and if you do, you will want to use figures (and perhaps other information) from our relevant datasheets in documenting your design.

We appreciate your checking with us for permission to use our copyrighted material from our datasheets, even though the kind of reproduction you describe—for nonprofit educational purposes—could be considered as the type of permitted copyright "fair use" that does not even require Atmel's approval. To the extent that our approval is required, we certainly do approve your use of figures, and portions of other information, from our publicly-available datasheets, in connection with your school project. We do ask that you attribute (provide a bibliographic citation to) the source of the material you use.

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Regards,

Leo Merken

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From: Anthony Bharrat [mailto:anthonyb2477@gmail.com]
Sent: Monday, December 03, 2012 9:25 PM
To: DL-SJO-Sales-CustomerService
Subject: Permission to reprint images for School Project

Hi,

My senior design group is designing a sleep management system and we are considering using the Atmega328 and the Atmega2560. We are required to write and submit a document with our design details. Can we use the figure in your datasheet that shows the pin out of the microcontroller?

Thank you,
Anthony Bharrat

Component Arts Permissions

From: **Miljan Braticevic** <miljan@componentart.com>
Date: Wed, Dec 5, 2012 at 10:45 AM
Subject: RE: Permission to reprint images for School Project
To: Anthony Bharrat <anthonyb2477@gmail.com>

Hi Anthony,

Sure, you have our permission to use our product images in your document.

Good luck!

Miljan Braticevic
President and CEO | ComponentArt Inc.
Office: 416-622-2923, ext: 223 | Fax: 416-620-0775
511 King St. West, Suite 400, Toronto, ON M5V1K4, Canada

ComponentArt Your Data on Any Device

From: Anthony Bharrat [mailto:anthonyb2477@gmail.com]
Sent: Tuesday, December 4, 2012 6:31 PM
To: Miljan Braticevic

Subject: Permission to reprint images for School Project

Hi,

I am a student attending the University of Central Florida. My senior design group is designing a sleep management system that will use a Windows App. We are considering the use of your product to help us make a Windows app. We are required to write and submit a document with our design details. Can we use an image of your charts to show how we would like our app to look?

Thank you,
Anthony Bharrat

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Subject: Permission to use image from datasheet

Ticket Thread

Wed, Dec 5 2012 5:20pm

Hi,

I am a student attending the University of Central Florida. My senior design group is designing a sleep management system and we are considering the use of the RN-42. We are required to write and submit a document with our design details. Can we use the figure in your datasheet that shows the pin out of the device?

Thank you,
Anthony Bharrat

Wed, Dec 5 2012 5:23pm - staff

Hello Anthony,

Yes, go ahead and use the pictures in the data sheet.

It would be great if you can share your final report with us.

Regards,

Rohit

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---------- Forwarded message ----------
From: **Meghan Stewart** <Meghan.Stewart@telerik.com>
Date: Wed, Dec 5, 2012 at 2:06 PM
Subject: RE: Permission to reprint images for School Project
To: "anthonyb2477@gmail.com" <anthonyb2477@gmail.com>

Hi Anthony,

Thanks for reaching out.

Yes, you can use the image from our website as long as it is not being redistributed for commercial use. You can download a trial, and screen shot the particular chart.

We appreciate you checking with us before using the image.

Kind Regards,

Meghan Stewart
Account Manager
Telerik Inc.
Phone: 888.365.2779 x123
e-mail: meghan.stewart@telerik.com
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From: Anthony Bharrat [mailto:anthonyb2477@gmail.com]
Sent: Tuesday, December 04, 2012 3:29 PM
To: Telerik | Sales

Subject: Permission to reprint images for School Project

Hi,

I am a student attending the University of Central Florida. My senior design group is designing a sleep management system that will use a Windows App. We are considering the use of your product to help us make a Windows app. We are required to write and submit a document with our design details. Can we use an image of your charts to show how we would like our app to look?

Thank you,
Anthony Bharrat

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Appendix B: References

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