A Portable Sleep Management System for Better Living

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***Abstract* — KnightTime is a system designed to monitor and aid the quality of sleep. It is intended to not only help the user quantify their sleep 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. A personal sleep management system will equip the user to combat mental and physical fatigue associated with poor sleep and a potential path to discovering sleep disorders. Consistent use of KnightTime will allow for a broader, more generalized understanding of sleep habits and associated health effects not easily discovered in a limited laboratory setting.**

***Index Terms* — Analog circuits, Operational amplifiers, Microcontrollers, Analog-digital conversion, Pulse Oximetry, Actigraphy, Photoplethysmography, Polysomnography, Quantified Self.**

I. INTRODUCTION

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 KnightTime sleep management system 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. KnightTime will equip the user to combat the mental and physical fatigue associated with poor sleep and a potential path to discovering somnipathies (sleep disorders). It can also provide a broader, more generalized understanding of sleep habits and associated health effects not easily discovered in a limited laboratory setting.

The sleep management system will provide data from biosensors to the user in as convenient a way as possible. 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. 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 data and how it is used.

Obtaining an optimal amount of sleep is not easily achieved by following simple strategies like allotting eight hours of rest and setting an alarm. 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 can help them wake up feeling alert and refreshed.

At present, there is also a large gap in the types of machines used to monitor sleep, ranging from the high-end medical devices used in a professional sleep study down to simple mobile applications that claim to wake the user in a light stage of sleep. Existing commercial products such as Zeo and WakeMate are less comprehensive and more expensive than the KnightTime system, and furthermore going out of business. One of the main motivations is the creation of a highly functional sleep system that could be considered a consumer product fit for the “Quantified Self” era.

II. SYSTEM OVERVIEW

KnightTime consists of three peripherals that contain sensors to collect environmental and biomedical data. Two of the peripherals will be attached to the user on their head and wrist for gathering biomedical data and providing an interactive alarm. The third peripheral is a base station capable of recharging the batteries of the two peripherals that are worn by the user as well as gathering environmental data. These peripherals connect wirelessly to a governing mobile application that provides the user interface.

A. Wrist Peripheral

The wrist peripheral uses an inertial measurement unit (IMU) as the primary sensor. The IMU data is used to create an actigraph. Actigraphy alone corresponds well to sleep cycles, and some mobile phone applications attempt to create an actigraph using only a phone’s onboard accelerometer.

The wrist peripheral also contains a vibration motor to use as an alarm or a gentle customizable indicator. The data is sent wirelessly over Bluetooth for convenience. As an added bonus, the same peripheral can be adapted for fitness applications such as motion tracking or as a pedometer.

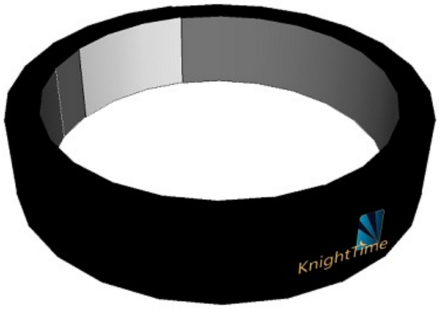

Fig. 1. 3D concept of the wrist peripheral in an enclosure that is attached to a wrist-band. The wrist-band will be made out of an elastic or Velcro material to fit all wrist sizes.

B. Headband Peripheral

The headband peripheral contains a heart rate sensor and a body temperature sensor. These measurements help track the state of sleep and provide insight into the user’s circadian rhythm. The headband includes an alarm buzzer and optional vibration motor to make sure the user wakes up on time. LED’s are also attached to the headband to provide optional light stimulation, which is helpful for users without windows or waking up early since light exposure can promote wakefulness.

Fig. 2. 3D concept of the headband peripheral in an enclosure that is attached to a standard sleeping mask.

C. Base Station

The base station contains sensors for measuring ambient light, ambient temperature and humidity, and ambient noise levels. The temperature and humidity information is useful both for helping the user determine the ideal climate for sleeping and for helping the system track changes in body temperature with respect to the room temperature. The light and sound levels offer the user information on conditions potentially affecting sleep or may trigger an alarm. Filtering the ambient sounds can indicate the potential presence of snoring to some degree since snoring tends to occur at low frequencies.

The base station is powered from an AC adapter and can act as a charging station for the wrist and headband peripherals as well as the user’s mobile device or any other

USB-powered gadget. A stand atop the base station provides a convenient dock for the user's phone or tablet throughout the night.

Fig. 3. 3D concept of the base station with a tablet attached.

III. SCIENCE OF SLEEP

Sleep is defined, for the scope of 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].

A. 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 electroencephalography, electrooculography, and electromyography. None of these data sources are expected to be within the scope of a compact, inexpensive, and most importantly comfortable consumer device yet. 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 a 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.

KnightTime aims to track sleep stages well enough to graph a somewhat accurate hypnogram for the user. To figure out how this might be possible, the physiological details of each stage of sleep need to be considered.

B. 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.

C. 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 [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 IMU will be useful in determining when a person is in stage N2 sleep.

D. 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 of 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 KnightTime seeks 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 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, 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 KnightTime, 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].

E. 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 of temperature regulation [14]. A system may detect REM through a combination of heart rate sensors detecting an increase compared to NREM sleep, possible respiration monitoring showing less regular breathing, IMU's 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.

IV. PULSE OXIMETRY

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 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 [17]. 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 was the selected option. There are other locations on the body that can be used such as the venous part of the wrist and the finger tips. The forehead was selected to be the best choice since people can sleep on top of their limbs, reducing circulation and effective measurement. 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. Signal processing will need to be performed on this, including a low-pass filter of around 5 Hz. The human pulse is not generally expected to exceed 200 beats per minute, which correlates to 3.3 beats per second. Artifacts and noise are expected from the physical movement of the person.

The approach is to feed the signal through an active high-pass filter to remove any DC component of the signal, through a 5 Hz low-pass filter, through a narrowband notch filter to eliminate the ever-present 60 Hz noise, and then through a variable-gain amplifier. Since the technique employed here is a form of photoplethysmography, which is basically the measurement of changes in volume with light, the 50 or 60 Hz notch filter is optional. 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.

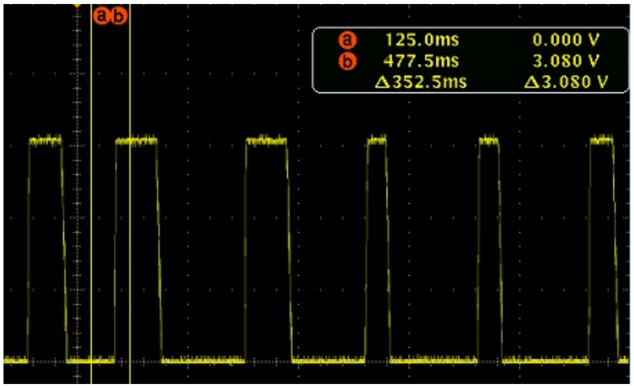

Fig. 4. Pulse signal after being conditioned by the circuit. A high gain is used to create a digital signal of the pulse.

V. ACTIGRAPH

An actigraph unit consists of an accelerometer or IMU as the primary sensor. 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 [18]. That makes the accelerometer or IMU 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 [18]. 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 is thought to correlate best with actual polysomnography, although there are conflicting studies, and is the primary method used in this project [19].

KnightTime incorporates an IMU module on the printed circuit board (PCB) of the wristband. The microcontroller will report the values read from the IMU over Bluetooth to the mobile application. The wristband thus constitutes an actigraph unit.

VI. SMART ALARM

The smart alarm component of this project attempts to wake the user up at the optimal time in the morning. Not only will it wake the user, but it can attempt to keep him or her awake by employing persistent alarms.

Waking the user at an optimal time is a major goal of the project. To have a smart alarm it will need to interact with the sensors and gather data to determine when would be an optimal time. 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 is 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 application will have the user perform a certain task that would require either mental or physical effort to complete. By performing this task, the user will have a hard time falling back to sleep and will experience reduced sleep inertia [20]. 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 [21].

The interactive element of the alarm will be designed to function from the application. The interactive smart alarm element can employ software, hardware, or both. The interactive alarms are optional for the user and not limited to the simple ones created for KnightTime. The modular nature of the system allows for the addition of creative alarms later, 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. As another example, a user might need to retrieve a fast moving toy car equipped with a buzzing alarm to turn it off. The software method would involve doing a simple puzzle on the mobile application. A simple puzzle could include many things such as solving a trivial algebra problem or completing a game of tic-tac-toe. The wearable accelerometer may be used to force the user to jump up and down until a sufficient amount of activity is detected to shut off the alarm. These tasks need not be extremely challenging but they all would require the user to perform an action that is outside the normal morning routine, stimulating him or her enough to stay awake.

VII. SOFTWARE

Once the system detects light 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 will have the option to see a representation on how, why, and when the system made decisions based on his or her collected data.

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.

A hypnogram is plotted by interpreting brain activity data collected from an electroencephalogram (EEG). However, in this project, the system must interpret temperature, heart rate, and movement data to infer what is usually determined from brain activity. The physiological cues mentioned in the science of sleep section are used in a state machine to help create a hypnogram instead of an EEG. While not completely accurate, the additional data provides a better picture than the 90% accuracy of actigraphy alone.

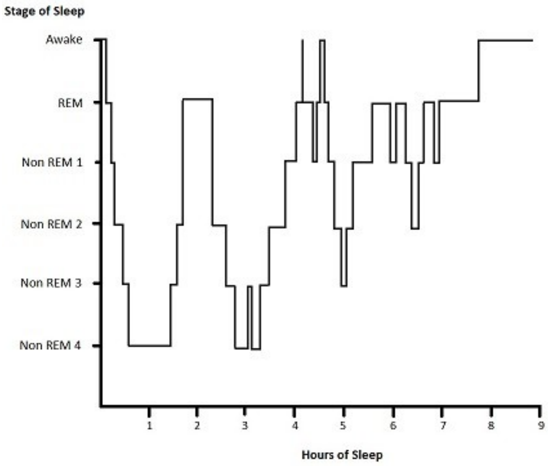

Fig. 5. Example of what a hypnogram looks like for a healthy adult.

In many 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 IMU. Hence, by trial and error, an iterative algorithm can be developed to determine when the user is transitioning between sleep stages.

The best time to wake someone up in order to have a higher state of energy and awareness is immediately after he or she completes the REM stage. At times within a REM sleep stage, a person's brain activity levels are highly similar to the levels of a fully awakened person. The difference is complete paralysis. Others indicators may be a high heart rate with body temperature drifting towards ambient temperature. Movement detected following this stage indicates completion. Momentary wakefulness from REM often naturally occurs, and is 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. It constantly checks whether it is a good time to wake the user based on the time frame that he or she 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 07:00 AM, then if he or she finishes REM sleep at 06:30 AM., the algorithm should determine that 06:30 AM is the best time to wake the user and trigger the alarm. The algorithm may wake the user in the lighter N1 and N2 stages if the user did not want to awaken until say 06:40 AM. If the entire window passes without a completion of REM or light stage of sleep encountered, it can be hard set to alarm at 07:00 AM regardless and use the persistent interactive alarm.

VII. CONCLUSION

From the inception, the team's goal was to design and implement a system that would help improve the quality of a significant portion of life. This project has served as an invaluable experience for each member. It has proved to provide challenges in all aspects of its design, allowing each member the benefit of learning new skills and expand upon his educational foundation in engineering.

The KnightTime project is a good proof of concept for a complete sleep management system. Given a larger budget and more time it has the potential to be a consumer product that everyone could benefit from using. Moreover, it may be further integrated with other health aggregation systems.

BIOGRAPHY

Anthony Bharrat will be graduating from the University of Central Florida with a Bachelor's of Science in Computer Engineering. He currently works as a co-op at NASA's Kennedy Space Center as a software engineer, where he plans to continue working upon graduation.

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Ryan Murphy will be graduating from the University of Central Florida with a Bachelor's of Science in Electrical Engineering. He plans to continue his education and pursue a master's degree in the future. Upon graduation, Ryan will be working at Lockheed Martin Global Training and Logistics as a systems engineer.

Bartholomew Straka will be graduating from the University of Central Florida with a Bachelor's of Science in Electrical Engineering and Minor in Mathematics. He currently interns at NASA's Kennedy Space Center. Upon graduation, Bartholomew will be working at Texas Instruments as a product engineer in their global rotation program.

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