Acoustic Sleep Apnea Detector

Team Members: Sean Hill (BME), Alex Kuley (BME), and Dan Merritt (EE)

Advisor: Dr. Brian Rothman†

Vanderbilt University 2010

†Department of Anesthesiology, Vanderbilt University Medical Center
Abstract

Obstructive sleep apnea (OSA) is a disorder characterized by periods of breathing cessation during sleep caused by an airway obstruction. Decreased oxygen levels in the blood caused by this disorder can lead to brain and heart damage. Patients suffering from sleep apnea are especially susceptible to damage in the 48 hours post-anesthesia. In this study, we design and construct an inexpensive device that records and analyzes tracheal sounds waves to detect sleep apnea and awake a patient at its onset. It was found that a tracheal breath sound has a characteristic frequency between 400 and 700 Hz. The collected sound waves were analyzed to detect a breath by comparing the frequency content of the wave with this frequency range. A program coded in Labview 2009 analyzes the data to determine the occurrence of sleep apnea based on this criterion. Should apnea be detected, the device will alarm and awake the patient before damage is incurred. The device and computer program was found to accurately identify 93% of apnea events and 96.2% of breaths in real time. This compared favorably to an alternative apnea detection program coded in MATLAB. These results serve as a proof of concept that apnea can be accurately detected using tracheal breath sounds. Future work would ideally incorporate the program into a microcontroller that can be housed on the microphone to form a self-contained apnea detection device for post-anesthetic patients.
Introduction

Obstructive sleep apnea (OSA) is characterized by repeated pauses in breathing during sleep due to airway obstruction. This is often caused by relaxed muscle tone during sleep that collapses the airway. An estimated 5% of the entire human population suffers from obstructive sleep apnea (OSA). In the US alone, an estimated 18 million suffer from this condition. Approximately 8 million of these Americans have a documented diagnosis of OSA, leaving 10 million people undiagnosed [Varaday et al]. Many of these people are not diagnosed simply because those who suffer from sleep disorders are typically not aware of it. Diagnosis requires overnight monitoring by machine or human, which can be expensive and time consuming [Varaday et al]. Unfortunately, undiagnosed apnea can put a person at risk for side effects ranging in severity from mild (e.g. non-restful sleep, shortness of breath) to severe (e.g. cerebral hypoxia). Furthermore, obesity and anesthesia increase the likelihood of an apnea sufferer experiencing these side effects [Gander][Golabbakhsh]. Some studies have found that about 1 in 4 Americans are obese. Also, the current annual number of hospital procedures requiring anesthesia is about 40 million and continues to rise each year. Monitoring hospital patients that meet one or both of these criteria is not feasible based on manpower alone. Also, due to the large number of patients with these apnea risk factors, using current, expensive apnea monitoring devices is not feasible. Undiagnosed apnea sufferers would not be able to use these expensive devices, as they require a doctor’s diagnosis prior to use. Therefore, to satisfy this need for monitoring patients with high apnea risk factors, an inexpensive, compact apnea monitoring device is desirable.

1 Gallup-Healthways Well-Being Index 2009 survey found that 26.5% of American adults are obese (WebMd.com, February 10, 2010).
2 Anesthesia Business Consultants, LLC, estimates that 40 million anesthetic procedures were performed in 2008 (anesthesiallc.com).
3 See economic analysis in Results section
Specifically, our goal was to create an apnea detection device that is easy to set up and use (i.e. no training required), provides a clear and accurate indication of apnea, and simultaneously wakes the patient and alert nearby hospital staff upon apnea detection. We also wanted to make our device comfortable enough to allow for normal sleep and less expensive than current apnea monitoring devices. Finally, we wanted it to be economically feasible for our device to be used on as many hospital patients as possible that meet one or both of the aforementioned apnea risk factors.

**Methodology**

The basic apnea detection parameter our device was designed to monitor was the sound of breathing (or more importantly, the absence thereof). From our literature search, we found that an apnea episode is defined as a period where breathing ceases from 10 seconds or more during sleep [Varaday et al]. It was also found that apnea could be categorized in three levels based on the number of apnea episodes in one hour: mild (5-14 episodes per hour), moderate (15-29 episodes per hour), and severe (30+ episodes per hour). Moderate and severe apnea put the patient at the most risk for physiological side effects post-anesthesia (mild apnea has not been found to put patients at risk post-anesthesia) [Mickelson]. Therefore, our device was designed to detect the number of apnea events in one hour of sleep and alert the patient and hospital staff if: the patient stops breathing for 15 seconds or more or the patient experience 15 or more apnea episodes in an hour (i.e. moderate to severe apnea occurs) during sleep post-anesthesia.

Moreover, our device was modeled to loosely emulate the Rainbow Acoustic Respiration Sensor by Masimo [Al Ali]. This device, which was submitted for patent in November 2009,
attaches via an adhesive strip to the lower portion of the neck, over the trachea. Anatomically, this location is called the suprasternal notch. The Masimo device uses a thin transducer to detect tracheal breath sounds. This device does not stand alone, and must be integrated with other Masimo Rainbow devices to monitor respiration rate. Also, unlike our device, the Masimo device is not designed specifically for apnea detection. Initially, like the Masimo device, we used a transducer for tracheal breath sound detection. The piezo transducer we used is pictured in Figure 2. To minimize the need for multiple pieces of equipment, we decided to deviate from the Masimo device and make our device stand alone. Specifically, we wished to wire the piezo transducer to a bandpass filter circuit to isolate breath sounds and a microcontroller circuit that would perform the apnea detection algorithm. In addition, since the piezo transducer could also be set to vibrate at certain frequencies, we wanted to use it as a speaker to alert for apnea. To test the transducer’s signal to noise ratio (SNR), the component was placed on the suprasternal notch during normal breathing. This test was done twice: in a quiet environment (empty classroom) and a noisy environment (room with 2 subjects talking 15 feet away.).
from the “patient”). The noisy environment test was performed to ensure that background noises, which are common in hospitals, would not overpower the transducer’s ability to detect a breath sound. The frequency range of interest was between 400-700 Hz. This was based on a literature finding that typical tracheal breath sounds fall into this range [Golabbakhsh]. Figure 3 shows that this transducer component is highly susceptible to background noise and has a poor SNR even in a quiet environment. Notice that there is less than a 5dB difference between the signal (1a) and noise (1b) for the quiet environment in the 400-800 Hz target range. The difference between signal (2a) and noise (2b) for the noisy environment is a little more pronounced (~5-10 dB). However, there is some mid and high frequency noise that pollutes the signal (2a). This was deemed unacceptable, and a new breath detection component was sought.

When searching for a new microphone, two types were considered: contact microphones and air-coupled electret microphones. We narrowed our choices because it was found that most lower-neck tracheal breath detection is done using microphones of these two types [Sovijärvi].
The high quality contact microphones we found were expensive and, thus, defeated the purpose of designing an affordable apnea detection device\textsuperscript{4}. On the other hand, electret microphones, which can be equally effective at picking up breath sounds, were found to be much cheaper\textsuperscript{5}. Therefore we selected an electret microphone: the RadioShack model 270-092. This model was chosen because of its price (less than $4). In one study, an electret microphone was attached to a stethoscope via plastic tubing to amplify breath sounds [Kraman et al]. So, we emulated this design by attaching our electret to a stethoscope directly. Specifically, a pediatric stethoscope (Primacare model DS-9291) was chosen for its compact size and minimal price ($6.50). The stethoscope amplification chamber and diaphragm were separated from the stem using a hacksaw. The separated amplification chamber is shown in Figure 4. The amplification chamber, a small washer, and the microphone were attached with epoxy (JB Kwik Epoxy, JB Weld, Sulfur Springs TX). The leads of the microphone were soldered to a 6 foot shielded cable with 1/8” audio jack (RadioShack model 42-2434). The final prototype is pictured in Figure 5. The prototype was evaluated for its frequency response and SNR at the target breath frequency range (400-700 Hz) using Audacity\textsuperscript{6}.

The next step in the design of our acoustic apnea detector was the creation of an apnea detection algorithm. The initial idea of using a built-in circuit and microcontroller to process the

---

\textsuperscript{4} Two contact microphones that were tested in a study of several microphones used to detect respiration sounds – the Sony ECM T150 and Siemens EMT 25C – cost $75 and $200 respectively [Kraman et al]

\textsuperscript{5} All air-coupled microphones tested in one study were less than $50. One microphone – the RadioShack model 33-1052 – costs $15 and was found to be equally effective as contact microphones, when coupled to an amplification chamber [Kraman et al]

\textsuperscript{6} Audacity is open source audio recording, manipulation, and analysis software distributed by SourceForge.net under the GNU General Public License.
audio signal was not implemented in the final design. This was due to the high complexity of programming a fast Fourier transform algorithm in the microcontroller’s programming language, assembly. Time constraints and lack of experience using assembly prevented the implementation of this complex algorithm. Instead, apnea detection via a computer program was explored. Two apnea detection programs were created: one in LabView and one in Matlab.

The 1st program was designed in LabView 2009 (National Instruments, Austin, TX). To alert the patient at the onset of sleep-apnea in real-time, the signal from the air-coupled microphone is sampled at 44.1 kHz. The 16 bit sound wave is recorded in 240 ms intervals, each of which is analyzed via an algorithm that computes the discrete Fourier transform of the data called the Fast Fourier Transform (FFT). This sampling interval was experimentally determined to be the optimum interval that would include a breath but average out random noise that may fall in the detection range. A Fourier transform calculates the magnitude of the input in as a function of frequency. The frequency associated with the maximum magnitude is extracted from the FFT data in LabView. If this value is in between the normal frequency range for tracheal sounds, 400 Hz and 800 Hz (a conservative range based on a study by Golabbakhsh), a breath is considered detected. If after 10 seconds, another breath is not detected, an apnea event is considered
detected, but no alert will sound unless 15 events are detected within one hour. A contingency alert was also programmed to sound if no breath is detected after 15 seconds. The LabView VI is pictured in the Appendix.

In addition, a live detection algorithm was implemented in Matlab (The Mathworks, Inc, Natick MA). The microphone input is split up into segments consisting of 1000 samples and is recorded at a 44.1kHz sampling rate. Each segment is processed using a 1000 point FFT and the amplitude at 464.5Hz is inspected because it is inside the determined frequency range. The amplitude is analyzed to determine if is greater than the threshold, 1.5 times the mean the amplitudes of all the frequencies in the FFT. A breath is considered detected if this segment and the five previous segments are above the amplitude threshold. If no breath is detected for 10 seconds then apnea is detected.

The sensitivity and specificity for each apnea detection program was found. The sensitivity and specificity calculations for the LabView program were based on 60 trials, 20 for each of 3 group members. Within each 20 trial segment, 10 apnea events and 10 normal

![Figure 6](image.png)

*Figure 6.* The GUI of the LabView program. Frequency is plotted in real time. Recall that this program considers any 400-800 Hz noise of sufficient amplitude a breath.
breathing events were simulated. The protocol for each apnea event simulation was to breathe normally for 5 seconds and hold breath for 10 seconds. The protocol for each normal breathing simulation was to breath at a comfortable level through the mouth for 10 seconds. Mouth breathing was selected because it is typically favored over nasal breathing by apnea sufferers [Varaday et al]. For the Matlab program, the sensitivity and specificity was based on 20 trials, 10 for each of 2 group members. Within each 10 trial segment, 5 apnea events and 5 normal breathing events were simulated according to the aforementioned protocols. The reduced number of trials for the Matlab program was done because the Matlab program was quickly determined to be less robust and less accurate than the LabView program. The tests on the Matlab program were just done as a comparison of alternative algorithms. Finally, to determine the accuracy of the LabView program in detecting breaths, 500 breaths were sampled at random intervals on one of our group members during a span of 2 hours. If the breath sound fell within the detected frequency range (400-800 Hz) and was visible on the GUI frequency plot (see Figure 6), then the breath was counted as detected. If the breath sound did not fall within the detection range and did not show up on GUI frequency plot, then the breath was counted as missed. Sensitivity and specificity were calculated according to equations 1 and 2, respectively (TP = true positive, TN = true negative, FP = false positive, FN = false negative). True positives were defined as apnea events correctly identified by a program (i.e. correct alert). True negatives were defined as correctly identified areas of breathing (i.e. no alert). False positives were defined as incorrectly identified apnea events (i.e. false alert). False negatives were defined as the lack of identification of a real apnea event (i.e. no alert when one was needed). All tests were performed with the subject lying down in a supinated position with the prototype apnea detection
device attached via Tegaderm adhesive (3M Company, Maplewood MN) to the suprasternal notch. The setup is shown in Figure 7.

\[
\text{Specificity} = \frac{TN}{TN + FP} \quad \text{(Eq. 1)}
\]

\[
\text{Sensitivity} = \frac{TP}{TP + FN} \quad \text{(Eq. 2)}
\]

![Figure 7. Anatomical placement of apnea detection prototype during testing](image)

**Results and Discussion**

The FFT of our electret microphone when listening to background noise and tracheal breath signal is shown in Figure 8. Comparing the two frequency plots in this figure shows that the SNR of this device in the frequency range 400-500 Hz is between 15-20 dB. This compares favorably to the SNR of the piezo transducer (<5 dB) we tested. In addition, this signal peak in the range of 400-500 Hz compares well with the peak tracheal breath frequency range in literature. This is shown if Figure 9, where one study found peak tracheal breath signal to occur
in the range of 450-700 Hz [Golabbakhsh]. Therefore, we determined that our microphone was adequate to detect tracheal breath sounds.

The results for the sensitivity and specificity tests for both the LabView and Matlab programs are shown in Table 1. As can be seen, the LabView program has a sensitivity of 0.933 and a specificity of 0.967, while the Matlab program has a sensitivity of 0.6 and a specificity of 1. Thus, the LabView program has a better sensitivity but a slightly lower specificity than the Matlab program. Since TN is a measure of correctly identified normal breathing, specificity for our apnea detection prototype is a measure of breath detection accuracy. Since TP is a measure of correctly identified apnea events, sensitivity for our device is a measure of apnea detection accuracy. Therefore, because the Matlab program has the higher specificity, it is more effective at detecting breaths. And the LabView program, with its higher sensitivity, is more effective at detecting apnea events. However, even though each program provides a unique benefit, the LabView program has the better balance of breath and apnea detection. Therefore, the LabView program is more suitable for our apnea detection device.

In the further testing of the LabView program’s breath detection accuracy, the results for the 500 breath test are shown in Table 2. Out of 500 breaths, 19 breaths were not detected by the

![Figure 8. Frequency plot for background noise (a) and tracheal breath signal (b) using the electret air-coupled microphone (RadioShack model 270-092). Target breath frequency range is noted.](image-url)
program. This means that either the microphone picked up a breath sound and the frequency of that sound fell outside the target range (400-800 Hz) or the microphone did not pick up a breath sound and the detection algorithm treated the event as silence. 481 breaths were detected, yielding a 96.2% accuracy (# detected/total) at correctly identifying tracheal breathing sounds. This performance was evaluated against that of the previously mentioned patented Masimo Rainbow device. The comparison is shown in Table 3. Our device’s breath detection accuracy (96.2%) compares well with that of the commercial Masimo device (99.8%). It should be noted that the breath detection accuracy for the Masimo device was calculated based on 21,405 breaths on multiple patients⁷. We did not have the time or resources to produce this much data. One thing that was not clear in Masimo’s clinical trial was if false positive breath detection events were counted as true positives (i.e. noise that appears to the device as a breath). In our trial, all 481 detected breaths were in the 400-800 Hz range (corresponding to the previously mentioned tracheal breath range shown in Figure 9). Therefore, our trial was designed to minimize false positives to get a more accurate accuracy reading.

---

⁷ Based on data from Masimo’s submission for the Rainbow Acoustic Sensor’s FDA approval, which is displayed on the Masimo website <http://www.masimo.com/rra/clinical_accuracy.htm>
The economic feasibility of our device was considered against current apnea detection devices. One popular device, the CPAP (Continuous Positive Airway Pressure) mask entails a patient wearing an oxygen mask attached to an air flow generator. This mask covers the mouth and nose, and the generator forces air continuously into the patient’s airway. The cost for a complete CPAP setup ranges from $500 to over $1000\(^8\). The total cost for the recording portion (microphone, 1/8” cable, and stethoscope) of our device is about $25, and in its current state it will use a computer for detection. A Netbook, a small affordable computer, costs less than $500. So, our full device is as expensive as the cheapest CPAP option, but is much more compact and comfortable. The development cost for our device is $6,800, calculated from $50 in parts (i.e. all tested components), and 3 students at $15/per hour for 150 hours of work.

The safety hazards associated with the device were evaluated in Design Safe. Potential hazards include electronic shock facilitated by contact between the microphone leads and the patient’s skin. This shock would be strengthened if sweat, saliva, or water increased the conductivity of the skin. This hazard could be best prevented by housing the microphone in a water-proof material. The primary safety hazards, however, are associated with disruption of the detection mechanism, which would then damage a patient if sleep apnea occurs undetected. Because the microphone is wired to a computer in this prototype, the patient could become

\(^8\) Data given on CPAP website. <www.CPAP.com>
entangled with the wire while sleeping. This could dislodge the microphone from the patient's throat and prevent apnea from being detected. A person walking past the patient could also trip on the wire, dislodging the microphone. Both of these safety concerns would be acknowledged in future models of the device, specifically if a microcontroller could be programmed to analyze the data in a self-contained device that would be placed on the neck. Another issue associated with the device is that it is not self-powered. This leaves the functioning of the device susceptible to power-outages. This would also be accounted for in a self-contained model because the device would be battery operated. Finally, because the data is being processed by a computer, any software malfunction that causes the computer to freeze would disrupt the functioning of the device. This remains a possibility regardless of the design of the system, but remains a relatively low risk. For more information, see the Design Safe report in the appendix.

**Conclusions**

In summation, our acoustic sleep apnea detection prototype successfully detects apnea events and breaths. Our device has approximately a 3% probability (1 – specificity) of detecting one sleep apnea event when it hasn’t occurred. In addition, our device has approximately a 7% probability (1 – sensitivity) of failing to detect one sleep apnea event. These percentages are acceptable, given that a single apnea event is insignificant when compared to the number of total apnea events (15+) required to trigger the alarm. Recall that our device was designed with the goal to detect moderate to severe apnea, which is characterized by 15 or more apnea events in one hour. A 93% probability (i.e. sensitivity) of overall apnea detection suggests that approximately 14 out of every 15 apnea events (0.933 * 15 events) will likely be detected. So if one apnea event is missed (e.g. 16 apnea events occur and only 15 are detected), our device will
still alert the patient and nearby hospital staff within a reasonable timeframe. Therefore, while our device may occasionally miss or falsely register an apnea event, it is still able to accomplish our goal. In addition, our device is accurate enough at detecting breaths to compare well with a patented device (the Masimo Rainbow Respiration sensor). As far as the physical aspects of our device, we were successfully able to make a device that was more compact and less restrictive than mask-based apnea devices such as the CPAP. And while our device does not treat apnea like the CPAP device, our device detects and diagnoses apnea severity (which the CPAP device is not capable of). Finally, regarding the economic goals of our project, we fell slightly short of making our device more affordable than popular apnea devices like the CPAP. As mentioned in the results section, our whole device (computer included) costs about as much as the cheapest CPAP model.

**Recommendations**

This project can be continued by developing a self-contained device that does not need to be plugged into a computer. This can be achieved using an analog to digital converter to convert the analog waveform into a digital signal. A digital signal processing chip would then be used to take the FFT of the digital signal. A microcontroller would then detect the breathing and classify when an apnea event has occurred. It would also classify the severity of the sleep apnea and alert using a built-in speaker when moderate sleep apnea has been detected. By using this microcontroller and built-in circuit, the new device could be made more affordable than our current device (which requires a computer). In the future, the device should be tested on actual apnea sufferers in coordination with FDA regulations. This will enable the detection algorithm of the device to be further verified.
Acknowledgements
Special thanks to our Advisor Dr. Brian Rothman, Dr. Joel Barnett for assisting in the prototype construction, and Dr. Kevin Seale and Dr. Franz Baudenbacher for help implementing the apnea detection algorithm in LabView.

References


For Appendix (IWB and Design Safe), see following pages:
Ideation Process

Innovation Situation Questionnaire

1. Brief description of the problem
Sleep apnea is a prevalent condition that restricts breathing while a patient is sleeping, causing the person to waken. This happens periodically throughout the night as a patient tries sleeping. By waking up the patient, the condition causes sleep deprivation which reduces memory capacity and other basic functions. It also reduces the amount of oxygen the body receives during the night, which can be fatal for patients of old age and damaging to everyone affected.

2. Information about the system
2.1 System name
Respiratory Tract
2.2 System structure
The respiratory tract is made up of two sections: the upper and lower tracts. The upper respiratory tract is composed of the nasal cavity, the soft palate, the pharynx and the larynx. The lower respiratory tract contains the trachea, bronchi, and lungs.
2.3 Functioning of the system
The system works to direct airflow into the lungs to facilitate blood oxygenation.
2.4 System environment
The system is in the neck anterior to the digestive tract and proximal to the major arteries feeding the skull. It is a very muscular region that surrounds cartilaginous rings of the respiratory pathways.

3. Information about the problem situation
3.1 Problem that should be resolved
The problem to be resolved is to reduce the cost of detecting sleep apnea in patients post-anesthesia.
3.2 Mechanism causing the problem
Sleep apnea occurs when the muscles of the soft palate and surrounding regions attenuate. When this occurs, the tongue, soft palate, and cartilaginous tissue recedes into the airway to at least partially obstruct it. This occurs during a patient's sleep cycle, so the patient is unaware of this occurrence. This continues as the patient sleeps, causing systemic damage.
3.3 Undesired consequences of unresolved problem
If the apnea goes uninterrupted, cerebral hypoxia and sleep deprivation onset.
3.4 History of the problem
Other attempts at detecting and alerting a patient to a sleep apnea incidence are expensive and complicated. They are often large machines that are hard to move, so the detectors are restricted to specific rooms.
3.5 Other systems in which a similar problem exists
None
3.6 Other problems to be solved
None

4. Ideal vision of solution
The patient has an apnea incident and is immediately awoken and alerted to the problem in a low cost manner.

5. Available resources
Component Resources: Adhesives, piezo contact microphone, piezo buzzer, circuit, LEDs.
Field Resources: Electrical energy from battery
Time Resources:
For the entire operation:
Time until event detection: 15 seconds
Time for alert: 10 seconds

Informational Resources: Fields irradiated from the system and components: noise, light

6. Allowable changes to the system
The respiratory tract cannot be altered, so no changes to the system can take place.

7. Criteria for selecting solution concepts
Desired Technological Characteristics Noise:

80 dB 0.25m from the device Light:

Constant LED operation indicating proper functionality
Flashing LED operation indicating low power

Desired Economic Characteristics

Cheap enough to be disposable
Desired Timetable
5 months for development, design, and implementation of solution concept.

8. Company business environment

9. Project data

Title: Sleep Apnea Detection Objective: Develop a cheap, instantaneous device that detects sleep apnea

Timeline: 5 months for development, design, and implementation of solution concept. Team:
Alexander Kuley, Biomedical Engineer
Daniel Merritt, Electrical Engineer
Sean Hill, Biomedical Engineer

Advisor Brian Rothman, M,D. 1211 Medical Center Drive 2301 VUH 37232-7614
(615) 343-9419

Problem Formulation

1. Build the Diagram
2. Directions for Innovation

1. Find an alternative way to obtain [the] (Awake Patient) that does not require [the] (Alert).

2. Consider transitioning to the next generation of the system that will provide [the] (Awake Patient) in a
more effective way and/or will be free of existing problems.

3. Find an alternative way to obtain [the] (Alert) that offers the following: provides or enhances [the] (Awake Patient), eliminates, reduces, or prevents [the] (Apnea Event), does not require [the] (Apnea Detection).

4. Find a way to eliminate, reduce, or prevent [the] (Apnea Event) under the conditions of [the] (Airway Obstruction).

5. Find a way to eliminate, reduce, or prevent [the] (Airway Obstruction) in order to avoid [the] (Apnea Event), under the conditions of [the] (Asleep Patient).

6. Find an alternative way to obtain [the] (Asleep Patient) that does not cause [the] (Airway Obstruction).

7. Try to resolve the following contradiction: The useful factor [the] (Asleep Patient) should be in place in order to fulfill useful purpose and should not exist in order to avoid [the] (Airway Obstruction).

8. Find an alternative way to obtain [the] (Respiratory Sounds) that offers the following: provides or enhances [the] (Apnea Detection), is not influenced by [the] (Apnea Event).

9. Find an alternative way to obtain [the] (Apnea Detection) that offers the following: provides or enhances [the] (Alert), does not require [the] (Respiratory Sounds).

Prioritize Directions
1. Directions selected for further consideration
None are applicable for our objective.

2. List and categorize all preliminary ideas
Not applicable

Develop Concepts
1. Combine ideas into Concepts
Prevent physiological damage caused by sleep apnea in anesthetized patients by detecting by tracheal sounds and waking the patient before the onset of hypoxia. The tracheal sounds can be acquired by fixing an air-coupled microphone to a patient's suprasternal notch and input the sounds to Labview. Labview can be programmed to analyze the sounds and activate an alarm when sleep apnea is detected.

2. Apply Lines of Evolution to further improve Concepts
The lines of evolution are not applicable to improving the device.

Evaluate Results
1. Meet criteria for evaluating Concepts
The evaluation can be completed when the device is constructed and a virtual interface can be programmed in Labview.

2. Reveal and prevent potential failures
The alarm could sound without an apnea event. This can be prevented by making sure the air-coupled microphone is adequately fixed to the patient's neck. The alarm could not sound during an apnea event. This is likely caused by external noise, in this case, a less sensitive microphone could be used. Also, more efficient active filters could be programmed in Labview.
3. Plan the implementation
The Labview will serve as a proof of purpose. Further work by computer engineers can program a microcontroller so that the acquisition, processing, and alarm can be combined in a singular device placed in a patient's neck.
**designsafe Report**

**Application:** Acoustic Apnea Detector

**Analyst Name(s):** Sean Hill, Dan Merritt, Alex Kuley

**Company:** Vanderbilt University Senior Design

**Facility Location:** Nashville, TN

**Assessment Type:** Detailed

**Limits:**

**Sources:**

Guide sentence: When doing [task], the [user] could be injured by the [hazard] due to the [failure mode].

<table>
<thead>
<tr>
<th>User / Task</th>
<th>Hazard / Failure Mode</th>
<th>Initial Assessment</th>
<th>Final Assessment</th>
<th>Status / Responsible</th>
</tr>
</thead>
<tbody>
<tr>
<td>All Users</td>
<td>electrical / electronic : water / wet locations Microphone or monitoring device may become wet from sweat or saliva, etc.</td>
<td>Minimal None Unlikely Low</td>
<td>Water-proofing, fixed enclosures / barriers Minimal None Negligible</td>
<td>Low</td>
</tr>
<tr>
<td>All Users</td>
<td>electrical / electronic : software errors Software may freeze or crash, failing to detect apnea</td>
<td>Slight Remote Unlikely Low</td>
<td>supervision / train user to check on device to ensure it hasn't froze/crashed Slight Remote Negligible</td>
<td>Low</td>
</tr>
<tr>
<td>All Users</td>
<td>electrical / electronic : power supply interruption Power outage would interrupt detection</td>
<td>Slight None Negligible Low</td>
<td>Uninterruptable power supply (implemented in most hospitals) Slight None Negligible</td>
<td>Low</td>
</tr>
<tr>
<td>All Users</td>
<td>slips / trips / falls : trip Patient or staff may trip over microphone wire</td>
<td>Slight Occasional Unlikely Moderate</td>
<td>Use wireless connection, or increase cable length to ensure cable lays flat on ground Slight Remote Negligible</td>
<td>Low</td>
</tr>
<tr>
<td>All Users</td>
<td>ergonomics / human factors : wire entanglement Patient may become entangled in wire during sleep / wire may become entangled with other wires</td>
<td>Slight Occasional Possible Moderate</td>
<td>Use wireless connection / use self contained device Slight None Negligible</td>
<td>Low</td>
</tr>
</tbody>
</table>