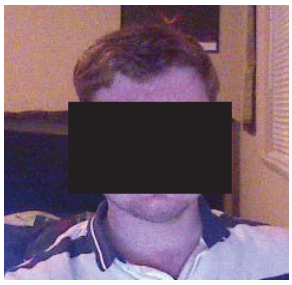
[redacted]

Infant Stimulus for Apnea of Prematurity

[redacted]

Project Proposers & Contact Information:

[redacted]
Chief Tech. Officer



[redacted]

[redacted]
COO & Team Leader

[redacted]

[redacted]
Chief Engineering Officer

Chief Marketing Officer

[redacted]

[redacted]
Chief Financial Officer

Chief Research Officer

[redacted]

Summary: This project addresses the issue of Apnea of Prematurity, and seeks to provide an interventional treatment that responds to and disrupts the infant's apnea in such a way that will alleviate the nurses of this current duty. The feedback loop created by our device will monitor the infant and output this monitoring data to an algorithm-containing device. This device will determine whether or not the infant is experiencing apnea; if apnea is detected, the device will initiate the stimulation, thus disrupting the apnea. This system, in its entirety, will be designed in an effort to be as non-invasive/obstructive as possible.

Stakeholder Point of Contact:

[redacted]
Medical-Engineering Liaison and Research Assistant Professor
Department of Surgery, Center for Materials Processing, and Department of Biomedical Engineering
The University of Tennessee
Office: [redacted] | Cell: [redacted] | Fax: [redacted] | [redacted]@utk.edu

Stakeholder Location: The University of Tennessee Graduate School of Medicine
1924 Alcoa Highway | Knoxville, TN 37920 | ~2.5 miles from campus

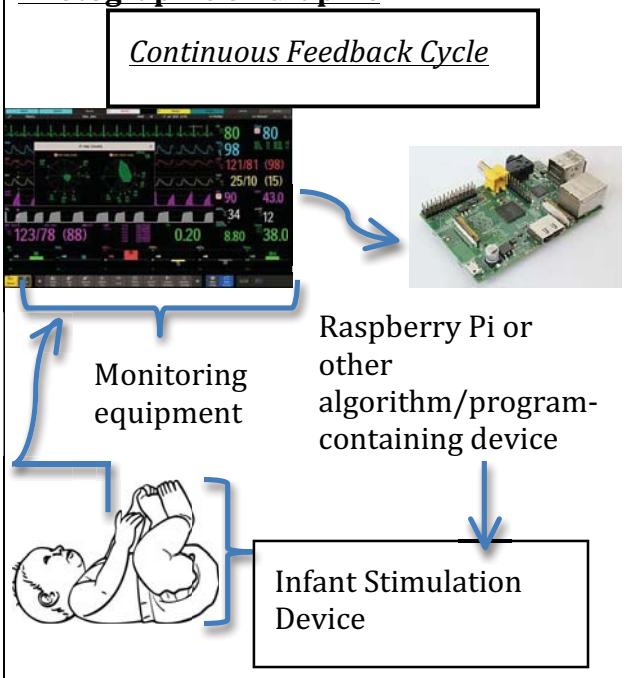
Quad Chart

Technology and Objective

When a child stops breathing due to apnea, typically a nurse must rush to shake, or stimulate, the infant so that he will begin breathing again. The objective of our invention is to alleviate nurses of their current role by detecting and subsequently stimulating the infant without the necessity of a nurse's intervention.

Utilizing a novel monitoring method designed by our team, the device will rapidly detect an apneic episode. If Apnea of Prematurity is occurring, the device will trigger a motor attached to the infant's foot, simulating the nurse's stimulation. This stimulus to the central nervous system will cause the child to begin breathing again. Furthermore, Biofeedback Solutions is investigating the possibility of designing a 2-in-1 system that would attempt to *prevent* apnea, while also interrupting it in such a scenario.

Photographic or Graphic



Proposed Technical Approach

The device will be a feedback loop in which apnea will be detected by Biofeedback Solutions' algorithm, stimulation will occur to provoke breathing, and stimulation will cease when breathing is again sensed. Biofeedback Solutions will design, prototype, test, and refine a novel system for detecting Apnea of Prematurity. Options include a thermistor near the infant's airways for sensing ΔT, a CO_2-sensing device, pulse oximetry in conjunction with spectroscopy, and others. The current proposed stimulation device consists of a small motor that will be attached to the child's foot by means of a soft sock, so as to prevent discomfort to the infant. Based on design constraints and simplicity, and in an effort to provide the best solution to this problem, a preferred alternative may be explored and pursued with regards to the stimulation device itself.

Rough Order of Magnitude Cost

- Materials and supplies (see Pg. 11)
  - Baby socks: <$10
  - Coin Vibration Motor: <$15
- Infant Monitoring Sys. (see Pg. 11)
  - Raspberry Pi Computer: ~$35
  - Various Wires and Connections: <$20
- Parts and sub-assemblies
  - Coding for vibration response (In-House) Free. (Outsourced) $10/hr
- Fabrication costs
  - Free (completed by team)
- Testing costs
  - Possible Rental of SimBaby at GSM. Cost for Rental: Free

Schedule and Deliverables

See **Appendix** for overall project timeline.

Participants (found on first page above.)

Introduction

The purpose of this project and our proposed solution is rather straightforward, and can be defined by the following paragraph:

> Biofeedback Solutions is seeking to create a device that will successfully detect and rapidly respond to Apnea of Prematurity. The essence of the device is a basic feedback loop, wherein novel monitoring equipment will be designed and prototyped, its output analyzed by a program/algorithm, and based on the results of the algorithm (whether or not the infant is experiencing an apneic episode), the stimulation device will be triggered. Once breathing is sensed again – by the algorithm – the stimulation will cease. Currently the task is completed by attending nurses, which will be relieved of this duty with the implementation of our device.

Based on a literature, product, and patent search (summarized below), as well as a query of multiple hospitals, there is currently no device in use that addresses the issue at hand. Also, based on preliminary investigations, there are few efforts being invested in such research at this point in time. As such, the UT Graduate School of Medicine has requested that a solution to this problem be provided.

Thus, our device provides heretofore-novel interventional treatment for apnea of prematurity. Such a device is not in widespread use, and because it directly addresses and provides a solution for an issue currently existing in the NICU, it is of certain clinical relevance. The issue at hand, current state of the art, and our proposed solution is described herein.

Background

The problem we are addressing and solving is intervening in apnea of prematurity by stimulating the infant during apneic episodes.

Apnea is breathing that slows down or stops from any cause. Apnea of prematurity refers to short episodes of stopped breathing in babies who were born before their due date.

<u>Symptoms:</u>

> Newborns, especially preemies, often have an irregular breathing pattern.
>
> These babies will have short episodes (5 - 10 seconds) of either shallow breathing or stopped breathing (apnea). These episodes are followed by periods of normal breathing.
>
> When there is very shallow or no breathing (apnea), the baby may also have a drop in heart rate. This heart rate drop is called bradycardia.
>
> Some babies may also have poor color and an ill-looking appearance. Apnea episodes that last longer than 20 seconds are considered serious.

Signs and tests:

Because most preterm and some sick full-term babies have some degree of apnea, these babies are hooked up to monitors in the hospital to watch their breathing, heart rate, and oxygen levels. Apnea or a drop in heart rate can set off the alarms on these monitors.

In most neonatal intensive care units (NICUs), cardiac monitors, pulse oximeters, and impedance pneumography are used to monitor for apnea of prematurity and the associated bradycardia and hypoxemia (abnormally low concentration of oxygen in the blood). The accuracy of pneumography is limited by movement artifacts and the inability to detect obstructive apnea episodes.

Treatment:

How apnea is treated depends on the cause, how often the breathing stops, and the severity of spells. Babies who appear to be otherwise healthy and have few spells per day are simply watched. They can be gently stimulated during their occasional episodes. A gentle tap to the sole of the foot or rubbing the back is often used to terminate a central apnea.

Babies who are well, but who have many episodes in which they stop breathing may be given a caffeine preparation to help stimulate their breathing. Sometimes the nurse will suction children with apnea, change their position, or use a bag and mask to help them breathe.

Proper positioning, slower feeding time, oxygen, and (in extreme cases) a breathing machine may be needed to assist in breathing.

Treatment is instituted if:

Apneic spells are frequent, prolonged, or associated with bradycardia or frequent hemoglobin oxygen saturation (SpO2) values below 90 percent.

OR

The infant requires intervention with bag and mask ventilation.

Prognosis:

Apnea is common in premature babies. Most babies have normal outcomes. Although mild apnea is not thought to have long-term effects, most doctors feel that preventing multiple or severe episodes is better for the baby over the long-term.

Apnea episodes that began after the second week of life or that last longer than 20 seconds are considered more serious.

Information taken from http://www.uptodate.com/contents/management-of-apnea-of-prematurity

An article with explanation of apnea of prematurity is found here: http://www.ohsu.edu/xd/health/services/doernbecher/research-education/education/residency/upload/res_lounge_AOP-Pathophys.pdf

Our solution is to design and create a feedback system that will detect apnea by monitoring an output from the infant, and send an impulse to the stimulation device for a predetermined amount of time and magnitude, thus 'waking' the infant's nervous system that will reinitiate breathing.

Relevant Research

The investigators found several articles that address the issue of apnea of prematurity. Of interest is the following literature (more detailed description can be found in **Appendix**):

1. Stimulation device that is 'stuck' on or comes in direct contact with the infant:

   Heart rate, oxygen saturation, pulse, thoracic impedance, nasal airflow, and electrocardiogram are recorded from the monitor to the laptop. Whenever an apneic spell is detected, the nurse has the option of triggering a 3-second, 10-V, 250-Hz square-wave pulse to the transducer. The vibrotactile transducer is placed noninvasively with tape on the infant's thorax. This stimulus should arouse the infant and end the apneic event. http://www.ncbi.nlm.nih.gov/pubmed/12613292

2. Infant's mattress comprises the vibration/stimulation device:

   Findings suggest that nonlinear properties of the immature respiratory control system can be harnessed using afferent stimuli to stabilize eupneic breathing, thereby potentially reducing the incidence of apnea and hypoxia. http://www.ncbi.nlm.nih.gov/pmc/articles/PMC2763836/

3. Stimulation device located on infant's foot:

   A portable design of a vibrotactile device for central apnea interruption in premature infants is developed. This small non-invasive device provides tactile stimulus on the infant's foot, stimulating the nervous system to help reinitiate breathing. The system consists of the vibrotactile device and a user interface which controls the activation of the vibrotactile unit based on the infant's physiological signals. Based on the preliminary results, the system provides adequate stimulation.

http://books.google.com/books?id=9HbAhWChR58C&lpg=PA180&ots=RCJkzWHr-z&dq=infant%20apnea%20vibrotactile&lr&pg=PA181#v=onepage&q=infant%20apnea%20vibrotactile&f=false

Similar article: http://gradworks.umi.com/14/72/1472364.html

4. Olfactory stimulaton:

   The present study examines whether exposure to an odor known to modulate the infant's respiratory rate could reduce the frequency of apneic spells.
   http://pediatrics.aappublications.org/content/115/1/83.long

5. Oscillating water bed utilized for apnea prevention:

   http://onlinelibrary.wiley.com/store/10.1002/14651858.CD000502/asset/CD000502.pdf?v=1&t=h77tdtym&s=0247a9b385f85735339f1ce6e633bb58ef357bca

6. Oscillating non-water bed utilized for apnea prevention:

   Bed which imparts a regular cephalo-caudal rocking movement, not exceeding 3° in either direction, in the hope of preventing apneic attacks by vestibular (inner ear, sense of balance) stimulation.
   http://adc.bmj.com/content/57/6/475.full.pdf+html

7. Prophylactic use of kinesthetic stimulation shown to be ineffective:
   http://onlinelibrary.wiley.com/store/10.1002/14651858.CD000373/asset/CD000373.pdf?v=1&t=h77uilem&s=c9b12a1f5ec0dcaa92d46b12f6be5f2c72a07f6c

   Again, kinesthetic stimulation is shown to be ineffective:
   http://www.ncbi.nlm.nih.gov/pubmed/10796212

8. Response to taste/smell and tactile stimulation during apneic episode:

   The interventions included a traditional tactile stimulation of moderate shaking applied to the infant's leg and an experimental oral intervention consisting of taste, smell, and oral tactile stimulation. Behavioral state changed to alertness when the infants received the traditional tactile intervention yet remained unchanged when the experimental stimulation was administered during apnea ($p = 0.0202$).
   http://www.ncbi.nlm.nih.gov/pubmed/8410645

9. Vertical pulsating stimulation:

   VPS is a nontoxic, noninvasive, and easy-to-implement method of alleviating central and mixed apnea types, it seems prudent to give VPS which has the stimulus characteristics to preterm infants experiencing apnea of prematurity before other treatment modalities currently in use are tried.
   http://www.ncbi.nlm.nih.gov/pubmed/8083624

The investigators also found multiple patents that address the issue of apnea of prematurity. Of interest are the following patents:

1. US Patent 5,555,891: Vibrotactile stimulator system for detecting and interrupting apnea in infants. Full text found here.
   This patent is extremely well-aligned with our design proposal. It will likely be highly referenced throughout the duration of this project. Furthermore, this patent cites several other patents of interest that will also serve as guidance throughout this project.

2. US Patent 4,694,839: Auxiliary stimulation apparatus for apnea distress. Full text found here.
   Again, this patent is very well-aligned with our design proposal. It discusses a foot or neck vibrotactile device for apnea interruption.

3. US Patent 4,630,614: Apnea monitoring apparatus.
   This patent also directly addresses part of our design, which is the detection of apnea itself, based on respiration rate. Again, this patent cites several other patents of interest and relevance which will assist in the design of our device.

Each of these literary pieces and patents allowed us an insight into ideas that have been somewhat successful at apnea intervention, as well as ideas that either haven't been well-received or were deemed ineffective. Taking these ideas to Dr. Stephens and the NICU physicians, we honed in on the approach we'll take while finding a solution to the issue at hand.

Societal Implications

The apparatus to be built will be used on prematurely-born infants. Addressing the issue of Apnea of Prematurity through the design of an interventional apparatus brings with it a few societal implications. First of all, the device will likely be relatively expensive, given the medical equipment requirements. The device will require specialized materials in order to be approved for use with premature infants (for example, anything contacting the infant, such as hydrogels, etc.).

Second, and of primary relevance, there is an inherent safety concern given that the device's ultimate application is use on not only a baby, but an underdeveloped, premature child. Testing a device with such a planned application will require extensive FDA and IRB approval. Throughout the exploration of product V&V and efficacy testing, safety must be at the forefront of the engineers' minds, and the engineers will always err on the side of safety when it comes to stimulation magnitude, duration, and any other inputs to the patient that could potentially have unsafe outcomes.

The designers see no reportable environmental implications of this apparatus. The manufacturability brings a few concerns though, because of the nature of the product and the fact that parts of it are patient-contacting, meaning sterilization is a concern. The part of the feedback loop that is monitoring an output from the infant falls into this category, and will need to be manufactured in a clean-room environment. Any item directly contacting the infant (hydrogel) will be disposable. Our effort will be to ensure that any part of the system that is within the infant's closed (incubator) environment is disposable, and every other component be reusable. For example, if we pursue the route of including a 'belt' that wraps around the infant to detect chest expansion and compression, the belt will be disposable. The sock that houses the vibrotactile unit (ideally inexpensive in nature) will be manufactured sterile and disposable. We will attempt to design a system in which the motor is re-usable, but this has not been decided on yet. Other manufactured parts are the micro-computer (or whichever device is decided to house the algorithm for the program which will detect and subsequently interrupt apnea). This won't need to be sterilizable, as it is non patient-contacting and can be kept away from the infant's environment.

Sustainability is built-in to the device, as it will be a reusable device. The only parts that won't be reusable are any patient-contacting parts (socks, electrodes or anything stuck on the infant's skin, etc.). Even so, there are no foreseeable novel sustainability challenges in the design of this product.

To summarize, the primary concerns are those of cost, the safety concerns that go with government approval and testing of the device, and the difficulty in the building of the device to desired safe specifications, and the manufacturability of sterile patient-contacting components of the design.

Statement of Work

Project work will be distributed as evenly as possible amongst all team members, as per the Team Contract. However, as it relates to each individual's specific role within the overall team effort (somewhat defined by each member's 'title within the company'), certain team members will spearhead and champion specific tasks within each project milestone. For example, Wesley is more adept at certain technical tasks that will be called upon in this project. Ivey has experience with technical writing and team leadership, so those specific skills will be utilized. Jake has proven his creativity and inventiveness with various suggestions and advice throughout the proposal process, so his ingenuity will come

into play for certain deliverables. Adam has a pre-med concentration, and so his knowledge will facilitate physiological applicability of certain aspects of our project.

Scope

The scope of this project primarily lies within the implementation at UT's Graduate School of Medicine. Though we likely won't see the project reach this milestone, that is the ultimate goal of our device. Given the nature of the various approval processes, a substantial amount of time is necessary when seeking implementation of a medical device, especially one that deals with application on preterm infants. These approving and governing bodies include the FDA and the Internal Review Board (IRB) within the UT Hospital. As such, our effort will be focused on getting as far as possible into this review/approval process in the amount of time we've been given. We seek to leave Dr. Stephens and the NICU physicians and nurses in the best position to continue the effort to reach implementation of our device.

Technical Descriptions

To begin, the sensing equipment employed to monitor an output of the premature infant will need to be extremely sensitive in order to accurately detect subtle changes. The next requirement is to ensure that the sensors and the monitoring equipment have a very fast response time in order to decrease the time required to detect apnea. Next, the vitals monitor (program/algorithm) must be able to dictate an action, or activate a secondary computer system to initiate a motor, vis a vi the stimulus. Under circumstances that a secondary computer will be required, the input to the microcomputer must be under 5 volts for an Arduino board, or under 3.3 volts for a Raspberry Pi. The motor must be able to be connected in such a fashion that the draw from the GPIO of the Raspberry Pi board is no more than 16 milliamps. Theoretically an external power supply to the motor could accomplish such, if necessary.

Design Input/Target Performance Criterion

Of the various parts that will make up the overall feedback loop, each part possesses specific design inputs, or specifications that dictate their performance criterion. Listed below are the specifications as they currently stand:

<u>Monitoring equipment</u>: The monitoring equipment has the following design inputs.

1. It must accurately and constantly monitor an output that is capable of differentiating apnea versus no apnea.
2. It must be as non-invasive as possible, considering the cabling, tubing, and other equipment that is already in the infant's immediate environment.

Raspberry Pi or other algorithm/program-containing device: The device that houses the algorithm/program has two tasks.

1. To detect apnea versus no apnea by instantaneously analyzing the data that is output to it by the monitoring equipment
2. To signal the stimulation device in the event that apnea is detected

Stimulation device: The stimulation device has two central design inputs.

1. It must be as non-invasive as possible, given the extreme fragile nature of the preterm infants.
2. It must effectively stimulate the infant so as to disrupt and end the apneic episode.

Detailed *Timeline* can be found in **Appendix**.

Description of Work Product

The product will be a monitoring and intervention system made up of three to four basic components. To start, there will be the method by which an output on the infant is measured. With this data being recorded by the computer, whether it be an external computer or integrated, the computer will sense the occurrence of an apneic episode. From this point, the computer will then tell the motor, which will be attached to the infant's foot by method of specialized sock or specialized gel (or potentially in another fashion), to activate, thus creating the desired stimulus to interrupt the apneic episode without needing a nurse to physically contact the infant.

The software will likely be coded in C++ or python

Parts: Thermistor, air pressure transducer, accelerometer, or other sensing device

Computer: Initial monitor, or feedback form monitor to separate micro computer

Motor: Small vibrating motor or fan (or similar non-invasive stimulation method)

Attachment: Specialized hydrogel or Socks (or other method yet to be decided on)

Should the raspberry pi be needed, GPIO will be used to take input and allow for output.

Estimation of Costs

- Materials and supplies
  - Baby socks: <$10
  - Coin Vibration Motor: <$15
  - Possible Infant Monitoring Systems:

[redacted]

        - Thermistor: $150-$200
        - Masimo Rad-57 Pulse Oximeter: $800
        - Blood CO@ Laser: TBD (further research needed)
        - Graseby MR10 Respiration Monitor: $300 (used)
    - Incubator Mattress: $40
    - Possible Raspberry Pi Computer: ~$35
    - Various Wires and Connections: <$20
    - Specialized materials (hydrogels, etc.): ~$200-$500 (very rough estimate)
- Parts and sub-assemblies
    - Coding for vibration response (In-House). Cost: Free.
    - Coding for apnea detection (In-House): Free. (Outsourced): $10/hour
- Fabrication costs
    - Minimal. All fabrication can be completed by team members. Cost: Free
- Testing costs
    - Possible Rental of SimBaby at GSM. Cost for Rental: Free
- Documentation costs
    - Possible Patent Costs

Qualifications of Proposers (résumés attached in **Appendix**)

[redacted]

[redacted] is a student at the University of Tennessee Knoxville. He has been pursuing a B.S. in Biomedical Engineering as well as a minor in Japanese language and is currently in the [redacted] senior class. He graduated from Memphis University School in Memphis, TN. He has an advanced understanding of computer systems and technology ranging from Windows systems to Linux systems and programming languages. His goal is to receive upper education in Biomedical Engineering and hopes to pursue work in the field of health monitoring systems or prosthetic attachments and augmentation.

[redacted] is currently involved with the UTK SC2 club. He also has hobbies that include, but are not limited to, working with computers, participating in rifle and pistol competitions, hiking, skiing, and scuba diving.

[redacted]

[redacted] is a BME senior at the University of Tennessee. He has completed one year of co-op work for Kimberly-Clark Corporation in Roswell, Georgia where he gained project management experience and was exposed to the numerous requirements and milestones of multiple engineering projects from concept to commercialization. He also has experience dealing with the rigorous FDA requirements that go into designing and commercializing a medical device.

[redacted] has experience with SolidWorks CAD modeling software, as well as rapid-prototyping. Ivey plans to pursue a Master's degree in BME with a concentration in neuroengineering, with specific interest in helping those with neurodegenerative disorders.

[redacted] is a senior at the University of Tennessee Knoxville pursuing a major in Biomedical Engineering. Originally from Memphis, TN, he graduated from Memphis University School. He aims to earn a masters in Biomedical Engineering during his time at the University of Tennessee, so he may find work dealing with the medical equipment sales.

[redacted] is currently an active member of the Epsilon Omicron chapter of Lambda Chi Alpha, where he has held the position of in-house risk management. His responsibilities included maintain a certain level of discipline and taking steps to ensure the safety of its members. He also annually participates in Lambda Chi's philanthropies benefitting St. Jude's Children Hospital and the North American Food Drive.

[redacted] is a Chancellor's Honors Program senior majoring in Biomedical Engineering with a pre-medical concentration. A Knoxville native, he graduated from Bearden High School.

[redacted] has worked as a research assistant for Dr. David Keffer in the Department of Chemical Engineering and has worked as part of the FUTURE Program for team-based design in the Department of Biomedical Engineering. During [redacted] he completed a study abroad trip in Cambridge, United Kingdom.

[redacted] is an active member of the UTK Starcraft 2 club. He also volunteers weekly with STAR, a therapeutic riding academy for those with disabilities. He currently works as an Honors Peer Advisor, meeting with honors student to discuss course selection and honors requirements.

References

Bloch-Salisbury, E., P. Indic, F. Bednarek, and D. Paydarfar. "Stabilizing Immature Breathing Patterns of Preterm Infants Using Stochastic Mechanosensory Stimulation." *Journal of Applied Physiology* 107.4 (2009): 1017-027. Print.

Garcia, A. P., and R. White-Traut. "Preterm Infants' Responses to Taste/smell and Tactile Stimulation during an Apneic Episode." (n.d.): n. pag. *PubMed*. Web. 11 Sept. 2012. <http://www.ncbi.nlm.nih.gov/pubmed/8410645>.

Jirapaet, K. "The Effect of Vertical Pulsating Stimulation on Apnea of Prematurity." (n.d.): n. pag. *PubMed*. Web. 11 Sept. 2012. <http://www.ncbi.nlm.nih.gov/pubmed/8083624>.

Marayong, Panadda, and Mehrdad S. Mostoufi. "Foot Vibrotactile Device for Central Apnea Interruption in Premature Infants." *Medicine Meets Virtual Reality* (2009): 180-82. Web. 11 Sept. 2012. <http://books.google.com/books?id=9HbAhWChR58C&lpg=PA180&ots=RCJkzWHr-z&dq=infant%20apnea%20vibrotactile&lr&pg=PA181#v=onepage&q=infant%20apnea%20vibrotactile&f=false>.

Marlier, Luc, Christophe Gaugler, and Jean Messer. "Olfactory Stimulation Prevents Apnea in Premature Newborns." *Pediatrics* 115.1 (2005): 83-88. 1 Jan. 2005. Web. 11 Sept. 2012.

Osborn, D. A., and D. J. Henderson-Smart. "Kinesthetic Stimulation for Treating Apnea in Preterm Infants." (n.d.): n. pag. *PubMed*. Web. 11 Sept. 2012. <http://www.ncbi.nlm.nih.gov/pubmed/10796212>.

Pichardo, Roman, Joseph S. Adam, Eric Rosow, Joseph Bronzino, and Leonard Eisenfeld. "Vibrotactile Stimulation System to Treat Apnea of Prematurity." *Biomedical Instrumentation & Technology* 37.1 (2003): 34-40. Print.

Tuck, S. J., P. Monin, C. Duvivier, T. May, and P. Vert. "Effect of a Rocking Bed on Apnoea of Prematurity." *Archives of Disease in Childhood* 57.6 (1982): 475-77. Print.

United States. US Patent and Trademark Office. *Apnea Monitoring Apparatus*. By Dan Atlas. N.p.: n.p., n.d. 23 Dec. 1986. Web. 11 Sept. 2012. <http://patft.uspto.gov/netacgi/nph-Parser?Sect2=PTO1&Sect2=HITOFF&p=1&u=%2Fnetahtml%2FPTO%2Fsearch-bool.html&r=1&f=G&l=50&d=PALL&RefSrch=yes&Query=PN%2F4630614>.

United States. US Patent and Trademark Office. *Auxiliary Stimulation Apparatus for Apnea Distress*. By William F. Timme. N.p.: n.p., n.d. 22 Sept. 1987. Web. 11 Sept. 2012. <http://patft.uspto.gov/netacgi/nph-Parser?Sect2=PTO1&Sect2=HITOFF&p=1&u=%2Fnetahtml%2FPTO%2Fsearch-bool.html&r=1&f=G&l=50&d=PALL&RefSrch=yes&Query=PN%2F4694839>.

United States. US Patent and Trademark Office. *Vibrotactile Stimulator System for Detecting and Interrupting Apnea in Infants*. By Leonard I. Eisenfield. N.p.: n.p., n.d. 17 Sept. 1996. Web. 11 Sept. 2012. <http://patft.uspto.gov/netacgi/nph-Parser?Sect1=PTO2&Sect2=HITOFF&u=%2Fnetahtml%2FPTO%2Fsearch-adv.htm&r=25&p=1&f=G&l=50&d=PTXT&S1=5555891&OS=5555891&RS=5555891>.

Appendices

Full explanation of references listed in **Background** section above.

1. Stimulation device that is 'stuck' on or comes in direct contact with the infant:

   The main components of the system are a Tacaid vibrotactile stimulator (Audiological Engineering, Somerville, MA), a neonatal physiological monitor (Model 511; CAS Medical Inc, Branford, CT), a laptop computer running Windows 95 by Microsoft, National Instruments' data acquisition cards DAQCard-1200 and DAQCard-5102, and a software application developed by Premise Development Corporation, Hartford, CT. Heart rate, oxygen saturation, pulse, thoracic impedance, nasal airflow, and electrocardiogram are recorded from the monitor to the laptop. Whenever an apneic spell is detected, the nurse has the option of triggering a 3-second, 10-V, 250-Hz square-wave pulse to the transducer. The vibrotactile transducer is placed noninvasively with tape on the infant's thorax. This stimulus should arouse the infant and end the apneic event.
   http://www.ncbi.nlm.nih.gov/pubmed/12613292

2. Infant's mattress comprises the vibration/stimulation device:

   Stimulation was administered to 10 preterm infants (postconceptional age: mean 33.3 wk, SD 1.7) using a mattress with embedded actuators that delivered small stochastic displacements (0.021 mm root mean square, 0.090 mm maximum, 30-60 Hz); this stimulus was subthreshold for causing arousal from sleep to wakefulness or other detectable changes in the behavioral state evaluated with polysomnography. We used a test-retest protocol with multiple 10-min intervals of stimulation, each paired with 10-min intervals of no stimulation. Stimulation induced an approximately 50% reduction (P = 0.003) in the variance of IBIs and an approximately 50% reduction (P = 0.002) in the incidence of IBIs > 5 s. The improved stability of eupneic breathing was associated with an approximately 65% reduction (P = 0.04) in the duration of O(2) desaturation. Our findings suggest that nonlinear properties of the immature respiratory control system can be harnessed using afferent stimuli to stabilize eupneic breathing, thereby potentially reducing the incidence of apnea and hypoxia.
   http://www.ncbi.nlm.nih.gov/pmc/articles/PMC2763836/

3. Stimulation device located on infant's foot:

   A portable design of a vibrotactile device for central apnea interruption in premature infants is developed. This small non-invasive device provides tactile stimulus on the infant's foot, stimulating the nervous system to help reinitiate breathing. The system consists of the vibrotactile device and a user interface which controls the activation of the vibrotactile unit based on the infant's physiological

signals. Based on the preliminary results, the system provides adequate stimulation. Further testing will be conducted to ensure the system safety and effectiveness before clinical trials.
http://books.google.com/books?id=9HbAhWChR58C&lpg=PA180&ots=RCJkzWHr-z&dq=infant%20apnea%20vibrotactile&lr&pg=PA181#v=onepage&q=infant%20apnea%20vibrotactile&f=false

Similar article: http://gradworks.umi.com/14/72/1472364.html

4. Olfactory stimulaton:

   The present study examines whether exposure to an odor known to modulate the infant's respiratory rate could reduce the frequency of apneic spells.
   http://pediatrics.aappublications.org/content/115/1/83.long

5. Oscillating water bed utilized for apnea prevention:

   http://onlinelibrary.wiley.com/store/10.1002/14651858.CD000502/asset/CD000502.pdf?v=1&t=h77tdtym&s=0247a9b385f85735339f1ce6e633bb58ef357bca

6. Oscillating non-water bed utilized for apnea prevention:

   We have constructed a bed which imparts a regular cephalo-caudal rocking movement, not exceeding 3° in either direction, in the hope of preventing apneic attacks by vestibular (inner ear, sense of balance) stimulation.
   http://adc.bmj.com/content/57/6/475.full.pdf+html

7. Prophylactic use of kinesthetic stimulation shown to be ineffective:
   http://onlinelibrary.wiley.com/store/10.1002/14651858.CD000373/asset/CD000373.pdf?v=1&t=h77uilem&s=c9b12a1f5ec0dcaa92d46b12f6be5f2c72a07f6c

   Again, kinesthetic stimulation is shown to be ineffective:
   http://www.ncbi.nlm.nih.gov/pubmed/10796212

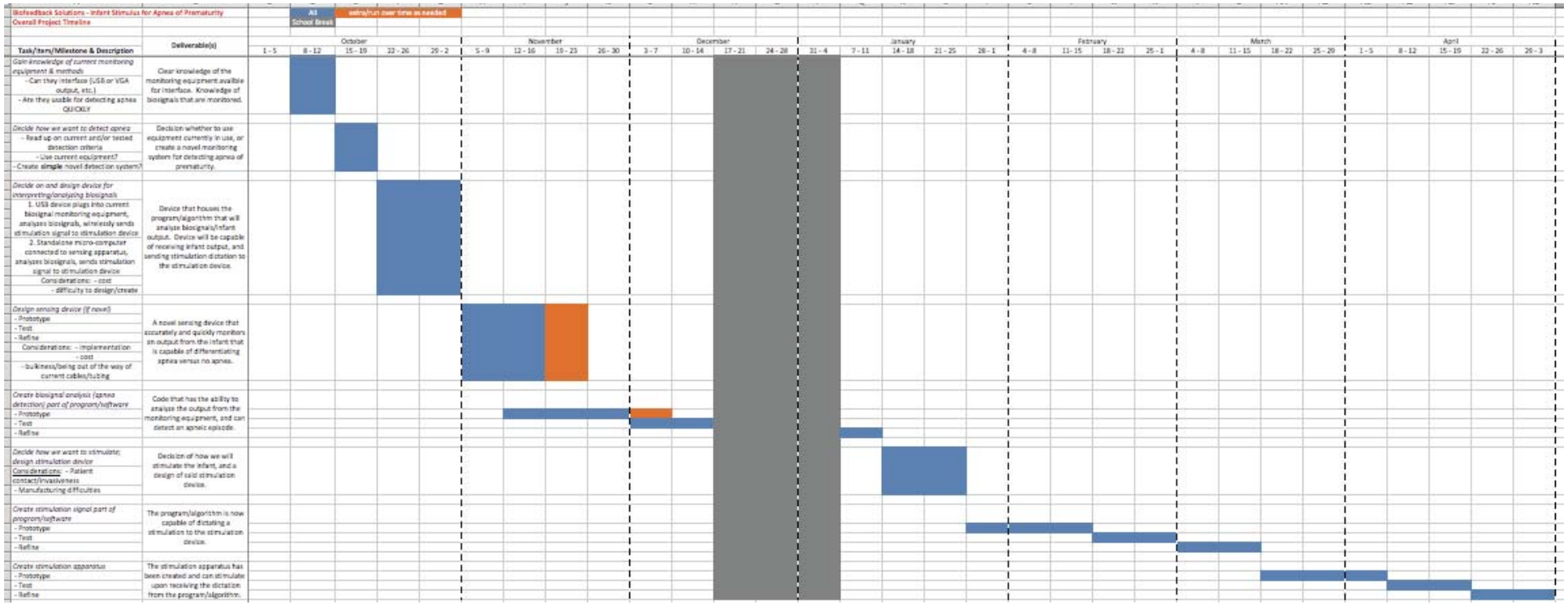
8. Response to taste/smell and tactile stimulation during apneic episode:

   The interventions included a traditional tactile stimulation of moderate shaking applied to the infant's leg and an experimental oral intervention consisting of taste, smell, and oral tactile stimulation. The time interval for reinitiation of respiratory effort was significantly shorter after infants received the experimental stimulation

(p = 0.0101). Behavioral state changed to alertness when the infants received the traditional tactile intervention yet remained unchanged when the experimental stimulation was administered during apnea (p = 0.0202).
http://www.ncbi.nlm.nih.gov/pubmed/8410645

9. Vertical pulsating stimulation:

   Placing preterm infants suffering idiopathic apnea of prematurity on the VPS had an effect on the infants' respiratory effort and achieved a reduction in the number of apneic episodes secondary to central and mixed apnea. However, VPS offered no benefits in the reduction of obstructive apnea in this study population. Because central apnea has been reported as the predominant type of apnea and VPS is a nontoxic, noninvasive, and easy-to-implement method of alleviating central and mixed apnea types, it seems prudent to give VPS which has the stimulus characteristics to preterm infants experiencing apnea of prematurity before other treatment modalities currently in use are tried. Further studies are warranted to determine if VPS is effective in a continuous long-term treatment for apnea of prematurity, for example, until the end of apnea.
   http://www.ncbi.nlm.nih.gov/pubmed/8083624


BioFeedback Solutions - Infant Stimulus for Apnea of Prematurity
Overall Project Timeline
All School Break
extra/run over time as needed
Task/Item/Milestone & Description
Deliverable(s)
October
November
December
January
February
March
April
1 - 5
8 - 12
15 - 19
22 - 26
29 - 2
5 - 9
12 - 16
19 - 23
26 - 30
3 - 7
10 - 14
17 - 21
24 - 28
31 - 4
7 - 11
14 - 18
21 - 25
28 - 1
4 - 8
11 - 15
18 - 22
25 - 29
1 - 5
8 - 12
15 - 19
22 - 26
29 - 3
Gain knowledge of current monitoring equipment & methods
- Can they interface (USB or VGA output, etc.)
- Are they usable for detecting apnea QUICKLY
Clear knowledge of the monitoring equipment availble for interface. Knowledge of biosignals that are monitored.
Decide how we want to detect apnea
-- Read up on current and/or tested detection criteria
- Use current equipment?
- Create simple novel detection system?
Decision whether to use equipment currently in use, or create a novel monitoring system for detecting apnea of prematurity.
Decide on and design device for interpreting/analyzing biosignals
1. USB device plugs into current biosignal monitoring equipment, analyzes biosignals, wirelessly sends stimulation signal to stimulation device
2. Standalone micro-computer connected to sensing apparatus, analyzes biosignals, sends stimulation signal to stimulation device
Considerations: - cost
- difficulty to design/create
Device that houses the program/algorithm that will analyze biosignals/infant output. Device will be capable of receiving infant output, and sending stimulation dictation to the stimulation device.
Design sensing device (if novel)
- Prototype
- Test
- Refine
Considerations: - implementation
- cost
- bulkiness/being out of the way of current cables/tubing
A novel sensing device that accurately and quickly monitors an output from the infant that is capable of differentiating apnea versus no apnea.
Create biosignal analysis (apnea detection) part of program/software
- Prototype
- Test
- Refine
Code that has the ability to analyze the output from the monitoring equipment, and can detect an apneic episode.
Decide how we want to stimulate; design stimulation device
Considerations: - Patient contact/invasiveness
- Manufacturing difficulties
Decision of how we will stimulate the infant, and a design of said stimulation device.
Create stimulation signal part of program/software
- Prototype
- Test
- Refine
The program/algorithm is now capable of dictating a stimulation to the stimulation device.
Create stimulation apparatus
- Prototype
- Test
- Refine
The stimulation apparatus has been created and can stimulate upon receiving the dictation from the program/algorithm.

Task/Item/Milestone & Description	Deliverable(s)
Gain knowledge of current monitoring equipment & methods - Can they interface (USB or VGA output, etc.) - Are they usable for detecting apnea QUICKLY	Clear knowledge of the monitoring equipment availble for interface. Knowledge of biosignals that are monitored.
Decide how we want to detect apnea - Read up on current and/or tested detection criteria - Use current equipment? - Create **simple** novel detection system?	Decision whether to use equipment currently in use, or create a novel monitoring system for detecting apnea of prematurity.
Decide on and design device for interpreting/analyzing biosignals 1. USB device plugs into current biosignal monitoring equipment, analyzes biosignals, wirelessly sends stimulation signal to stimulation device 2. Standalone micro-computer connected to sensing apparatus, analyzes biosignals, sends stimulation signal to stimulation device <u>Considerations</u>: - cost - difficulty to design/create	Device that houses the program/algorithm that will analyze biosignals/infant output. Device will be capable of receiving infant output, and sending stimulation dictation to the stimulation device.
Design sensing device (if novel) - Prototype - Test - Refine <u>Considerations</u>: - implementation - cost - bulkiness/being out of the way of current cables/tubing	A novel sensing device that accurately and quickly monitors an output from the infant that is capable of differentiating apnea versus no apnea.
Create biosignal analysis (apnea detection) part of program/software - Prototype - Test - Refine	Code that has the ability to analyze the output from the monitoring equipment, and can detect an apneic episode.

Decide how we want to stimulate; design stimulation device Considerations: - Patient contact/invasiveness - Manufacturing difficulties	Decision of how we will stimulate the infant, and a design of said stimulation device.
Create stimulation signal part of program/software - Prototype - Test - Refine	The program/algorithm is now capable of dictating a stimulation to the stimulation device.
Create stimulation apparatus - Prototype - Test - Refine	The stimulation apparatus has been created and can stimulate upon receiving the dictation from the program/algorithm.

Education:

08/94 to 05/02 Presbyterian Day School
Elementary School
Memphis Tennessee

08/02 to 05/08 Memphis University School
High School
Memphis, TN

08/08 to 05/13 University of Tennessee at Knoxville
B.S. Biomedical Engineering, May 2013
Overall GPA: 2.84, Spring 2012: 3.23, Summer 2012: 3.65

Experience:

04/05 to 05/08 Boy Scouts of America Troop 48, Life Scout, Germantown, Tennessee

08/06 to 08/06 Camp Bear Track, Counselor in Training, Drasco, Arkansas

Continuing Freelance Computer Building/Technical Support
Apple, BSD, Linux, Server, Solaris, Windows, Various Hardware

Skills:

Computer Skills: OS: Apple, BSD, Linux, Solaris, Windows. Programming: Java, C, C++, MATALB. All computer hardware troubleshooting

Positions of Leadership: Boy Scout Squad Leader, Website Design Team, Server Administrator.

Awards & Honors:

Phi Sigma Theta National Honor Society, University of Tennessee Knoxville, 2008

Sigma Alpha Lambda National Leadership and Honors Organization, University of Tennessee Knoxville, 2009

Hope Scholarship: 08/08 to 12/09

Education:

University of Tennessee, Knoxville — Aug. 2008 – present
Bachelor of Science, Biomedical Engineering — Projected Graduation Date: May 2013
GPA: 3.68/4.00

Experience:

Kimberly-Clark Corporation – Roswell, GA
Research & Engineering Co-op -- August 2011 – August 2012

Kimberly-Clark Health Care, Pain Management & Systems Engineering: Jan. 2012 – Aug. 2012

- Designed and constructed bench-top system for use in establishing baseline cooled and uncooled Radiofrequency lesion characterization [V&V] data in various ex-vivo mediums
- Executed core R&E work during product development process, from concept to bench-top V&V testing, of two significant medical device launches
- Designed experiment and performed RF ablations in live swine to examine safety and efficacy of prototype cooled-RF probes with intended use in cervical spine chronic pain relief
- Integrated acquired Design History File documents into KC's Design Control Database in order to comply with company policy and FDA auditing regulations

Kimberly-Clark Professional, Industrial Safety: August 2011 – December 2011

- Conducted and presented statistical data analysis on current cut glove market; leveraged research findings to support product launch
- Gathered feedback directly from end-users of our products; reacted accordingly based on their needs while navigating within the limiters placed on our team
- Core R&E team member of exploratory project involving innovative redesign of glove manufacturing process of form-fitting elastomeric gloves
- Utilized SolidWorks CAD software to modify and optimize hand shape mold used in glove sizing and production

Technical and Other Skills:

- Microsoft Word, Excel, PowerPoint, and Outlook
- SolidWorks CAD Software, MATLAB computing software
- Hands-on work in bioskills cadaver laboratory (worked with fluoroscopic C-arm manipulation)
- Customer complaint [laboratory] investigation experience
- Design History File (DHF), Design Control Database (DCD), and Quality Mgmt. Sys. experience

Honors/Activities:

Notable achievements and Leadership:

- Eagle Scout
- Alto Saxophone Section Leader (high school band)
- Traveled throughout Europe with Kentucky Ambassadors Band

Scholarships:

- UT College of Engineering Scholarships
- KY/TN District Kiwanis Scholarship
- Marshall County Rotary Club Scholarship
- Westlake Chemical, Engineering Scholarship
- Beta Theta Pi "Balanced Man" Scholarship

Organizations and Honor Societies:

- Gamma Beta Phi National Honor Society (Corresponding Secretary, Aug. '09 – May '12)
  - Responsible for records of members' attendance at club functions and records of community service earned
- Memberships in other National Honor Societies: Phi Sigma Theta, Omicron Delta Kappa, Sigma Alpha Lambda, Phi Eta Sigma, National Society of Collegiate Scholars

Objective

To acquire engineering experience through analyzing a problem, finding its solution, and manufacturing the solution in the time allotted for the course, while continuing to develop my interests in Biomedical Engineering.

Education

Memphis University School High School Memphis, TN	08/03-05/09
University of Tennessee-Knoxville Bachelor of Science in Biomedical Engineering	December 2013

Work Experience

Food City		
Cashier & Courtesy Clerk	Knoxville, TN	Summer 2012
Memphis University School		
Sports Camp Counselor & Coach	Memphis, TN	Summer 2010
Paulsen Printing Company		
Hand-work	Memphis, TN	Winter 2010

Honors/Awards/Activities

- Annual Participation In Lambda Chi's Watermelon Bust Philanthropy Benefitting St. Jude Children's Hospital
- Greek Community: Member of Epsilon Omicron Chapter of Lambda Chi Alpha

Computer Skills

- Matlab, Excel, Powerpoint,, Mac Operating Systems, Video Production

Education:

University of Tennessee at Knoxville
B.S. Biomedical Engineering, expected May 2013
Cumulative GPA: 3.87
Relevant Courses: Dynamics, Thermodynamics, Organic Chemistry, Circuits, Biomechanics

---

Work Experience:

STAIR, UTK Department of Chemical Engineering (8/11 to Present)..…..Knoxville, TN

- Research Assistant to Dr. Keffer

UTK Chancellor's Honors Program (8/11 to Present).....…….Knoxville, TN

- Honors Peer Advisor

Tennessee Orthopedic Clinic (7/11 to 8/11)…….……Knoxville, TN

- Over 40 hours of shadow experience in clinic and surgery

Concord Par 3 Golf Course (5/07 to 8/10)……Knoxville, TN

- Cashier
- Course Mower

Skills:

Computer based: Word, Excel, Powerpoint, basic MATLAB, Windows OS
Leadership experience/positions
Key Club (Volunteerism Club with over 200 members) – Secretary (07/08), President (08/09)

Activities and Awards:

Member:

- Chancellor's Honors Program
- Tau Beta Pi (Engineering Honors Society)
- National Society of Collegiate Scholars

Scholarships:

- Tennessee Hope plus Merit Supplement (8/09 to Present)
- Len and Nancy Lois Neubert Scholarship/Engineering (8/09 to Present)
- UT Chancellor's Tennessee Scholar's/ Thomas D. Dunlap Scholarship (8/09 to Present)
- Ira Gladson Community Service Scholarship (8/09 to 5/10)
- Kiwanis Key Club Scholarship (8/09 to 5/10)

Awards:

- Key Clubber of the Year-- 2009

Volunteer work:

- STAR (Shangri-la Therapeutic Academy of Riding)
- Love Kitchen
- Fantasy of Trees

Extracurricular activities:

- Study abroad in England (Summer 2011)
- Sports (Intramural Soccer, Running)
- Tau Beta Pi