Alleviating Alarm Fatigue in the NICU

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1.0 Executive Summary

In cooperation with Dr. Lee Budin, pediatrician and head of the Center of Excellence at Lurie Children's Hospital in Chicago, we designed a system that eliminates redundant phone alarms in the Neonatal Intensive Care Unit (NICU). The hospital has encountered trouble with alarm fatigue, or desensitization due to repeated alarms. Several nurse observations and meetings at Lurie's with our client allowed us to gain a better understanding of how the system of alarms works in the NICU.

Currently, there is no method to prevent nurses from receiving alarms on their phones if they are already present in their patient's room. A nurse often has his or her hands full and cannot turn off their phone's alarm. This loud alarm is both annoying and inconvenient to the nurses and the patient's families. Our design uses a Radio Frequency Identification (RFID) reader and tag to sense a nurse's presence in the room and subsequently suppress the redundant phone alarms that have been causing so much distress.

The RFID design combines an Ultra High Frequency (UHF) Reader with a directional antenna and adjustable range with UHF tags that nurses will wear as ID tags. These two components combine to create a hands-free identification system that is within the range of a single patient's room. The reader will read the tag on the nurse when he/she is present within the room, and then suppress the signal from the patient monitor to the nurse's phone.

The RFID design eliminated the primary nuisance, redundant alarms, while simultaneously meeting the requirements and specifications desired for use by our client and the NICU at Lurie Children's Hospital.

Requirements:

- <u>Patient Safety</u>: Because the design has no direct connection to the system that monitors the patient, there will continue to be an alarm every time the neonate deviates from his or her set parameters. However, a redundant phone alarm will not sound if the nurse is present in the room.
- <u>Eliminates Redundant Phone Alarms</u>: The design allows for the suppression and subsequent elimination of all redundant phone alarms. The nurse's RFID tag, situated on their ID's, will send a signal to a reader when in range and will keep the monitor from sending an alert signal to their phone.
- <u>Does not Interfere with Current Nurse Protocol</u>: Since the design is a hands-free, passive system, the nurses will continue their current practices and not notice a difference, except for the absence of annoying phone alarms.
- <u>Cost efficient and simple to implement</u>: Each monitor only needs a UHF RFID reader and each nurse only needs a UHF RFID tag, which cost less than $500 per room. The identification system is also relatively easy to implement, as it does not require any training.

2.0 Introduction

2.1 Alarm fatigue puts patients in danger

Alarm fatigue is a phenomena that currently plagues hospitals around the world. It appears as a result of alarms constantly ringing within a unit, or even a hospital in general. Nurses are required to check on patients once they set off an alarm, but treatment of the patient is not always necessary. The patient could be having a natural response to external stimulation, such as movement upon hearing a loud noise, or they could even have a physiologic anomaly like a congenital heart defect or underdeveloped lungs that causes the patient to set off alarms frequently. The longer the nurses are exposed to this stimulation, the less urgent each alarm seems. This situation is similar to the well-known fable "The Boy Who Cried Wolf". Each time a non-actionable alarm, one that does not require any action, sounds, the nurse becomes less and less inclined to respond urgently to any alarm. This could lead to dangerous delays in nurse response that could be detrimental to patient health. In 2011, an 89 year-old heart patient died due as a direct result of alarm fatigue at Massachusetts General Hospital. For more information about alarm fatigue, please refer to Appendix B.

2.2 Redundant alarms are disturbing nurses

Our team was asked to design a device that would combat alarm fatigue due to desaturation alarm alerts in the Neonatal Intensive Care Unit (NICU) at Lurie Children's Hospital. Frequent oxygen desaturation alarm alerts are sounding in the NICU, and many of them require no action. For patient safety, there is a redundant alarm system that alerts multiple devices, including the patient's monitor and two nurses' phones, about the alarm that is going off. The nurse's fatigue is not coming from the monitors themselves, but the extra ringing from their phones, especially when they are already in the room, caring for the patient who is alarming.

2.3 Alternative algorithms take time to develop

To tackle this problem, our initial goal was to create an algorithm or prototype that increased the specificity of oxygen saturation critical alarms in the NICU so that nurses could more effectively respond to the most urgent alarms. After attending meetings with our client and performing numerous observations in the NICU, we determined that this might not have been the correct direction for a project that was constrained to ten weeks. We moved away from the algorithm idea, and instead decided to make a recommendation to the company that makes the monitors, Philips. It is likely for an improved algorithm like this to be implemented in the future.

2.4 Alarms are hard to turn off when hands aren't free

The patient's monitors are often out of reach, and the alarm can only be silenced manually. If they are not turned off, the monitor sends a signal to the patient's nurse's phone, which vibrates and rings loudly. This method of alerting the nurse is effective when the nurse is away from the patient, however, it is unnecessary when the nurse is present in the patient's room. Eliminating these unnecessary alarms is the first step in combating alarm fatigue. We saw that an RFID system may be a viable option.

2.5 Using RFID readers and tags can reduce alarm fatigue

The Radio Frequency Identification (RFID) scanner eliminates unnecessary alarms by sensing the nurse's presence in the patient room. A reader will be embedded in the patient monitor, and the nurses will wear a tag that sends out the RFID signals. Once the nurse enters the room, the reader receives a signal and turns off the monitor's ability to send an extra alert to the nurse's phone. The monitor itself will still alarm since the nurse is not always looking at the monitor, but the phone will not go off. Once the nurse leaves the room, the reader in the monitor does not receive any more signals and will proceed to send alerts to the nurse's phone when an alarm goes off.

This proposal explains the users, requirements, and implementation of the design, as well as recommendations for future iterations and testing.

3.0 Users and Requirements

The following information is drawn from our first interview with our client, Dr. Lee Budin, from the Center of Excellence at Lurie Children's Hospital. For a complete summary of this interview, including more about the primary problem we are tackling, see Appendix C.

3.1 Users and Stakeholders

3.1.1 Users

The primary users of our design will be the nurses on staff in the NICU at Lurie Children's Hospital in Chicago. Our RFID sensor is designed to help identify and locate nurses in order to eliminate redundant phone alarms. The nurses will be the ones who interact most with the patient monitors, and are the ones who receive the immediate notification of any alarms from their respective patients. They will be the ones wearing the RFID tags that can be used to deactivate the phone alarm while they are in their patient's room

3.1.2 Stakeholders

Patients and their families are a primary stakeholder in the development of a solution to this problem. Patients are the ones who are put in danger when the negative effects of alarm fatigue are exhibited. In several cases across the United States, there have been instances in which a patient was harmed due to a delayed nurse response that came about due to uncontained alarm fatigue.

Lurie Children's Hospital is also a stakeholder because they are striving to avoid potential litigation. Alarm fatigue has recently become one of the leading healthcare technology hazards. By finding an alarm management solution, the hospital would not have to worry about dealing with alarm fatigue and potentially disastrous situations in which patients are hurt.

3.2 Design Requirements

The following requirements were determined through extensive user observation. Discussion with the nurses in the NICU as well as our client allowed us to pinpoint one of the most frustrating issues in the NICU. For the complete summary of our observations and how we went about them in the NICU, please see Appendix D and E.

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In order to fully and effectively aid the nurses our design needs to meet a few requirements. It must:

- ensure the safety of the neonates
- turn off redundant phone alarms
- Preserve nurses' everyday protocol
- Be feasible to implement within the hospital

3.2.1 Ensure the safety of the neonates

Patient safety and health is the highest priority in our design. They are in the hospital to heal, and if we were to inhibit that process at all, we would be doing a disservice to our client. Any compromise in this area would be counter-productive. The problem we were presented with isn't centered around the patient. The implementation of the design involves the patient, but is centered around the nurse. Our design is meant to improve the satisfaction of the nurses, who will then provide higher quality care to the patient, allowing them to heal more quickly. The patient's health is not to be adversely affected by our design. They are the top priority.

3.2.2 Turn off the redundant phone alarms

The design needs to turn off redundant phone alarms. A major source of nurse desensitization, or alarm fatigue, is the redundant alarms that are being sent to the nurses' phones while they are in their patient's room. Whenever a patient's vitals, such as oxygen saturation in our case, dips below an unsafe boundary, known as the desaturation limit, the nurse is alerted through the patient's monitor as well as their phone's alarm. The phone alarm is meant to get the attention of the nurse when he or she is not in the room; however they still sound when the nurse is present in the room, even though it is not necessary. Listening to the sounds of the alarm can be exasperating and as a result, nurses may respond slower and less enthusiastically when future alarms go off. This could be detrimental to patient health and safety, which is our main priority. Through user observations with several nurses, it was determined that the most annoying part of the alarms is the inability for nurses to silence the alarms even when they are in the alarming patient's room. In order to increase nurse satisfaction and maintain patient safety, our design needs to eliminate the frustrating, redundant alarms.

3.2.3 Preserve nurse protocol

Our design also must preserve current nurse protocol. Nurses go through years of training to learn the best ways to treat their patients, and it is not our place to tell them how to do their jobs. Instead, we are to implement a design that can be used as an accessory in their current procedures. The design need not take any more time out of the nurse's day in order to maintain the current level of efficiency. Any decrease in effectiveness of the nurses could jeopardize the wellbeing of the patients, which goes against our first requirement.

3.2.4 Be cost efficient and easy to implement

Another requirement for the design is that it must cost-effective. The design needs to be compatible with all current equipment, so the purchase of all new equipment can be avoided. The current monitors and technology being used are some of the best available. This often means that they are also expensive. Few corporations enjoy using large sums of money to implement a basic design. If future iterations prove to be groundbreaking, there might be a longer discussion, but for our purposes, no expensive alterations to the technology will be necessary.

A design that meets a combination of all these requirements should be inherently unobtrusive and easy to use. Integration into the current protocols should be manageable and practical, pleasing all users and stakeholders.

4.0 Design Concept and Rationale

The Radio Frequency Identification (RFID) sensor is an assistive device that will increase the ease at which nurses in the Neonatal Intensive Care Unit at the Lurie Children's Hospital are able to avoid redundant alarms. It consists of an RFID reader integrated into the patient monitoring system, and tags that double as nurse ID's. Once the nurse enters his or her patient's room, the signal that is sent to their respective phones from the patient monitor when an alarm is set off is repressed.

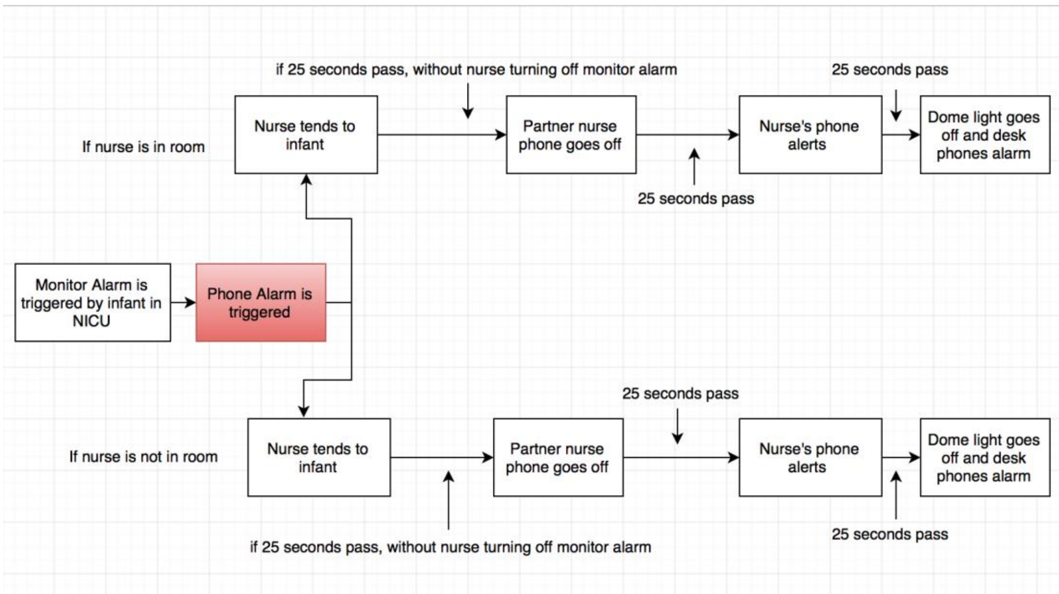

Figure 1: Current Path of an Alarm

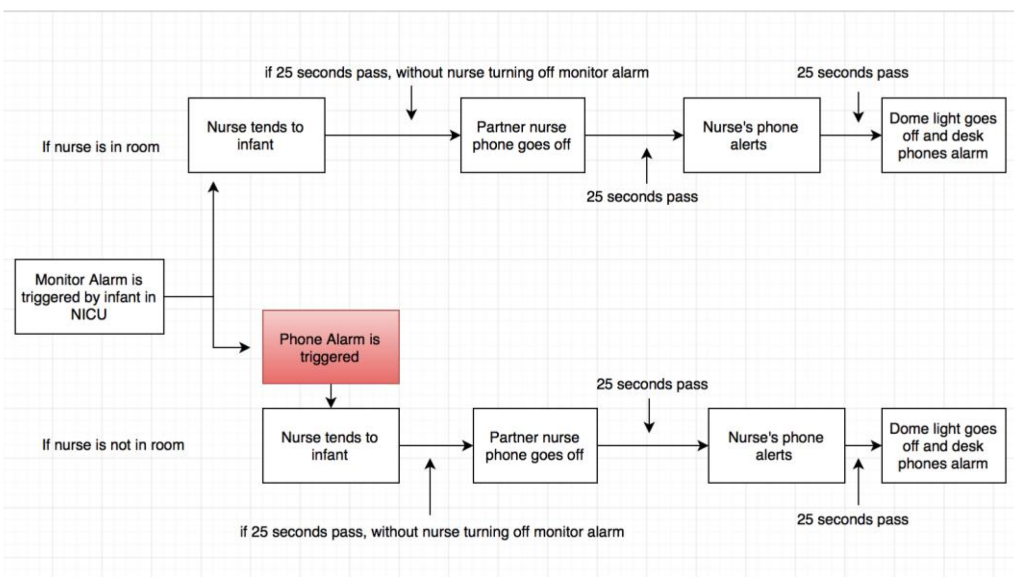

Figure 2: Path of alarm with RFID sensor

4.1 The range of an RFID reader can be limited by gain and frequency

The reader will have a range limited to the size of a patient's room, in order to prevent a nurse's close proximity to the room from repressing the phone alarms. This will be achieved through the appropriate adjustment of gain and frequency. The gain of each RFID reader determines the overall beam-width of the waves, affecting the range of the reader; the higher the gain, the more focused the beam, and the farther the waves travel. The gain and range can be adjusted according to the size of each room.

Frequency also plays a role in the determination of range. For our purposes, an Ultra High Frequency (UHF) reader will be necessary since our target range is between 5 and 12 feet. Low frequency and High Frequency readers both have ranges less than 5 feet, which is unsuitable. For more information about RFID and how it works, see Appendix F.

4.2 The UHF RFID reader has useful specifications

We recommend the use of the LinkSprite Long Range UHF RFID reader, which has both a directional antenna and adjustable read distance. The range on this reader is between 1 meter and 5 meters, which suits our need for a 5-12 foot range. The integrated directional antenna allows for the prevention of waves travelling into adjacent rooms behind the monitor. This reader costs $460, much less than an entirely new monitor. No extraneous burden placed on the hospital, and only a technician will be needed if there are glitches or problems. Instead of buying 44 $20,000 monitors, the hospital only has to spend a fraction of that cost on our design. For a complete bill of materials, see Appendix G.

Figure 3: LinkSprite UHF RFID reader

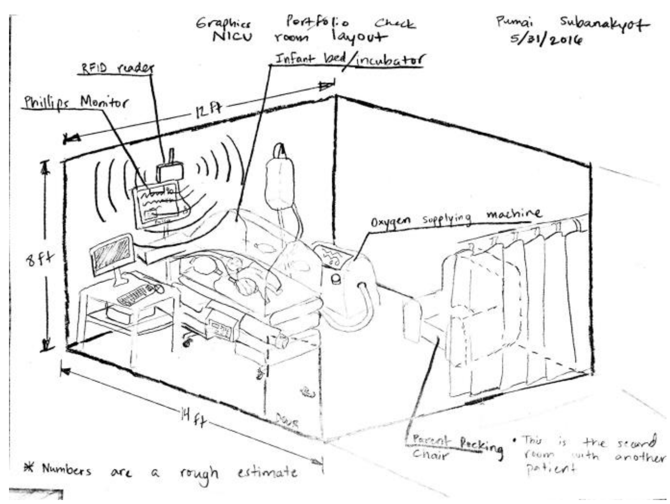

Figure 4: NICU room layout with RFID reader

4.3 The RFID reader can be integrated almost seamlessly

The RFID reader will preferably be installed into the physiological monitor so that the alarm signal that is sent to nurse phones by the middleware system, Connexall, can be repressed. Using the reader and the tags will be hands free and is meant to be very simple, allowing the nurses and other hospital staff to continue their current practices with no change after the design's implementation.

Because the design will only repress phone alarms, the safety of the neonate will still be insured because only redundant alarms are repressed. If a nurse is outside the patient room, the phone alarm will still ring, and when they are inside the room, the phone alarm will remain silent, but the patient monitor alarm will still ring. The monitor alarms are much quieter and will not disturb the nurses as much as the phones do. The use of RFID eliminates the need for any touching of monitors or pressing of buttons, so the design will not interfere with daily nurse protocol, and nurses will be able to effectively tend to the patients as they currently do. With our design in place, the nurses will not have to change anything they currently do. The only thing that will change is the number of phone alarms.

4.4 Nurses wear UHF RFID tags like ID badges

The tags that will communicate with the reader are blank cards with transmitters built in. We recommend using the LinkSprite UHF tag. It has a range of 5 meters, which is more than suitable for our max target range of 4 meters. The tags would be placed directly behind the nurses' current ID's, eliminating the need for the hospital to order new tags for nurses.

Figure 5: LinkSprite UHF RFID Tags

The nurses will wear the tags behind their identification cards and will not need to perform any extra tasks after the software and hardware are both set up correctly. A Nurse's unique RFID will be put into the system so that they are paired with their patients' rooms. The nurse's RFID tag, if in a patient room, will keep the nurse phones from dinging while they are in their patient's room, which has become a nuisance.

The design will satisfies all requirements from our users and stakeholders, with the added benefit of reducing alarm noise disturbance of the infants. The implementation of our design, and subsequent repression of redundant phone alarms through the use of radio frequency identification will reduce alarm fatigue within the NICU.

A low-fidelity prototype is being used to demonstrate the functionality of the RFID. A low-cost reader connected to an Arduino, and some Python code allows us to simulate various situations in the NICU. For a more in depth description of how we put together our demonstration, see Appendix

H. To learn how we determined the ideal parameters and settings for our demonstration, see our performance testing summary and guide in Appendix I and J.

5.0 Future Recommendation

The current method we have designed to reduce alarm fatigue is effective, but not yet comprehensive. There is potential to develop an even better way to combat alarm fatigue. Our current design works to combat the noise caused by redundant alarms, but does nothing to keep the alarm from sounding in the first place. There are a few areas in which our design can be improved and even added upon.

5.1 Continue to test the RFID system for bugs

While the RFID system works in theory, it is important to test it in a real, hospital setting. We were able to test the very basic functionality of the system on a small scale, but there were no full scale tests. The consistency of the full scale reader needs to be tested and confirmed, and the ideal positioning of the reader within the room should be determined. All current design ideas are speculative and need to be performance tested before implementation. Several failure modes have been identified and the hospital should follow some of our recommendations in order to improve upon the design before final implementation. A list of the failure modes we found, and some recommendations to prevent them can be found in Appendix K.

5.2 Develop a new algorithm that increases alarm specificity

In future iterations, the design may incorporate a new algorithm within the physiologic monitors. This algorithm would alarm only when there is a large change in oxygen saturation over a short period of time, or when there is a small change over a long period of time. The current algorithm is fairly basic, alerting nurses of a desaturation alarm of any severity, after ten seconds. There is no differentiation between a desaturation at 60% and a desaturation of 83%. Even to an untrained eye, it is evident that one of these two alarms is more significant than the other. A more precise algorithm would swap out the current 10-second delay and replace it with a variable delay which depends on the severity of each desaturation. To determine the exact delay times that correspond with each of the desaturation values, extensive testing and insight from experts in the field will be necessary. By virtue of increasing the specificity of the alarm, this variable alarm algorithm would decrease the overall number of alarms in the NICU, preventing the negative effects of alarm fatigue.

5.3 Implement patient-specific parameters to reduce alarm frequency

Additionally, alarm specificity can be further improved through the individualization of patient oxygen saturation parameters. Current protocols have the nurse's setting the upper and lower oxygen saturation limits at 96% and 86% respectively. The desaturation limit sits at 85%. While this range of parameters is sufficient for the majority of patients in the NICU, it leaves some room for improvement, since not every patient is the same. Some babies have physiological characteristics that limit their oxygen saturation, so it is illogical for them to be subjected to the same parameters as a baby with a more fully developed physiology.

5.4 Standardize communication to encourage more individual patient discussion

Individualized settings would naturally result in fewer alarms, since they cater to each patient. These settings could be implemented through a more robust, standardized system of communication between nurses, the ones who spend the most time with the patients, and the doctors. Current culture in the NICU has nurses firmly sticking with the default parameters. While this is the standard, it results in a number of alarms that could be prevented through the use of more individualized parameters. Continuous communication of patient settings between nurses and doctors will create a culture change that will ideally lead to a shift away from the rigid culture of default settings, allowing for the implementation of patient specific oxygen saturation settings.

Individualization does not mean that parameters will be adjusted arbitrarily based on the number of alarms going off. Instead, careful analysis of patient data and activity by nurses and doctors will allow them to decide whether or not the settings should be altered. Not every patient will have new parameters. For some, the default settings may become the individual settings. The goal of making patient-specific parameters is not to eliminate default settings, but rather to optimize them.

It is more likely that an alarm that goes off for a patient with individualized parameters is actionable. This increase in specificity eliminates many of the non-actionable alarms that contribute to the high number of alarms currently in the NICU. Fewer alarms means less alarm fatigue, paving the way for greater nurse satisfaction and better patient care.

A very preliminary version of this type of communication was tested for one week in the NICU. A summary of the tests premise and results can be found in Appendix L and Appendix M.

5.5 Develop a self-learning algorithm

A final recommendation for future iterations of our design is a combination of the two recommendations from above. We recommend Philips, the company that makes the monitors, to develop a new, self-learning algorithm for oxygen saturation that adjusts to each patient. That way, a human does not have to be the only one who can change the parameters. Instead, the monitor can record and sense the normal levels where the patient usually stays, and then recommend or even change the settings accordingly. The monitor, of course, would have set safety precautions so it does not adjust to a level that is unsafe for the patient.

The feasibility of implementation of a design like this is low for now, since technology is not yet trustworthy enough, but once technology becomes viable, this design would make the process of individualizing parameters more efficient. Essentially, this design would be so dynamic that non-actionable alarms would be eliminated. The monitor would learn the patient's behavior and combine this knowledge with the variable alarm system from above. This would eliminate alarm fatigue because each time an alarm sounds, there is no doubt about whether it requires action or not. A development of this technology would not only be useful in the NICU, but in units in hospitals around the world.

While some of these recommendations can be implemented sooner than others, they are all options that we believe can improve upon our initial design. Our design, which shows proof of concept and function, has great potential to be built upon. All of these solutions are capable of decreasing alarm fatigue, which is both encouraging and promising.

6.0 Conclusion

Alarm fatigue is one of the most pressing challenges that hospitals are facing today. Device after device, companies are developing new, useful alarm technology without considering the effects of constant alarms and issues with alarm management. Nurses are being desensitized to the alarms, and patient lives are being put on the line.

6.1 Take a different approach to the problem

Because of the desire to have a functioning deliverable, we looked to address the nurse satisfaction side of the problem rather than the monitor specific approach. We found that we could tackle this problem by changing the way specific alarms are silenced. One nurse told us that alarms still get sent to her phone even while she is treating that patient and it is both difficult and annoying to turn them off. Whenever a nurse's hands are busy, there is no way of turning the alarms off on his/her phone or in the monitor, leading us to hypothesize ways of turning off the alarms remotely. Further rumination led to the decision to use a Radio Frequency Identification (RFID) reader and corresponding tag.

6.2 RFID sensors and tags work to combat alarm fatigue

The RFID reader uses electromagnetic fields to automatically and wirelessly identify and track tags attached to objects such as a nurse's ID card. The RFID reader is able to quickly identify nurses in patient rooms. RFID readers integrated into patient monitors will sense the presence of a nurse. As a result, the monitor will alarm, but it will not send an alarm to the nurse's phone. This eliminates the need for the nurse to physically touch her phone to silence the alarm whenever the patient deviates from the set parameters, making the job much more pleasant. The RFID tag will not prevent the alarm from the monitor, only the phone alarm. By repressing only the unnecessary phone alarm while the nurse is present, the RFID tags do not compromise patient safety.

6.3 A low-fidelity RFID demonstration has been developed

In order to demonstrate this idea, we have purchased and programmed an Arduino with an RFID reader that will be able to read ID cards and identify them. With this capability, we have set up a basic demonstration that shows the final design's function, simulating how the reader would alter the alarm system. By showing how a hospital room in the NICU works with and without the RFID, our client and audience will see how the final design will be beneficial when implemented. If made mainstream, future iterations of our design have great potential to quell effects of alarm fatigue in the NICU, and other hospital units.

6.4 Benefits of using RFID system

The major benefits of using RFID is that it is cost efficient and easy to implement. The reader and tag that is needed for this specific situation will cost roughly $500 total. Also, there will be no learning curve for the nurses in how to use the technology. The reader simply needs to be set up in the room, and the only thing the nurses need to worry about is making sure they have the RFID tags on their ID cards. With proper implementation, nurses will feel the benefits right away without having to perform any extra action.

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Appendix A - Project Definition

Project Name: Oxygen Saturation Alarm Management in the NICU at Lurie Children's Hospital
Client: Dr. Lee Budin
Team Members: Sebastian Dobon, Alex Fong, Jonathan Shiler, Pumai Subanakyot
Date: June 6, 2016
Version: Final

Mission Statement: To design a system that increases nurse satisfaction in the Neonatal Intensive Care Unit at the Lurie Children's hospital by combating the effects of redundant, oxygen saturation alarm alerts.

Project Deliverables: A completed prototype and complementary demonstration to show how the number of redundant oxygen saturation alarms will be reduced. A recommendation to the monitor company will also be made. There will be a report and presentation to further explain the project.

Constraints:
-Must be assembled/developed at a cost of no more than $500
-Must be completed by June 6, 2016

Users/Stakeholders:
-NICU patients and families
-Nurses and Neonatologists
-Lurie Children's Hospital
-Hospitals in General
-Institute for Healthcare Improvement (Dr. Budin is using this project for his course there)

Requirements	**Specifications**
• Must turn off redundant alarms • Must preserve nurses' everyday protocol • Must be feasible to implement within the hospital • Must not compromise patient safety	• Cell phone alarm is turned off, but the monitor alarm is not • Nurse response time is less than or equal to nurse response time from before the implementation of the design • Compatible with existing monitors and devices • No changes in treatment techniques

Table 1: Design Requirements and Specifications

Appendix B: Background Research

In order to effectively approach and understand our project, significant research had to be done before any progress could be made. From the phenomena of alarm fatigue to the physiologic defects that premature babies are born with, a variety of topics were explored with the intention of becoming more well prepared to tackle the problem.

Pulse oximetry can be interfered with by movement

Pulse oximetry is a process used to measure oxygen saturation in a patient's blood. A LED is typically projected through a patient's finger, or even toe, and the light that is shone through it is received by a photodetector on the other side of the finger. The percentage of light that makes it through to the receptor is related to the amount of oxygen in the patient's blood.

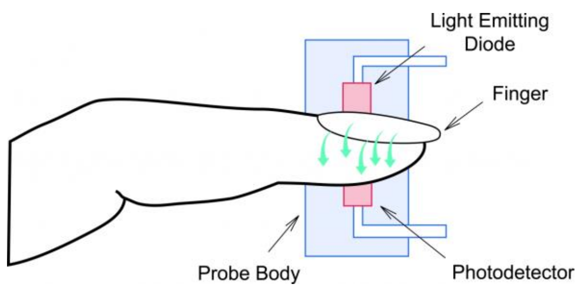


Figure 6: Pulse Oximeter Diagram

This is the primary methods used to track the baby's oxygen saturation level in the NICU; however, it is not infallible. Patient movement can interfere with the amount of light that is received by the receiving end of the probe. In many instances, this is the cause of a desaturation alarm. While the patient may have a perfectly normal oxygen saturation level, they may be moving and affecting the fidelity with which the probe is receiving. As a result, many false alarms are triggered by misreading probes, contributing to the overall noise in the unit.

Frequent alarms create a phenomena known as alarm fatigue

The primary way that nurses keep track of the health of their patients is through the patient monitoring system. A system of complex device tracks virtually every vital sign from heart rate, to blood pressure, to oxygen saturation level. It is inefficient for a nurse to spend his or her whole day watching a single patient's monitor, so a system of alarms alerts nurses when they are away. An unintended consequence of this alarm system is the subsequent fatigue that nurses feel after the respond to alarm after alarm. This phenomena is known as alarm fatigue. Recently, it became the health technology hazard of the year. Many alarming devices have been developed without considering how to manage them. As a result, alarm management has gained increasing priority.

High alarming patients are the primary cause of alarm fatigue

During a study of alarm fatigue in a specific unit, it was discovered that 10% of patients set off 65 % of all alarms. These high-alarming patients were each assigned to a single nurse in an effort to reduce the number of alarms. With the trouble patients under a more watchful eye, the number of alarms was able to be reduced, proving that by taking care of the most acute patients, the number of overall alarms can be reduced.

Neonatal patient care is difficult

Few alarm management studies have been conducted in neonatal units due to the fact that the patients are so delicate and need individualized settings. Default parameters sometimes do not suit the patient well since many factors, including their age factor into their optimal settings. There have been discussions to use adult patient care techniques in neonatal units, however, these practices, such as lowering the SpO2 levels, or including a delay, could be detrimental to a patient of such small size.

Built-in delays reduce the number of alarms

In an effort to reduce the overall amount of noise caused by alarms, hospitals have explored ways to eliminate or subdue alarms. One way that was determined to be both safe and effective was the implementation of a delay in some of the alarms. In the case of oxygen desaturation alarms, it is not necessary in most cases to alarm immediately when the patient dips below the desaturation parameter. However, once the patient has spent a set amount of time below that level, the alarm is allowed to ring. Built-in delays are usually around 10 seconds long and give the patient some leeway to self-correct before their alarm rings. These delays allow for the reduction of alarms, satisfying nurses, patients, and their families. Additionally, they work to combat the harmful effects of alarm fatigue.

Lowering oxygen saturation limits increases infant mortality

The Benefits of Oxygen Saturation Targeting (BOOST) studies were performed to test the effects of oxygen saturation levels on neonates. Studies were conducted in the United Kingdom, New Zealand, and Australia. Neonatal patients were randomly chosen to be put into a low saturation level (85-89%), and a high range (91-95%). The results of the study show that the low group had a higher rate of mortality, while the high group had a higher rate of retinopathy of prematurity, a condition which causes the growth of blood vessels in the retina, leading to blindness. Neither of these situations is optimal, and as a result, hospitals and doctors around the world have become hesitant to deviate from set oxygen saturation parameters.

Appendix C: Client Interview Summary

We had our first meeting with our client Dr. Lee Budin, a medical director for the Lurie Children's Center, in the Ford Motor building on Monday, June 4, 2016. All team members were present. The purpose of our meeting was to learn more about the problem that hospitals were having with the alarms set off by physiological monitors for neonates. This appendix will discuss the information and knowledge about the problem that we obtained through speaking with Dr. Budin.

NICU patients are being closely monitored
Dr. Budin told us that these physiological monitors kept track of children's' oxygen saturation, pulse, and blood pressure. These components each had certain parameters programmed into the monitor so that if they rose or fell to an unsafe level, nurses or clinicians could be alarmed to come assess the situation.

There are many causes for alarms in the NICU
However, he showed us charts and graphs and pointed out that the main cause of false alarms were due drops in oxygen saturation level, so we narrowed our focus to this. Budin gave us an example of how this works: if the monitors have their oxygen saturation level set to 85%, then anytime the child's levels drop below this, an alarm will sound. He then informed us of the many causes of a false alarm, such as children tossing and turning, having poor circulation, or entering deep sleep. Other causes of drops of oxygen saturation could include sickness or outdated monitors. Aside from the drops in oxygen saturation, many neonates are born with lung disease which cause them to operate normally oxygenation levels as low as 80%. Budin told us that in contrast to the drops, extremely high levels of oxygenation were not a huge concern to evaluate because this occurred less frequently.

Nurses are being negatively affected by the repeated alarms
All these aspects attribute to the frequent alarms that are pinged directly to nurses within the area ten seconds after thresholds are passed. After exposure to so many of these alarms, some nurses have become desensitized to the alarms and are responding slower, expecting to be met with another false alarm. Data has been collected on nurse response times and has been recorded in terms of seconds.

Alarms are either actionable or non-actionable
Alarms are divided into two categories: actionable and non-actionable alarms. To be considered an actionable alarm, the neonate's heartbeat must be reliable and must show symptoms such as appearing blue to the skin. An alarm is considered non-actionable if the child is moving around, if the skin's color appears normal, and if other causes of false alarms mentioned earlier are evident.

The hospital has alarm data, but it is not extremely useful
Dr. Budin then told us that there is not enough data recorded on whether an alarm was actionable or not, but he did tell us that there is data on nurse response times. The problem with this data is that it is not very reliable because nurse response times are recorded once nurses get into the NICU

room and touch the monitor. Some nurses may touch the monitors much later than after they help the neonate, some may touch the monitor right away, and others may not touch the monitor at all. Budin stated that there have been accounts of nurses stating the oxygenation parameters are too high and wanting to decrease the percentage, but most do not make these changes in fear that lowering it too much could lead to health concerns with the neonates. Although the nurses are the closest to their patients, they tend to follow protocol, while the clinicians who have more knowledge about safe oxygenation levels are simply too busy to look at each neonate case by case.

Appendix D: User Observation Plan

The following guidelines are what are to be used at all future observations at Lurie Children's Hospital. It is important to be as nonintrusive as possible in order to get the most accurate experience. The nurses should be left to do their jobs without disruption initially before any questions are asked. Information gathered from observing is as important as information gathered directly from the nurses. The goal is to learn how the alarms are affecting the nurses and what can be changed in order to improve their work experience.

- **Observations**
    - Find problem rooms (frequent alarms)
    - Observe average blood oxygen level
        - Sick patient?
        - Will it ever get better?
        - ASK QUESTIONS
        - Are the alarms anything critical?
    - Look at probes
        - Signs of wear/ improper function
    - Observe equipment
        - Can we add our own sensors?
    - Response to a desat
        - What is the procedure?
        - What can we learn?
- **Questions for Nurses**
    - Very rough estimate- how many actionable vs non actionable alarms?
    - How do you respond to a desat?
        - Walk through the process
    - Does the alarm turn off on its own once triggered?
    - How often do you change the settings?
    - Is there a minimum range for the oxygen level?
        - Why?
    - Is movement a frequent issue?
    - Most effective types of stimulus (just barely actionable)

Appendix E: User Observation Summary

About the Initial Visit

On April 27, 2016, Sebastian and Alex visited the Neonatal Intensive Care Unit (NICU) at Lurie Children's hospital in order to observe the current protocols and issues raised by the client, Dr. Lee Budin. The personnel they worked with were Registered Nurses Barb Fleming, Katie, Jessica and Sandra. These nurses helped walk them through the usual procedures in the NICU and allowed them to ask any necessary questions they had during observations. The end goal of this observation was to experience what the nurses go through and see how they respond to alarms constantly going off. Sebastian was set up to follow a nurse in the North side of the NICU, while Alex was with a nurse in the South side of the NICU. Nurse, and primary contact, Barb Fleming, kindly set them up with patients who were "noisier" than others so that they could get a better feel for what an alarm filled day is like.

About the NICU

The NICU consists of 44 single-family rooms, meaning there is only one patient per room. Usual practices in the hospital assign one nurse to two patients. In the cases where the nurse is caring for an extremely acute patient that nurse will only be responsible for that one patient (very uncommon). In cases where one patient is ready to be discharged in the near future, the nurse may have three patients. After speaking with one of the nurses, Katie, it was made aware to Alex that the nurses can have a primary patient or patients, which they spend most of their time caring over during their stay, but there are many instances in which the nurses rotate patients, depending on their shift. In these cases, nurses usually take a few hours to get accustomed to the habits of each patient.

Patients in the NICU are very different

Patients in the NICU are all in different stages of development, each having their own individual quirks. For example, current protocol sets the parameters for oxygen saturation at 86-96%, but a patient may deviate from these settings due to their unique physiology. Babies in the womb all have something called the patent ductus arteriosus (PDA), which is a connection between the pulmonary arteries and the aorta, which diverts some of the blood flow headed for the baby's lungs back into the heart. In the womb, babies only need enough blood flow to develop the lungs. Babies born after full gestation will take a few breaths, and the PDA will close, but babies born prematurely still have their PDAs. This keeps some of their blood from being oxygenated, which will keep their saturation levels from being consistent. This means that often a patient's O2SAT can drop as low as 70% for 20-30 seconds, and there is nothing that can be done about it. Knowing the physiologies and stages of development of each patient allows the nurses to discern to a certain degree whether an alert is dangerous or not, even if it is a red alert. This leads to nurses often not doing anything until a patient has DESATed for a longer period of time.

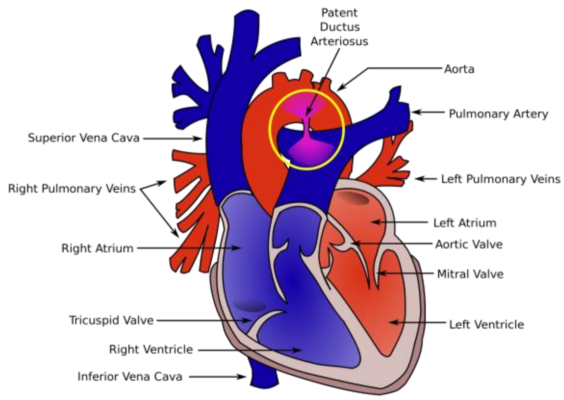


Figure 7: The Patent Ductus Arteriosus in the Heart

Since Sebastian and Alex were split up, the appendix is divided into two sections, one part being the experiences of Sebastian, and the other being the findings of Alex.

Alex's Observations from the first visit

General Observations

- There is a lot of the same dull beeping sound coming from the monitors, so it is hard to tell where each alarm is coming from, especially just by ear.
- Even if there is a red alert, the nurse does not go running, especially if they are already helping a different patient

Oxygen Desaturation Procedure

- Desat alert (red alert) goes directly to attending nurse's phone
- Attending nurse has choice to accept the alarm or escalate it to another nurse
- Nurse responds
  - Alert doesn't necessarily require action, it just needs to be turned off
  - If alarm is paused while patient is being treated, but they are still outside the set parameters after one minute, the red alert will sound again

Oxygen Saturation Probes

- Small adhesive strip attaches probe (Massimo SET) to patient
- Location of the probe is changed every 6 hours, after hands on assessment by nurse
  - Prevents skin issues including rash and discomfort
- If the probe is not performing adequately (i.e. the cord is frayed), nurses will change the entire probe
- If adhesive is not sticking properly, nurse will change the adhesive
- Probes run into issues while patient is moving
  - Pulse oximetry was designed for use on anesthetized patients, who are absolutely still
  - Massimo SET is better than the competition, but not infallible

Alarm alerts

- Oxygen saturation alarms are set at a default low of 86%, high of 96% and desat at 95%.
- High and Low saturation alarms are yellow alarms (do not go directly to nurse's phones)
- Desaturation is a red alert
- If the patient self-corrects, the alarm will stop sounding, but its notification will "latch" onto the monitor
    - The nurse will then see what happened previously when they next enter the room
    - Yellow alerts do nothing to the nurses
    - Red alerts will continually send alerts to the nurse's phone until they respond, even if the patient has self-corrected.
    - Latched notification, especially if red, worries families

Current Protocol

- Nurses will set the oxygen saturation parameters to the default settings
    - Low-86% High-96% Desat-85%
    - Very narrow window to work within
- Doctors, Nurses, Fellows, etc. round once each morning to discuss the patient's progress and behavior over the previous 24 hours
    - According to the nurse, this amount of communication is sufficient, especially since the doctors are usually readily available even outside of rounds
- Doctors then perform a brief exam of the patient
- Depending on the specific case, the doctor will recommend a change in the oxygen saturation parameters
- As of December of 2015, nurses have the authority to alter the parameters of the patient on their own, but the default settings are well ingrained into their minds, so it is difficult to deviate from the norm

Nurse Phones

- Not iPhones
- Receive the alarms, allow the nurse to "accept" or "escalate" (pass on)
- Allow nurses to call or text anyone on the patient's team (i.e. doctor, nutritionist)
- Only work inside the hospital's system
- Only compatible with other similar phones

Moving Forward After the First Visit - Alex

There are currently two methods of analyzing alarm data that could be very useful to our project. One is the work of the hospital's biomedical engineering department. An excel spreadsheet that refreshes every minute, tracks the alarms in each room in real time. From the spreadsheet, one can monitor the type and number of alarm that come from each room. Using this data, one could easily find the "noisy" children and investigate why they are having so many alarms. Additionally, there is a built in function in the Philips monitors that charts the oxygen saturation at which the patients spend the majority of their time. This is called histogram technology. After some deliberation with Ms. Fleming, it was concluded that a potential solution could involve an analysis of the first set of data, identifying the "noisy" patients, and then further analyzing their histogram data. By finding the range of oxygen saturation that patient spends most of his/her time in, the doctor and nurse could then consult with each other to change the patient's parameters accordingly.

Setting patient parameters based on gestational age
The parameters for each patient could be further specified by a guideline determining the standard parameters based on gestational age, similar to that which has been at Johns Hopkins. Since each patient comes in at a different stage of development, it would make sense to have different standards for specific subgroups, rather than a universal standard.

Discussion about using a new more specific algorithm
Another potential solution that was discussed was the incorporation of a new algorithm into the current alert system. For many patients, going slightly below a set desat parameter for a little longer than the set delay is not traumatic. One could work to develop and implement a new algorithm that would only alarm if there was a big change in a small amount of time or a small change over a long amount of time. The technology to measure "if" instances is already in place for other vital measurements, yet it has not been applied to oxygen saturation measurements. An incorporation of this algorithm along with the improved system of individualized parameterization could greatly reduce the number of red alarms seen in the NICU daily.

Ms. Fleming encouraged us to look more into the BOOST studies conducted worldwide. These studies would give us much more insight into the nuances of setting oxygen saturation parameters.

Sebastian's observations from the first visit
General Observations

- There is a lot of noise in the NICU in general. At any given time, you can likely hear at least one alarm beeping
- Many nurses seemed to complain about the loud refrigerators (they're really loud)
- Nurses at this hospital work 12 hour shifts, and the tiredness + stress leads to the alarm fatigue
- One nurse said she has seen other nurses ignore/miss alarms because they are too tired and desensitized to notice
- RFID tags had been used in the past, but they were bulky and had to be worn high up, so the nurses ended up taking them off. Barb mentioned that there were newer tags that supposedly worked better and were smaller

Oxygen Desaturation Procedure

- Once a red DESAT is triggered, it cannot be stopped from going to the nurse's phone, even if the patient self-corrects. This is because the monitor sends a signal to the nurse's phone to alert whether the alarm is active or latched
- Escalation pattern: Nurse -> nurse's backup -> back to nurse -> room dome light-> central dome light

- MOST of the time when there is a desat, nurses will not come running but rather keep an eye on the O2 level, sometimes from the other room. This is because de-sats are usually uncontrollable dips due to the PDA

Oxygen Saturation Probes

- The hospital had recently started recycling probes. Instead of throwing them away, they are sent off to a different company that sends back recycled probes
- No proof, but one nurse said people have theories that the recycled probes are less reliable

Nurse Phones

- Use an application called Voalte One
- Specialized phone, nurse said they used to have iPhones, but the phones weren't rugged enough
- Now have a specialized Motorola phone with a scanner and 24 hr. battery

Moving forward after the first visit - Sebastian

Ideally, the monitor would not have an alert that is based on a hard limit for blood ox levels, but rather a function based on blood ox level and time spent there. This is because, due to the PDA, there are random times when the preemie's blood ox level can drop a little for a substantial amount of time, and then self-correct. The current settings give a ten second delay between when the desat happens and the alert going off, giving the preemie that window of time to self-correct. This has reduced the number of alerts, but it inherently has some problems. If the preemie were to desat to 20-30%, the nurses would want to know immediately rather than after a 10 second delay. Conversely, if the preemie desats to around 75%, the nurse would only want to know if this condition persists for upwards of ~30-60 sec (rough estimate from observations). I think that the reason for the current system and lack of the aforementioned one is that the monitors are designed with mostly adults in mind. These are not specialized monitors with features unique to NICU physiology, but just general monitors that go into all hospital rooms. Ideally, this change would manifest itself as a software update for the monitors, using a mathematical equation to determine when to alarm. However, the monitor company has not been very receptive to adding features based on the requests of just one hospital -- they have asked for things in the past. Ultimately, we must look at the academic literature to determine if there have been calls in the medical community to implement this type of feature. If there is currently no trace of this idea in the literature, we should look into advising the team to publish something so that monitor companies have ideas for updates in the future. I am also interested in finding a way to help this specific NICU as soon as possible. This is very preliminary, but another thing that I have thought of is adding extra alarms for the blood ox levels at different time intervals. I'm not sure if the system will allow for adding multiple alarms for the same vital sign. If it were possible, we could set multiple alarms at decreasing time intervals, depending on the severity of the desat.

Observations from the second visit

Alex

- Overall, much quieter this time around
- Problem that was raised was duration of the alarms rather than the number

    - I.e. nurses are assisting patients, but they can't turn alarm off, so the families get stressed, and the nurses get stressed as well.

Jonathan

- Nurse had two patients
    - Patient 1 is awake and she is tending to him
    - Patient 2 is in another room and asleep
- Biggest improvement would be to be able to turn off alarm from phone when in one room and patient alarming in another room
    - Better if nurse could do that while tending to other patient and monitoring other patients levels
- Heart problem patients are expected to have lower levels since they may have lower resting heart rate
- Alarm isn't judgement call, it is all about patient safety first
- Current escalation of alarms is good
- Scenario 1: Alarm goes off, issue resolves itself (levels back to normal) and nurse has to go to the other room to touch monitor to stop alarm
- Scenario 2: Alarm goes off, levels stay low and alarm goes off on the nurse's phone as well as, if long enough, on the main speaker alarm.
- Yellow alarms are ok and parents don't freak out about them
- SpO2 sensor most affected by movement.
    - Maybe new sensor?
- Sensor may act up but data of monitor would be incorrect and it is an easy fix to replace sensor
- Average stay in the NICU is 3 months.
- Primary patients are kept with corresponding nurses. They try to keep nurses and patients together but monitoring everyone is difficult.

Questions from the second observation

- Is keeping patients linked to nurses good or bad?
    - Hypothesis: Good because will understand patient's condition more and will be more knowledgeable of how to tend to patient
    - Hypothesis: Bad because nurse will get used to the patient and will be desensitized by alarms and issues

Observations from Pumai's first visit

On May 16, 2016 Pumai Subanakyot visited Lurie Children's Hospital and observed two nurses tend to premature twin brothers. The nurses only had two years of experience in the hospital, and the babies had been in the NICU for two months on that day. After observing the nurses' phones and the Philips monitors near the bedside of the patients, many yellow alarms and a few red alarms were seen and heard via the monitors, the nurses' phones, and the dome light in front of each room.

Alarms are reduced as the patient stays longer

After a discussion with the patients' mother, who was a blogger, it was found that a month prior, the babies were setting off 200 alarms in a twelve hour session, which was reduced to one hundred a week ago. It has lowered even further to about sixty alarms per twelve hours. At this point in their progression, the nurses did not seem to be annoyed at all by around sixty alarms per session. Caring for the young babies seemed manageable and NOT overwhelming.

Nurses want a remote system to turn off alarms

When asked what the nurse wanted in terms of helping with the problem of the alarm and phone alarm not being able to be turned off when taking care of the infants, the nurse responded that she wished there was a remote that could be used to turn off the alarm on the monitor, rather than walking up to it and touching the screen. The infants' desaturation level was set at 85, and the yellow alarm set at 86. When questioned about whether or not conversation about adjusting these parameters had ever taken place, the nurse answered that these numbers were protocol, and that the only time an infant would be considered for a change was if they were a cardiac problem-prone infant. She stated that ALL patients in the NICU have their parameters set at this 85/86 level.

Conclusions after the third observation

After finishing the observation with the infants and nurses, Pumai met with Barbara Fleming, the Clinical Nurse Specialist at the NICU, to speak about further progress in the team meetings with Dr. Lee Budin. At a prior meeting, it was said that the next step was to send the constantly updated excel sheet data to the doctors or nurses at the beginning of the day so that they can be used during the communication of possible parameter change. This extra step had been going on for about one to two weeks in the NICU. When asked about whether it has made any significant change on the top five ringers, Barb stated that the doctor had found the extra data to be insignificant towards her analyses of the infants. The doctor said that the data had only reiterated what she had already found, and so as far as they have been practicing this extra conversation with data, she has not currently found a significant reason to keep using the data. She concluded that the data is telling her that these top five ringing infants are only ringing because they are very sick and need a lot of careful attention.

Appendix F: Secondary Research

RFID, also known as radio-frequency identification, is a form of AIDC, auto identification and data capture that involves using radio waves to send and capture information. A RFID system is made up of two parts: the reader and the tag.

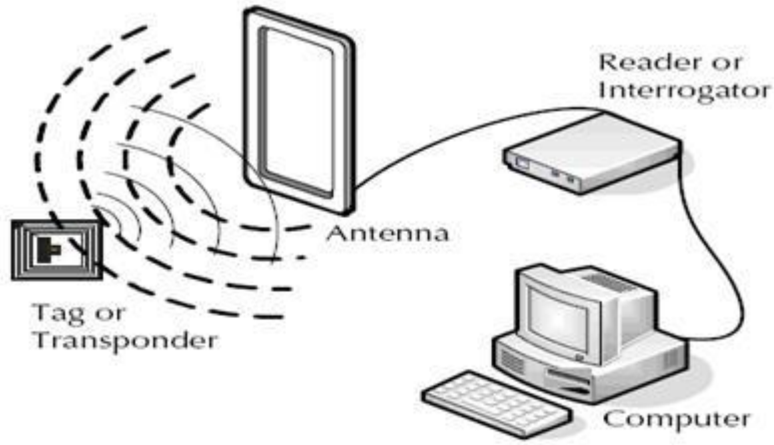


Figure 8: RFID system and components

How an RFID reader works

The reader is made up of two parts, an antenna and a transceiver. The transceiver generates a radio signal that may vary in range from a few inches to hundreds of feet, depending on the technology. This signal is then transmitted through the antenna, which can then be picked up by the tag, which is most likely placed on the object needing to be identified. The tag can be in the form of a sticker or small chip the size of a grain of rice. For nurse identification purposes, it is ideal to be in the form of a sticker that can be placed onto their hospital IDs.

Active and passive tags are different

RFID tags come in two forms: active and passive. Passive tags are cheaper, smaller, and weaker because they do not possess a battery. These tags have to be powered by the readers, while in contrast, active tags are much stronger and can send generate and send signals independently at the cost of size and money. Passive tags are made up of two main elements: an integrated circuit and an antenna. Passive tags can typically carry 96 bits of memory, but they can range from 2 to 1000 bits.

The antenna's purpose is to absorb radio-frequency waves sent by the reader, receive data, and send back data. The range at which this is effective is dependent on the size of the antenna. With a larger antenna, more data can be collected and sent out at higher ranges.

Active tags are different in that they have an on-board power supply and on-board electronics. The built-in power supply, usually a battery, allows the tag to independently transmit data without needing the original signal from the reader. Active tags can read much farther than passive tags, with distances of up to 100 feet. The on-board electronics can consist of microprocessors, input/output ports, and sensors, all of which can contribute to other various uses. For example, if

RFID tags were used on food products such as milk, a temperature sensor could be used to make sure that a printed expiration date was not later than the actual time it expired.

Both passive and active tags can be useful in many settings, and choosing between the two is a matter of the situation, cost, and preference.

Appendix G: Bill of Materials

The following table shows the materials, vendors, and cost of all the components to be used in our design. The cost shown is per room.

Item	Description	Qty	Vendor	Part Number	Unit Price	Total
UHF RFID Reader	-directional antenna -adjustable range (1-5m)	1	LinkSprite	LSID-0702	$460.00	$460.00
UHF RFID tag	-10 meter range	1	LinkSprite	LS0832	$3.59	$3.59
					Total:	$463.59

Table 2: Bill of Materials

Appendix H - Mockups

Definitions

Breadboard - a board for making an experimental model of an electrical circuit
Protoboard - a breadboard that is especially useful for preserving a prototype through soldering all the components in place.
Arduino - an open-source electronics platform that sense the environment by receiving inputs from many sensors, and affects its surroundings by controlling light, motors, and actuators.
RFID reader - a device used to wirelessly identify tagged objects through radio signals

Overview

The RFID system functionality begins when the RFID reader generates an electromagnetic field. This field causes electrons to flow through the RFID tag's antenna and power up its chip which doesn't have its own power source. The chip then responds by sending its stored data back out as another radio signal which is received by the RFID reader. The reader then sends the data to the Arduino Uno which is hooked up to a computer via a USB cable. This allows us to interpret the signal and trigger actions specific to our demonstration through Arduino code.

Mockup 1: Breadboard + Arduino + RFID Reader

Our first mockup is a system that utilized a breadboard to create a circuit with an Arduino Uno, a RFID reader, a RFID reader breakout, a passive RFID tag, and wires and lights. The RFID reader breakout is attached to the RFID reader in order to make the reader easier to attach to the breadboard. After that, the circuit is made and the Arduino is hooked up the computer where it gets its power supply and code. Its functionality follows the traditional functionality of a RFID reader and passive tag.

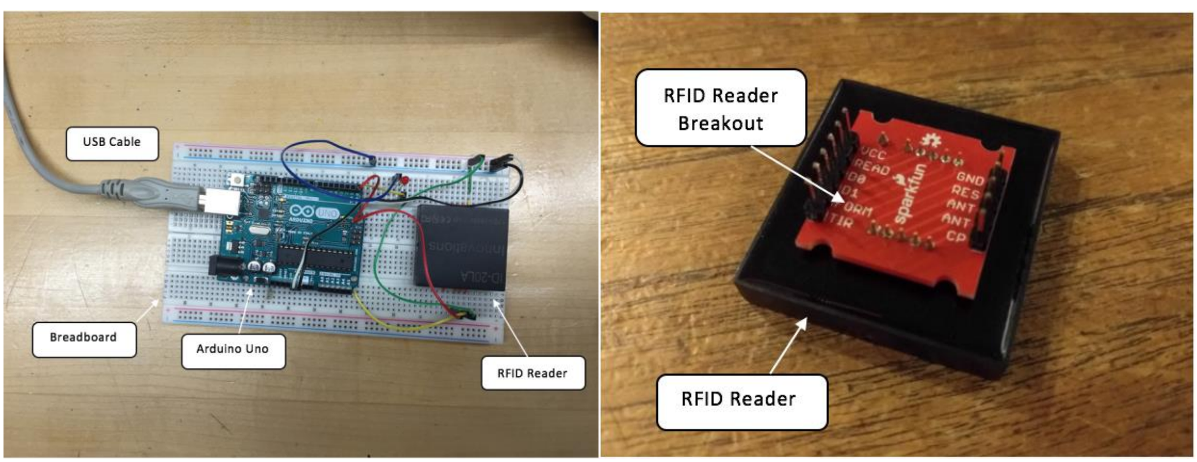


Figure 9: Breadboard mockup

Mockup 2: Protoboard + Arduino + RFID Reader

Our second mockup is a system that utilized a solder-able protoboard with an Arduino Uno, a RFID reader, a RFID reader breakout, a passive RFID tag, and wires and lights. Like before, the RFID reader breakout is attached to make the RFID reader easier to attach to the protoboard. After having done testing on our first mockup, we were comfortable enough to make our system more permanent and solder the components onto the protoboard. This made our system cleaner, more compact, and more resistant to falling apart unexpectedly due to loose wires or faulty connections.

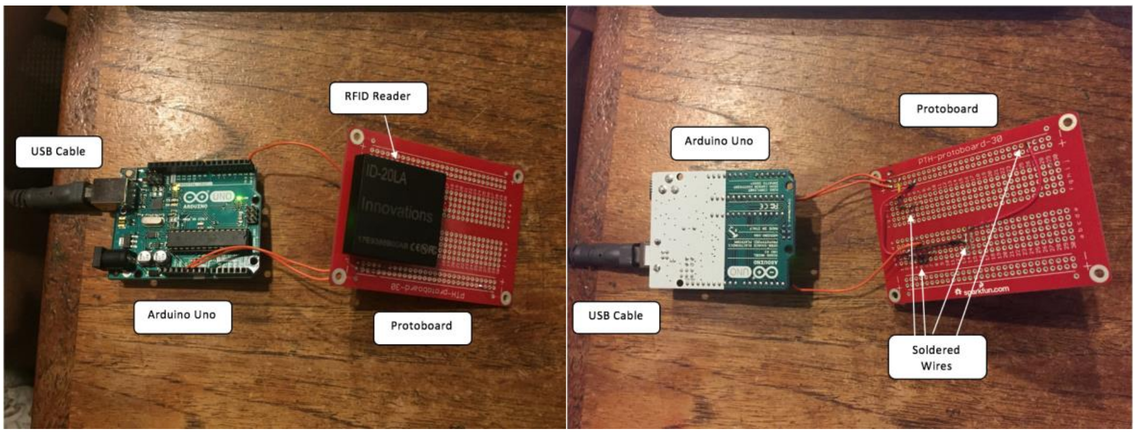


Figure 10: Protoboard mockup

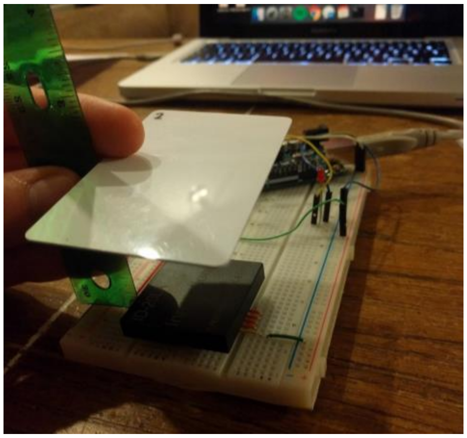
Appendix I: Performance Testing Guide

After breadboarding and getting the circuit to work, there were a number of tests necessary to inform our construction of our demo. The three things we tested were byte transfer rate (more on that later), card read distance, and card swipe speed.

16.1 Test for byte transfer rate

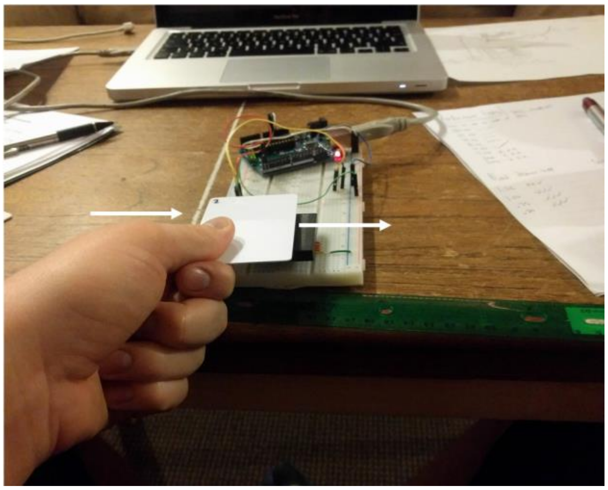
The first thing we needed to do was test the transfer rate of information from the RFID reading chip to the Arduino processor. The chip transfers the unique ID of the RFID tag one character (one byte) at a time. In the code to transmit this ID to the computer, we needed to know how long to wait for this information. If a new character didn't come in the specified time, the Arduino would think the ID has ended and transmit the whole string of characters on to the computer. If we chose too short of a time, we would get the IDs broken up into two or three smaller strings. If we chose too long a time, the whole system would slow down and the reading of the tag wouldn't look as seamless and instant in the demo. To figure out the optimal timing, we tested different parameters and considered it a pass if it didn't break up the ID for five tests in a row. We then chose the fastest time that passed.

16.2 Test for maximum read distance



Another thing we wanted to test was maximum read distance. This one was fairly straightforward and boring to test. To test the read distance, we held a ruler straight up from the RFID reader chip, and very slowly lowered the tag until the read light came on. We then recorded this distance, tested twice more, and averaged the results.

16.3 Test for maximum swipe speed



The final thing we wanted to test was maximum swipe speed of a RFID tag. More precisely, at how many inches per second can a card pass over the reader and still be a successful read. To test this we laid a ruler horizontally next to the breadboard and started a timer. We then practiced moving the card at a steady speed such that it passed the desired amount of inch marks within one second. When we felt confident in our ability, we made three trials of each swipe speed and recorded the results as pass/fail.

Appendix J: Performance Testing Summary

Results from the byte transfer test

For the first test, the data transfer rate test, we found that 10 ms was the optimal time to wait for the next character, because it was the fastest speed that ensured a full ID transmission. Moving forward, this means that we will set our delay to X ms.

Read time	Pass/Fail	Pass/Fail	Pass/Fail	Pass/Fail	Pass/Fail
100ms	✓	✓	✓	✓	✓
50ms	✓	✓	✓	✓	✓
25ms	✓	✓	✓	✓	✓
15ms	✓	✓	✓	✓	✓
10ms	✓	✓	✓	✓	✓
5ms	X	✓	X	X	X
2ms	X	X	X	X	X
1ms	X	X	X	X	X

Table 3: Byte Transfer Test

Results from the read distance test

For the read distance test, the ideal read distance was within 1 inch. Moving forward, this means we know we want to try to get the card within .75 inch of the card reader, to ensure a high chance of a successful read. The chance is never 100% because RFID readers can sometimes be finicky and inconsistent.

Read Distance	Pass/Fail	Pass/Fail	Pass/Fail
1.25 inches	X	X	✓
1 inch	✓	✓	✓
0.75 inches	✓	✓	✓
0.50 inches	✓	✓	✓

Table 4: Read Distance Swipe Test Results

Results from the swipe test

For the swipe test, we found that a speed of 4 in/sec was the fastest speed that passed 3 times in a row. Moving forward, this means that we will aim to swipe the card at (a little less) in/sec to try to have a high chance of a successful read.

Swipe Speed	Pass/Fail
1 inch/sec	✓
2 inches/sec	✓
3 inches/sec	✓
4 inches/sec	✓
5 inches/sec	X

Table 5: Swipe Speed Test Results

Appendix K: Failure Mode Effects Analysis

The following table is a compilation the possible failure modes the RFID design could encounter. In the chart, (S) stands for severity, (O) stands for occurrence, and (D) stands for detectability. The higher the number in each category, the worse the failure. The Risk Priority Number (RPN) indicates the overall severity of each failure mode.

Function	**Failure Mode**	**Mechanism**	**Current Controls**	**S**	**O**	**D**	**RPN**	**Recommended Actions**
Reader sends out radio wave signal within space of patient room	Does not read, no identification	Improper placement	Instructions on placement	5	1	5	25	Significant performance testing and weekly checks
RFID tag stuck onto nurse's ID picks up signal and sends back identification data	Nurse's tag is broken or lost	Reader's signal is not strong enough	Metal clips	5	2	5	50	Have replacement tags ready
Reader tells Connexall to suppress phone alarm of nurse in room	Connexall fails to suppress phone alarm	Poor wiring	Quality control in monitors	5	1	5	25	Software checks done by tech department or whoever set it up
Reader tells Connexall to suppress phone alarm of nurse in room	RFID tag on nurse ID stops picking up signal	Signal interference Bad implementation Software glitches	Tests to make sure system works	5	2	4	40	Get a stronger reader, or better tags

Table 6: Failure Mode Effects Analysis

Appendix L: User Testing Guide

The iterative PDSA process

In order to test the performance of some of our ideas without interfering with hospital procedures, our team worked alongside our client's previously assembled team. Consisting of neonatologists, current nurses on staff in the NICU, doctors on rotation at the hospital, and technology management specialists, the team has been conducting a testing protocol known as a PDSA, which stands for Plan, Do, Study, Act. The team meets first to discuss a problem and devise a way to combat it, then implements the change that was agreed upon. After the testing period is finished, the team reconvenes during a "study" period to see if the implemented change was helpful or not. Based on their conclusions, the team will either standardize the change, or begin another PDSA cycle. The iterative process allows for teams to make progress towards beneficial change.

Current rounding processes lack discussion of oxygen saturation parameter

After our initial meeting with our client and professors, it was decided upon to test a more standardized mode of communication between nurses and doctors. Current protocol is for doctors and associated personnel to make rounds on each patient every morning. During these rounds, the doctors and nurses discuss the patient's status over the previous 24 hours. There is no discussion of patient oxygen saturation parameter settings unless the patient has a unique physiology such as a heart defect, which calls for specific settings. The default settings are used almost universally within the unit so it is not unusual for the topic to not be brought up.

Testing standardized doctor/nurse communication

Using an excel spreadsheet developed by one of our client's team's data specialists, nurses and doctors can view the number of alarms in the entire NICU over the previous 12 hours, and find the patients who have been alarming the most. Based on one PDSA, it was decided upon to have the doctors and nurses be sent this data each morning before rounds. After finding the top five alarming patients, the nurses and doctors will have a discussion about whether the oxygen saturation parameters of those patients are specific enough or not. The patient's settings will then be changed or left the same.

Based on the results of this PDSA, a standardized mode of communication will either continue to be improved upon or moved to a lower priority if not effective enough.

Appendix M: User Testing Summary

During the week of May 5, the benefits of the identification of the top 5 alarmers in the NICU and implementation of a standardized mode of communication was tested.

Identifying the top 5 alarmers does not help
After a week of implementation, it was determined that the identification of the top 5 alarming patients and subsequent discussion of their parameters was not of substantial utility to the nurses or the doctors. Extensive analysis of the trouble patients revealed and confirmed that they were the sickest patients in need of the most attention and treatment. There is very little room for alteration for a sick patient because they need to be carefully watched over.

More than just the top 5 alarmers should examined
As confirmed by the weeklong study, the sickest patients are also the highest alarming patients. It is unwise to alter their parameters. However, this does not mean that developing and implementing patient specific parameters in the future is a dead end. Patients who are more stable are likely to have more flexibility in their ability to have their parameters adjusted. Creating patient specific parameters doesn't mean that every patient needs to be set at different settings than the default ones. It just means that they have parameters that are optimized for them. Those could very well be the default ones, as is the case for the sickest patients in the NICU.

A standardized mode of communication should continue to be pursued
The current culture in the NICU does not readily allow for the adjustment of patient oxygen saturation parameters. This is because there is not a culture of communication between nurses and doctors about the parameters. If a conversation between the two parties is encouraged, it will become the norm and both nurses and doctors will become accustomed to changing the settings according to each patient's needs. This system of communication could bring about the individualization of patient settings, resulting in a more specific alarm, thus reducing the number of alarms in the NICU. While the weeklong test didn't bring about the desired results, there is great potential for the implementation of a system of communication that ultimately results in the increased specificity of oxygen desaturation alarms.