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CMAG: IoT Baby Monitor

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ENTITLED

CMAG: IoT Baby Monitor

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CMAG: IoT Baby Monitor

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SENIOR DESIGN PROJECT REPORT

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Abstract

Sudden Infant Death Syndrome, also known as SIDS, is the leading cause of mortality in infants from one month to one year of age. We propose a video-based baby monitoring system with Internet of Things (IoT) capabilities to help shorten the response time of SIDS cases. Using a video amplification technique developed at MIT dubbed “Eulerian Magnification” to amplify subtle movements we can compare pixel color differences in frames for breathing detection in a recorded video of a baby. In the event that abnormal movement is detected from the baby an alarm will be generated to notify the parents or guardians.

CMAG

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Chapter 1

Introduction

1.1 SIDS Background

Sudden Infant Death Syndrome, abbreviated as SIDS and also known as crib death, is one of the leading causes of mortality among infants between one month and one year of age. While the number of SIDS cases has decreased to an all-time low thanks to awareness raised by various institutes, there are still around 1600 cases in the United States alone [1]. The exact cause of SIDS is not known, but it is believed to be linked to abnormalities in the arcuate nucleus, which is the portion of the brain that controls breathing and arousal from sleep. Sudden Infant Death Syndrome is a single category under the classification of Sudden Infant Unexpected Death Syndrome, or SIUDS [2]. The numbers alone shown the prevalence and seriousness related to SIDS and SIUDS. Throughout the rest of the paper both cases will be referred to as SIDS as the project is more targeted towards tracking the breathing rate of the subject.

1.2 Project Need

There is a need in the world for a baby monitor that can more accurately keep track of a baby's condition. Many current baby monitors consist of either a video camera or a microphone or a combination of the two. Naturally there are some limitations to having such a simple system with a main drawback being that a parent may not know if the baby is experiencing an episode of SIDS. Cameras and microphones by themselves and in tandem are not able to detect when SIDS is happening, which causes a greater response time from the parent, which in turn could lead to the loss of life. Being able to keep track of a baby's state should give parents a better peace of mind which results in better sleep at night, something that every parent or guardian could use.

1.3 Project Objectives

The goal of the project is to create a noninvasive video based baby monitoring system with Internet of Things, or IoT, capabilities. By detecting if the baby is experiencing an abnormal breathing rate the alarm will be generated to notify the parents or guardian. Through the generation of an alarm the parents or guardian will have a quicker response time in the event of an episode of SIDS, resulting in a saved life. The project was inspired by a motion magnification technique in video developed by MIT called Eulerian magnification, discussed further below. The IoT is utilized to communicate through SMS, or short message services, to message the parent or guardian as soon as an abnormality is detected.

1.4 About the Internet of Things

The Internet of Things, abbreviated as IoT, simply refers to a network of objects that are connected to the internet. Since the Internet of Things is such a broad category it encompasses many devices and is growing at a rapid rate. In 2015 there were approximately 15.4 billion IoT devices. IHS Markit, a financial resource company, expects there to be 30.7 billion IoT devices by 2020 while Intel, a technology company, expects there to be 200 billion by 2020 [3]. Currently of the 15.4 billion devices about 28.3 million are wearable, but that number is expected to increase to around 80 million by 2020. The total global spending on the IoT in 2016 was 737 billion dollars, and was projected to reach 1.29 trillion dollars in 2020. As one can see based off of the numbers alone, the IoT is a prominent field that is only getting bigger. Perhaps one of the main reasons why the IoT is so large is that it aims to make life more convenient, and people are more likely to invest in things that make their lives easier. The IoT is integrated into our baby monitoring system for a quick response time and to provide a greater sense of security for parents during the night.

1.5 Eulerian Magnification Background

In 2013 a group of nine MIT students released a video processing technique called Eulerian Magnification. The goal of Eulerian Magnification was to magnify movements and motions that cannot be seen with the naked eye. Eulerian Magnification operates by taking in any standard video sequence as an input and applies spatial decomposition and temporal filtering to the frames [4]. The end result is an output video with greatly amplified movement even if very little visible change could be detected in the original video. Previous attempts made to exaggerate subtle motions in video involved the Lagrangian perspective, which is based off the theory of tracking trajectory over time to do motion estimation. However, these methods have proved to be computationally expensive and prone to unwanted behavior compared to more recently developed Eulerian magnification.

Chapter 2

Design and Implementation

2.1 About the Artik 10 Board

The team was given an Artik 10 board to be used in the implementation of the project. The Artik 10 is an IoT board released by Samsung with a octa-core architecture and a quad processor. It also has a 32 bit ARM CPU that makes it ideal for high computation activities such as image processing, 3D graphics, and drones. The board has DRAM and flash memory capabilities while also supporting Wi-Fi, Bluetooth, and Zigbee. In addition the Artik has USB and MIPI camera compatibility and a Mali T628 MP6 graphic processing unit that can show HD videos at 120 frames per second. Finally, the physical board comes at a relatively small size of 29x39x1.3 mm.

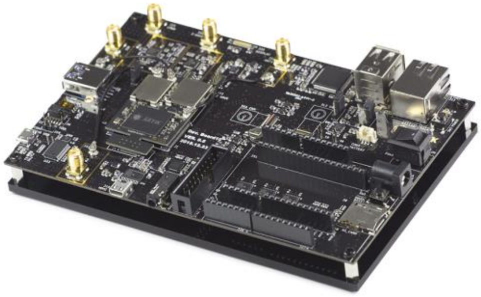


Figure 2.1: The Samsung Artik 10 board

2.2 System Diagram

Figure 2.2 is a pictorial diagram that represents the final operation of our system. The system can be broken down into three major subcategories: the video acquisition portion, the breath detection algorithm portion, and the alarm portion. The first system subcategory, the video acquisition portion, is represented by the first two sequential images in the diagram, which are a video camera and the Artik board. A night vision video camera is connected to the Artik board and used to capture a video of the baby. The second system subcategory, the motion detection algorithm portion, is represented by the third and fourth images in the sequence. The third image represents the process of Eulerian magnification and the fourth image represents the algorithm for motion detection. The third and final system subcategory, the alarm portion, is represented by the fifth and sixth sequential images, which are Twilio and a cell phone. Twilio is used to generate an alarm to a parent's phone in the event that an emergency situation is detected from the algorithm.

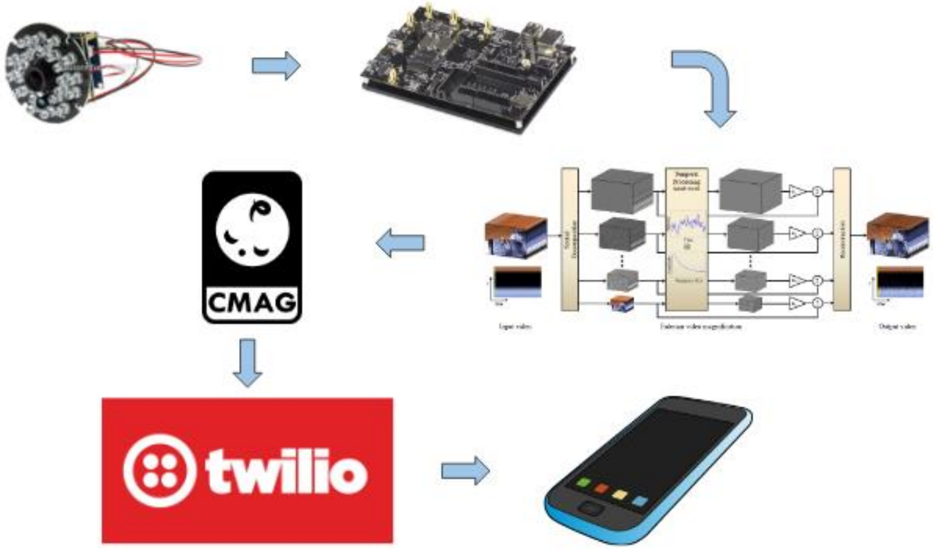


Figure 2.2: Final Design Pictorial Diagram

2.3 Requirements

The requirements for the baby monitoring system can be broken down into two categories: functional and nonfunctional requirements. Functional requirements regard what the system does while nonfunctional requirements outlines the manner in which the functional requirements will be accomplished. Both types of requirements are tabulated below:

Table 2.1: Functional and Nonfunctional requirements

Functional Requirements (CMAG will…)	**Nonfunctional Requirements** (CMAG will be…)
Accurately keep track of baby's state	Easy to use
Run in real time	Maintainable
Run for long periods of time	Reliable
Generate alarm in emergency situation	Safe

2.4 Constraints

One of the main constraints dealt with in the project are the limitations of Eulerian magnification. Since Eulerian magnification was designed by an outside team making specific changes without understanding the entire overview could risk potentially breaking the algorithm. Many of the files in Eulerian magnification are connected to one another, so one small change could trickle down and cause unforeseen problems down the line. The team avoided modifying the Eulerian code as much as possible to avoid these potential mistakes.

Eulerian magnification also works best on a stable video, which means that it is imperative to have the camera stabilized while filming is taking place. To ensure camera stability a bendable stand with a clip on the end was used to hold the camera in place. The stand was bendable enough to be shaped to the required position but sturdy enough to hold the camera still when it was attached. If the camera is moved during filming Eulerian magnification may produce an unstable result and therefore the data from the outputted video may be unable to be accurately analyzed.

The runtime of MATLAB was one of the final major constraints that needed to be taken into consideration. While the algorithms the team developed ran rather quickly in contrast running Eulerian magnification took a rather substantial amount of time. Processing a 30 second video clip took around a minute and thirty seconds in MATLAB, which is a rather lengthy amount of time. The runtime of Eulerian magnification was one of the constraints that was not able to be successfully worked around, but is something that can hopefully be reduced in the future.

2.5 Initial Implementation Method

Figure 2.2 is a block diagram of outlining the team's initial implementation method. Originally the plan was to capture and store a video of a baby on the Artik board in real time. After that Eulerian magnification would be run on the video on the board, creating a new video file that contained amplified movement. The chest movements of the baby from the amplified video would then be converted into a sinusoidal wave for analysis. The wave, representing the baby's chest movements, would then be uploaded into a cloud, which could then be accessed later by a parent or medical provider. The wave would then be analyzed in the cloud for any abnormalities. If any abnormality is detected than an alarm would be generated to the user's phone. In addition to the streamed and amplified video would be available to view at any point, most likely through the user's phone.

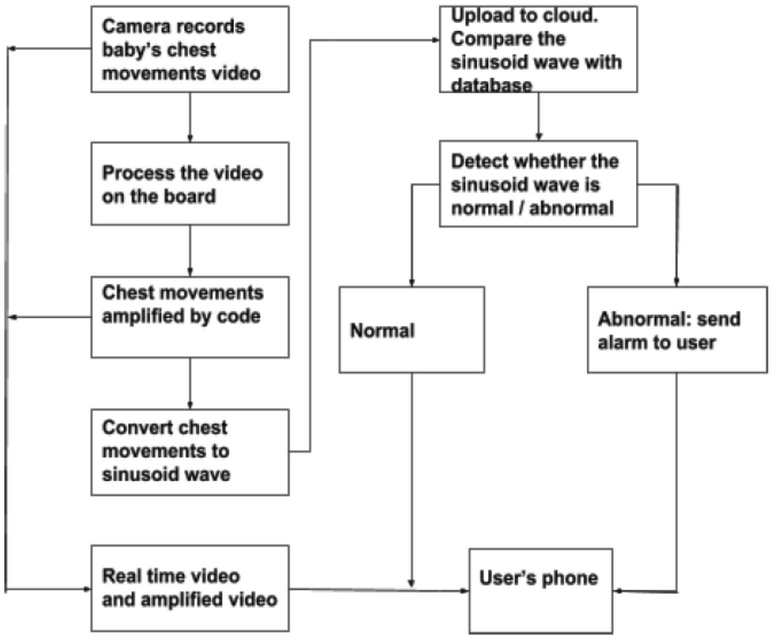

Camera records baby's chest movements video
Process the video on the board
Chest movements amplified by code
Convert chest movements to sinusoid wave
Real time video and amplified video
Upload to cloud. Compare the sinusoid wave with database
Detect whether the sinusoid wave is normal / abnormal
Normal
Abnormal: send alarm to user
User's phone

Figure 2.3: Initial Implementation Block Diagram

2.6 Implementation Alternatives

One of the main implementation alternatives considered was to use a raspberry pi. A raspberry pi would have been cheaper and more compact, which are two pretty significant features over the Artik board. However, as the team received the Artik 10 board for free there was an obligation to see what could be done with the technology. If working with the Artik proved to be too complicated or if there were too many unsupported features then a raspberry pi could be considered.

There were also a couple of viable different implementation methods that could be used for alarm generation. One possible idea that was suggested was creating a phone application with a bell. The bell would shake in the event of an emergency. Perhaps the main issue associated with an application would be the risk of the user having a dead phone or unintentionally muting their phone before bed. Another possible implementation method for the alarm system could be a wireless receiver attached to any sort of physical noisemaker that would generate noise in the event of an emergency.

In the end the team decided to work with the Artik board as all of the tests that involved capturing short videos through the Artik were successful. There was also the prospect of running Eulerian magnification through the Artik board due to its high processing capabilities. The final implementation method used for generating an alarm was to send a text message to the user's phone. Even though there was still risk of having a user with a muted or dead phone using SMS was the simplest yet effective way to let someone know that something is wrong.

2.7 Technical Familiarity

Before beginning the project the team had some experience coding in MATLAB and C. Experience with MATLAB came from taking a variety of electrical engineering courses, such as Electric Circuits, Linear Systems, and Digital Signal Processing. Experience with C came from taking introductory computer engineering courses such as Introduction to Programming, Advanced Programming, and Data Structures. The Linear Systems and Digital Signal Processing course provided invaluable framework for the project.

Working with the Artik was a challenge for the team since it was a relatively new product and had limited documentation. Going through various tutorials was helpful to get a better understanding of the functionality of the board. Even though the team was familiar with MATLAB, more functions had to be learned in order to advance the project. Eulerian magnification had many previously unheard of functions that needed to be researched for better understanding. In addition some Java needed to be learned in order to generate a text message with Twilio.

2.8 Technologies Used

In addition to the Artik board, additional other hardware and software were required for use in the project. The only other piece of hardware used in the project was a night vision camera. Access to a computer and cellular phone was also required to make use of software such as PuTTY, MATLAB, and Twilio. The hardware and software use is detailed below:

2.8.1 Night Vision Camera

Since the intent of the project was to record footage of a baby sleeping during the night a night vision camera was necessary. The team has selected to use a 5 MP CMOS UVC USB

Camera module with a 2.1 mm lens and 24 infrared LEDs. The camera also has a high frame rate of 30 fps and a 1280x720 resolution in addition to coming attached to a 1m cable. Originally the team looked for MIPI cameras but chose a USB camera in the end due to a wider variety of night vision options and compatibility. The camera chosen is a relatively high quality piece of equipment as the team was initially not sure what the optimum resolution and fps would be to work at.

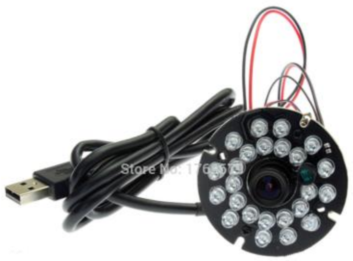


Figure 2.3: Night Vision Camera

2.8.2 PuTTY

PuTTY is a free open source SSH, or secure shell, program written in C and was the primary method of issuing commands and communicating with the Artik board. By connecting the Artik board to a computer through USB and launching PuTTY one can log in to the board. On the first run through PuTTY has to be initialized by inputting the serial communication port number that is read through the device manager. The speed of the serial link in bits per second should be set to 115200 with connection type set to serial. After these parameters are saved PuTTY does not need to be reinitialized on subsequent launches.

2.8.3 MATLAB

MATLAB, an abbreviation of Matrix Laboratory, is a numerical computing environment that is used by millions of scientists and engineers across the world. MATLAB is a very powerful tool that comes with a large variety of applications and functions that can be used for a wide range of purposes, such as graph creation and system simulations. Eulerian magnification was constructed in MATLAB so access to the program was necessary for the project. MATLAB was also the primary choice for breath detection algorithm development due to how powerful the numerical analysis is and the existing compatibility with MIT's code.

2.8.4 Twilio

Twilio is a cloud communication platform as a service that allows developers to send and receive text messages using a web service application programming interface, or API. Using the Eclipse IDE, or integrated development, for Java one can use Twilio to generate text messages to a user's phone. After creating an account one receives a unique security identifier, or SID, and authentication token that needs to be used in order to send and receive text messages. A Twilio trial account also provides one free phone number to send messages from with the user's desired input.

2.9 Cost

The total cost for the project is detailed in Table 2.2. The total cost for all materials sums to $200. As the Artik board was loaned to us for free the effective cost to the team was $50. The school provides access to MATLAB for free, which reduced the cost of the project as basic access to MATLAB costs $50 for students and $150 for home users. A free Twilio account was also used although it could be potentially upgraded for further functionality, such as access to multiple phone numbers.

Table 2.2: Cost of Materials

Item	**Cost**
Artik 10 Board	$150
Night vision camera	$50
MATLAB Access	Free with school
Twilio Access	Free trial account
Total:	$200

2.10 Risk Analysis

During the design process there were certain risks that needed to be addressed. The following table, table 2.2, lays out five of the biggest risks, the probability of occurrence, the severity of the issue, the impact in the event of occurrence, and a mitigation strategy. The impact is calculated by multiplying the probability by the severity.

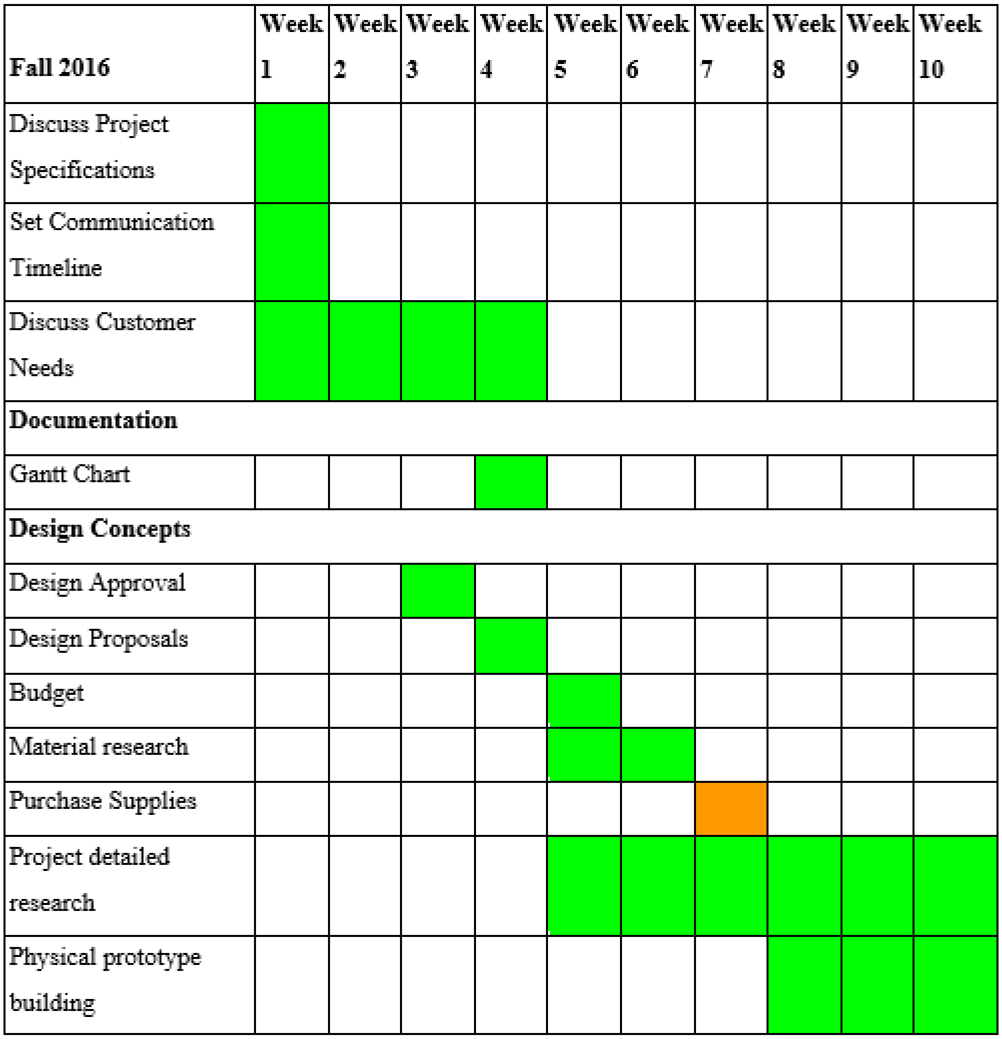
Table 2.3: Risk Analysis

Risk	Probability	Severity	Impact	Mitigation Strategy
Artik does not have necessary feature(s)	.6	7	4.2	-Try to utilize known features -Use different hardware
Running out of development time	.5	8	4	-Try to stick to schedule -Have weekly meetings to stay updated
Lack of technical ability	.5	7	3.5	-Do more research -Get outside help
Requirements change	.4	4	1.6	-Be flexible to new requirements -Ask why did old requirements change
Components break	.3	5	1.5	-Keep components in box -Keep spare components

2.11 Development Timeline

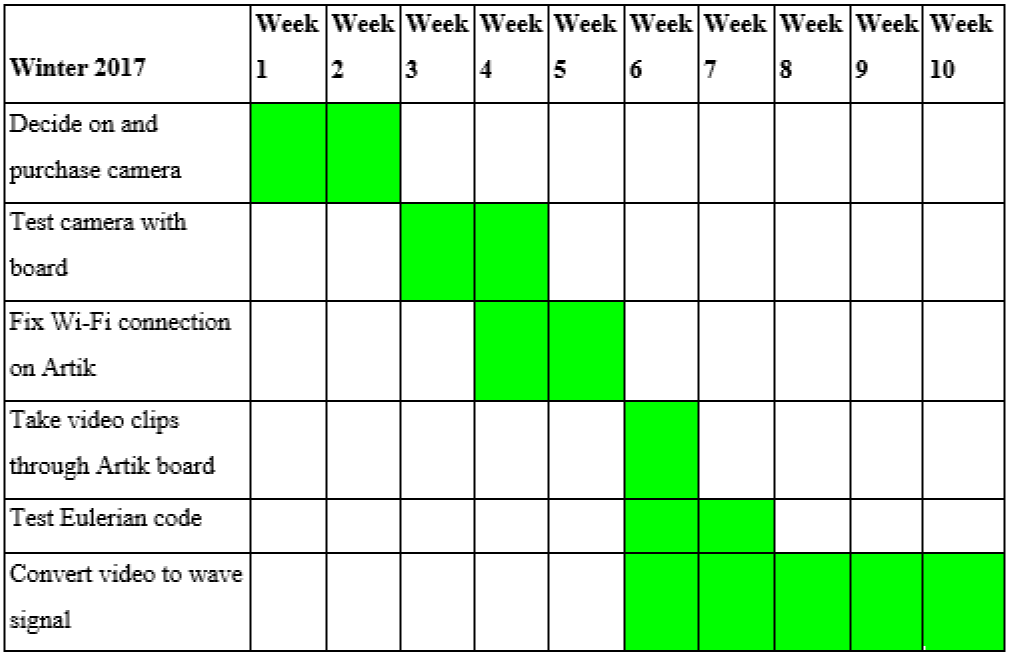
The Gantt chart for each quarter as predicted is as detailed below, and there are three quarters. Green highlight indicates that initial plan was followed to completion while orange highlight indicates that the initial plan was not followed.

Table 2.4: Gantt Chart for Fall Quarter



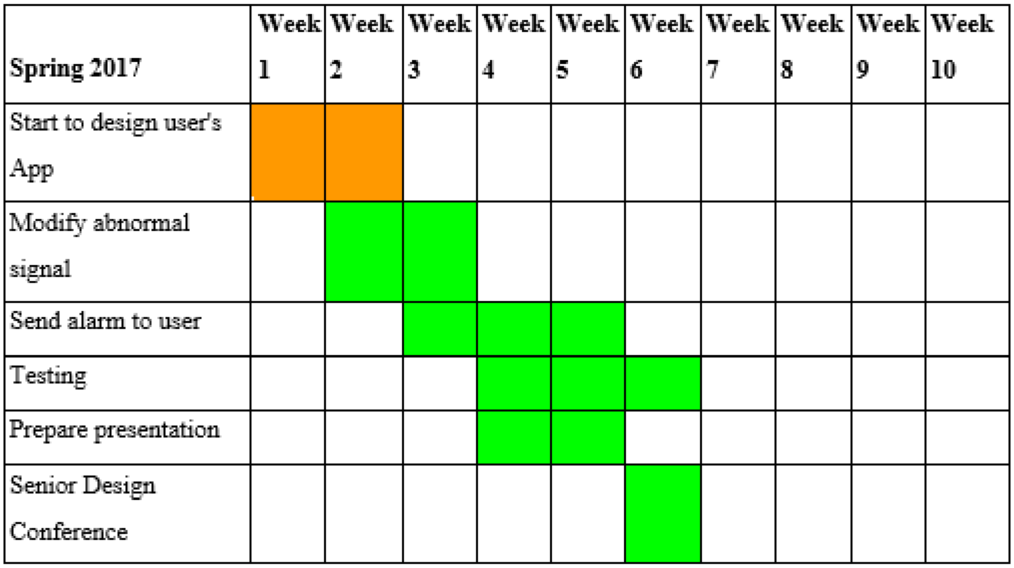
Fall 2016	**Week 1**	**Week 2**	**Week 3**	**Week 4**	**Week 5**	**Week 6**	**Week 7**	**Week 8**	**Week 9**	**Week 10**
Discuss Project Specifications	🟩									
Set Communication Timeline	🟩									
Discuss Customer Needs	🟩	🟩	🟩	🟩						
Documentation										
Gantt Chart				🟩						
Design Concepts										
Design Approval			🟩							
Design Proposals				🟩						
Budget					🟩					
Material research					🟩	🟩				
Purchase Supplies							🟧			
Project detailed research					🟩	🟩	🟩	🟩	🟩	🟩
Physical prototype building								🟩	🟩	🟩

Table 2.5: Gantt Chart for Winter Quarter



Winter 2017	**Week 1**	**Week 2**	**Week 3**	**Week 4**	**Week 5**	**Week 6**	**Week 7**	**Week 8**	**Week 9**	**Week 10**
Decide on and purchase camera	🟩	🟩								
Test camera with board			🟩	🟩						
Fix Wi-Fi connection on Artik				🟩	🟩					
Take video clips through Artik board						🟩				
Test Eulerian code						🟩	🟩			
Convert video to wave signal						🟩	🟩	🟩	🟩	🟩

Table 2.6: Gantt Chart for Spring Quarter



Spring 2017	**Week 1**	**Week 2**	**Week 3**	**Week 4**	**Week 5**	**Week 6**	**Week 7**	**Week 8**	**Week 9**	**Week 10**
Start to design user's App	🟧	🟧								
Modify abnormal signal		🟩	🟩							
Send alarm to user			🟩	🟩	🟩					
Testing				🟩	🟩	🟩				
Prepare presentation				🟩	🟩					
Senior Design Conference						🟩				

Chapter 3

Roadblocks

3.1 Internet Connectivity

One of the first issues that arose when working with the Artik board was connecting to the internet. Since the team initially wanted to store data in a cloud the board would need to be able to connect to the internet. After connecting the Wi-Fi antenna to the Artik board and launching PuTTY the wpa_supplicant.conf file can be modified to allow access to the internet. In PuTTY a Wi-Fi scan command can be entered to see the available networks. Initially when the scan command was run no networks appeared. The no network problem was remedied by updating the Artik Image.

By running the *cat /etc/artik-release* command the current version of the board was found and it was discovered that an update was necessary. Through use of a microSD card and reader and the program Etcher the image on the board was able to be updated and some of the issues were resolved. Checking to see if the latest image was installed on the board should have been done earlier but it is sometimes easy to overlook factors like that.

After updating the Artik image networks appeared when running the scan command. From then the wpa_passphrase command was run to save the school's network information to the board. Using the vi command the wpa_supplicant was able to be verified by matching the correct contents of the file. Despite making sure that the supplicant file had what was required, the board still did not have connectivity when trying to do an additional update. The lack of connectivity may have had to deal with stricter security measures on the network created by the school. To circumvent the Wi-Fi connectivity issue an ethernet cable was plugged directly into the board to finish the updates.

3.2 Streaming

Video streaming would have ideally been used in order to continuously keep track of the baby. An ffserver.conf file could be modified in order to stream using the Artik, using Artik as a RTSP, or real time streaming protocol, server. Using a video player program on a computer such as mplayer it would then be possible to view the video captured from the board. Despite creating a ffserver.conf file that was exactly the same as the recommended one, launching the ffserver yielded no response in PuTTY.

Since running the ffserver was unsuccessful, python could also be used to implement streaming in combination with OpenCV and Flask. Flask is a micro web framework that uses a technique where the server provides a response to a request in chunks. The next chunk in line replaces the previous chunk to produce an animated effect in a browser. Unfortunately attempting to stream with python code also yielded no response. Debugging errors with the Artik and PuTTY is a rather difficult task since the Artik is a relatively new product, shipped in May of 2016. Due to the shorter lifespan of the product there is much less documentation available, and if the official documentation does not run as expected then there are not many other resources to turn to. It is still not known why both attempts to stream using the Artik have failed.

Even if the streaming had worked as intended there would still be the issue of running Eulerian magnification on the stream in real time. To work around the issue of not being able to stream and running Eulerian magnification on a stream a method was devised utilizing a known working feature of the Artik board. The method devised involved capturing short video segments through Artik and then running Eulerian magnification on the shorter clips for later analysis, which was the process used in the final design.

3.3 Running Eulerian on Artik

The MATLAB Coder application can be used to convert MATLAB code into C code. The Coder was intended to be used in order to run Eulerian magnification on the Artik board. When running the Coder on MATLAB code a compatibility measurement is created on a scale of one to five. Eulerian magnification is composed of 95 separate MATLAB files and there are frequent occurrences of calling MATLAB unique functions that had poor compatibility with the Coder. Poor compatibility can be fixed by altering and reformatting the code contents, but the team did not want to risk changing files without understanding the bigger effects. After realizing that too many of the files had poor compatibility conversion ratings and realizing that too much of the file contents had to be changed the idea of attempting to run Eulerian magnification on the board was abandoned. To carry on with the project and to test the legitimacy of the idea Eulerian magnification was run directly through the computer instead.

3.4 Using Twilio for SMS

There were a two big initial issues when using Twilio in an attempt to send a text message using Java and Eclipse. The first issue that arose was that the code failed to generate any message at all. Since the code was derived based off of given sample code from the Twilio website the fault probably did not lie in the code itself. The failure to generate a SMS was fixed by authenticating a phone number into the Twilio console user settings. Ideally other phone numbers could receive text messages by changing the user's number within the Java code, however when testing with different numbers the phones did not receive any sort of message. The reason the other phones were unable to receive messages is likely due to the limitations of using a Twilio trial account and having only one phone number assigned to the account.

Chapter 4

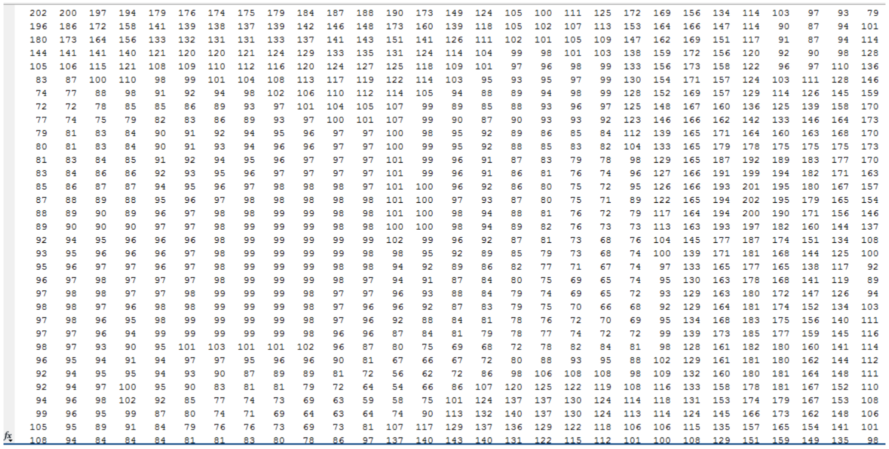
Breath Detection Algorithm Testing and Results

4.1 Capturing Video

To capture video clips through Artik the ffmpeg package needs to be installed. Ffmpeg is commonly used package used to encode and decode video. Once the package has been installed a video can be captured using the *ffmpeg -f alsa -ac 2 -i hw:0 -f v4l2 -s 640x480 -i /dev/video0 -t 20 video.mpg* command. Despite having a higher available resolution on the camera, the film was captured at a lower resolution of 640x480. The lower resolution speeds up the process of capturing clips and a higher resolution was not necessary for the purposes of the breath detection algorithm.

4.2 Counting Pixels

After the video clip is captured and moved to a computer Eulerian magnification can be run through MATLAB. Once the movement in the clip has been amplified the movement of the baby's chest can then be more easily tracked over time. Figure 4.1 is a 640x480 matrix that contains a number corresponding to a pixel color value in a single frame. The frame rate of the video, 30 fps, and the total number of frames in the video are stored as variables for further use.



202	200	197	194	179	176	174	175	179	184	187	188	190	173	149	124	105	100	111	125	172	169	156	134	114	103	97	93	79
196	186	172	158	141	139	138	137	139	142	146	148	173	160	139	118	105	102	107	113	153	164	166	147	114	90	87	94	101
180	173	164	156	133	132	131	131	133	137	141	143	151	141	126	111	102	101	105	109	147	162	169	151	117	91	87	94	114
144	141	141	140	121	120	120	121	124	129	133	135	131	124	114	104	99	98	101	103	138	159	172	156	120	92	90	98	128
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74	77	88	98	91	92	94	98	102	106	110	112	114	105	94	88	89	94	98	99	128	152	169	157	129	114	126	145	159
72	72	78	85	85	86	89	93	97	101	104	105	107	99	89	85	88	93	96	97	125	148	167	160	136	125	139	158	170
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79	81	83	84	90	91	92	94	95	96	97	97	100	98	95	92	89	86	85	84	112	139	165	171	164	160	163	168	170
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88	89	90	89	96	97	98	98	99	99	98	98	101	100	98	94	88	81	76	72	79	117	164	194	200	190	171	156	146
89	90	90	90	97	97	98	99	99	99	98	98	100	100	98	94	89	82	76	73	73	113	163	193	197	182	160	144	137
92	94	95	96	96	96	98	99	99	99	99	99	102	99	96	92	87	81	73	68	76	104	145	177	187	174	151	134	108
93	95	96	96	96	97	98	99	99	99	99	98	98	95	92	89	85	79	73	68	74	100	139	171	181	168	144	125	100
95	96	97	97	96	97	98	99	99	99	98	98	94	92	89	86	82	77	71	67	74	97	133	165	177	165	138	117	92
96	97	98	97	97	97	98	99	99	99	98	97	94	91	87	84	80	75	69	65	74	95	130	163	178	168	141	119	89
97	98	98	97	97	98	99	99	99	98	97	97	96	93	88	84	79	74	69	65	72	93	129	163	180	172	147	126	94
98	98	97	96	98	98	99	99	99	98	97	96	96	92	87	83	79	75	70	66	68	92	129	164	181	174	152	134	103
97	98	96	95	98	99	99	99	99	98	97	96	92	88	84	81	78	76	72	70	69	95	134	168	183	175	156	140	111
97	97	96	94	99	99	99	99	99	98	96	96	87	84	81	79	78	77	74	72	72	99	139	173	185	177	159	145	116
98	97	93	90	95	101	103	101	101	102	96	87	80	75	69	68	72	78	82	84	81	98	128	161	182	180	160	141	114
96	95	94	91	94	97	97	95	96	96	90	81	67	66	67	72	80	88	93	95	88	102	129	161	181	180	162	144	112
92	94	95	95	94	93	90	87	89	89	81	72	56	62	72	86	98	106	108	108	98	109	132	160	180	181	164	148	111
92	94	97	100	95	90	83	81	81	79	72	64	54	66	86	107	120	125	122	119	108	116	133	158	178	181	167	152	110
94	96	98	102	92	85	77	74	73	69	63	59	58	75	101	124	137	137	130	124	114	118	131	153	174	179	167	153	108
99	96	95	99	87	80	74	71	69	64	63	64	74	90	113	132	140	137	130	124	113	114	124	145	166	173	162	148	106
105	95	89	91	84	79	76	76	73	69	73	81	107	117	129	137	136	129	122	118	106	106	115	135	157	165	154	141	101
108	94	84	84	84	81	81	83	80	78	86	97	137	140	143	140	131	122	115	112	101	100	108	129	151	159	149	135	98

Figure 4.1: Pixel Representation of a Frame

After Eulerian magnification is run the clip is converted to grayscale using the *rgb2gray* function to reduce the numerical range of the pixel values, which also reduces the variance of different recorded scenarios. After converting the video to grayscale and going through multiple frames 200 was chosen as a threshold value to represent significant change, and anything below that value could be considered as noise. Using MATLAB a basic filter was designed to ignore the pixel values below the cutoff value and to calculate the sum of the total count of pixels with value greater than 200 in each frame.

4.3 Representing Motion Over Time

Using MATLAB to plot the sum of the pixel count greater than the threshold value per frame a sinusoidal wave is able to be generated that represents the baby's chest movements over the course of the video clip. The contrast between figure 4.2 and figure 4.3 shows the necessity for Eulerian magnification. Figure 4.2 is a pixel summation over time from a video not amplified by Eulerian magnification while figure 4.3 is the pixel summation over time from the same video amplified by Eulerian magnification. The large initial spike is due to a rapid movement. A much clearer sinusoidal wave can be observed in figure 4.3 compared to figure 4.2 due to the amplified chest movements, which results in a greater color change in each frame.

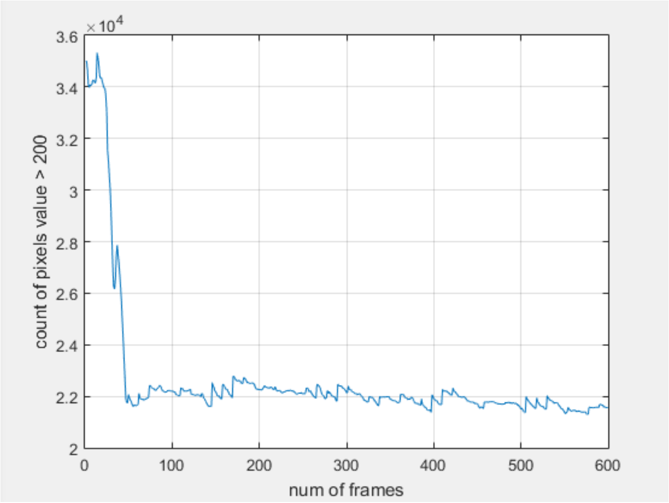


Figure 4.2: Chest Movement Plot Generated from Original Video

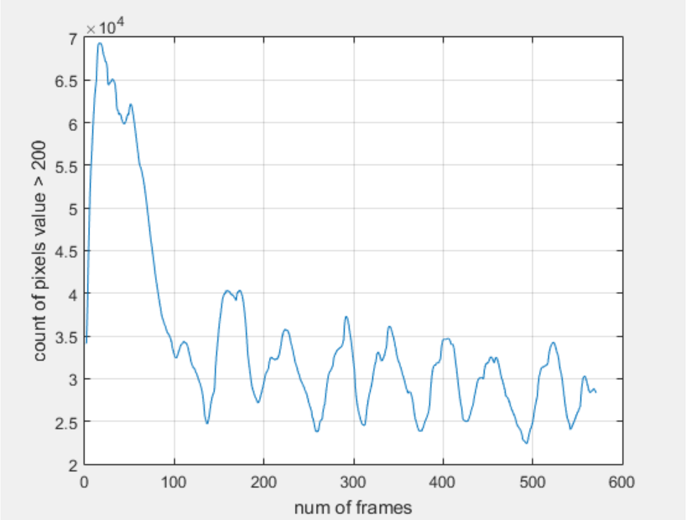


Figure 4.3: Chest Movement Plot Generated from Eulerian Video

To simulate different scenarios the team created 13 different sample videos for analysis. Some of the videos contained breathing and others were videos containing no movement at all. The thirteen different videos after Eulerian magnification is plotted in figure 4.4. Even though many of the videos displayed similar sinusoidal behavior, the magnitudes of each plot vastly differed, partially due to different lighting conditions. The vast differences in magnitudes makes it harder to generate an algorithm that will work in multiple scenarios as some of the videos with no movement, or "noise", had larger magnitudes than videos with breathing.

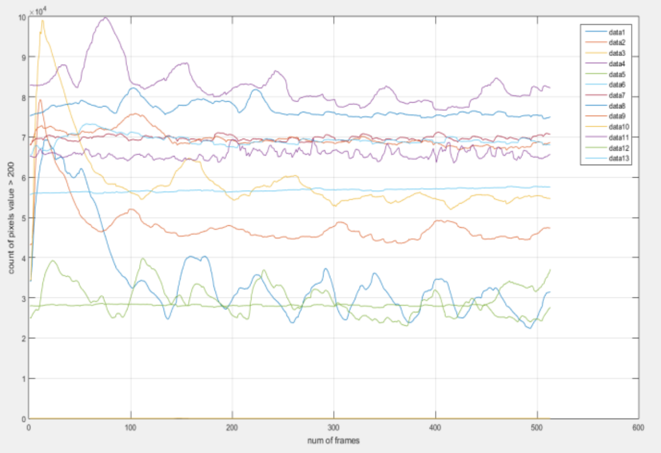


Figure 4.4: Chest Movement Plot from 13 Different Videos

To better analyze the plots the magnitude of each plot was “normalized” by calculating the pixel differences between each frame over time. Using this strategy the magnitude of all of the different videos with breathing were able to be fit within the range of -3000 to 3000, making them easier to compare to one another. In addition to that, the plots of the videos containing noise were reduced to a significantly smaller magnitude than the plots of the videos that contained breathing. This method of normalization allows for videos of different scenarios to be easier analyzed.

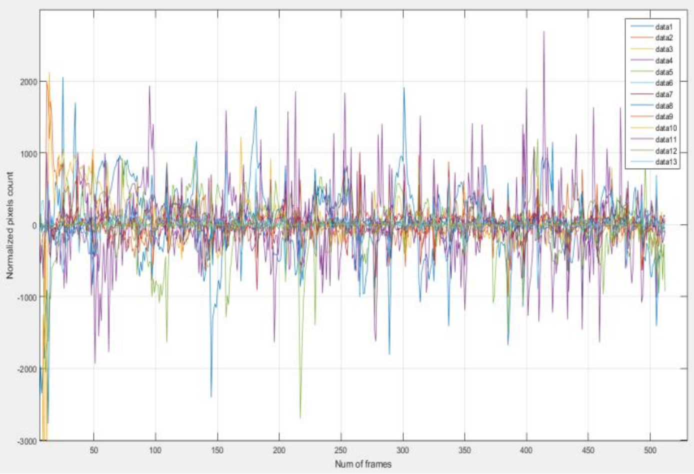


Figure 4.5: Normalized Chest Movement Plot from 13 Different Videos

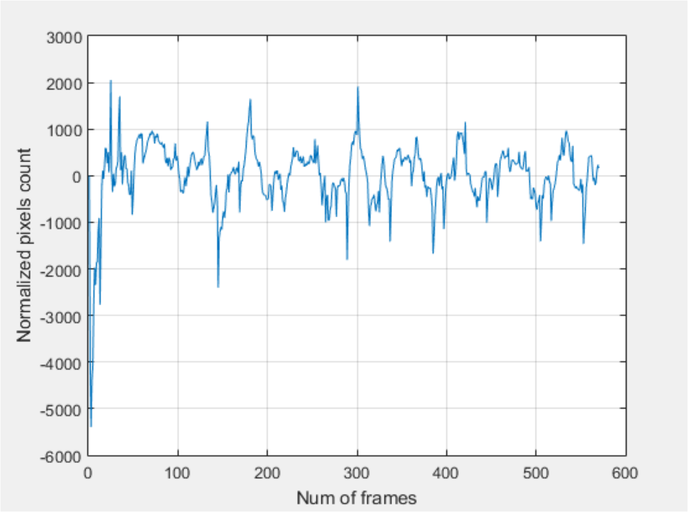


Figure 4.6: Normalized Eulerian Video Plot

4.4 Detecting Abnormalities

It would be easier to detect an abnormal breathing pattern and generate an alarm working with data in the frequency domain. After obtaining a normalized pixel count plot in time domain, a fast Fourier transform, *X1 = abs(fftshift(fft(ab, fft_len))),* was used in MATLAB to convert the time domain plot into a frequency plot. The resulting plot from the original video is shown in figure 4.7.

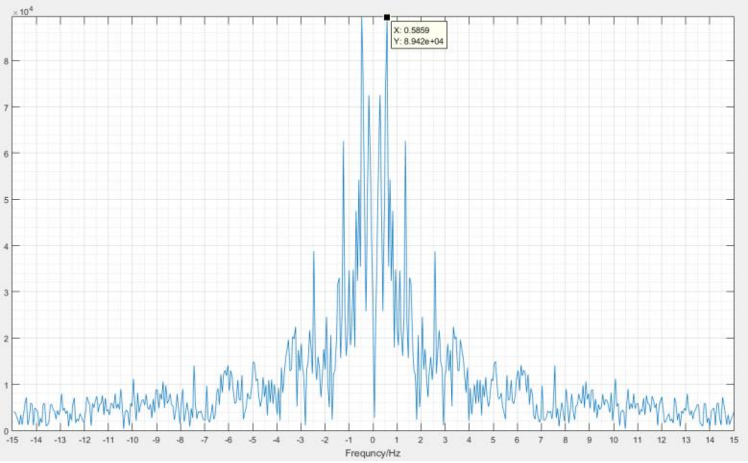


Figure 4.7: Frequency Domain Plot of Normalized Video

A newborn baby's maximum breathing rate is 60 breaths per minute, which corresponds to 1 Hz. Therefore we do not care about frequency values that are much larger than 1 Hz, and so 1.6 Hz was chosen as a cutoff. To eliminate these unnecessary frequencies and to clean up the plot a low pass filter was added using the *B = firpm(100, [0 .09 .1 1], [1 1 0 0])* command in MATLAB, which is a linear-phase FIR filter using the Parks-McClellan algorithm. Figure 4.8 is a plot of the low pass filter used and it was designed with small band edges, dropping from 1 at 0.09 to 0 at 0.1. The low pass filter was than applied to the frequency domain plot using the command *filt_out = filter(B, 1, ab).* The result is shown in figure 4.9.

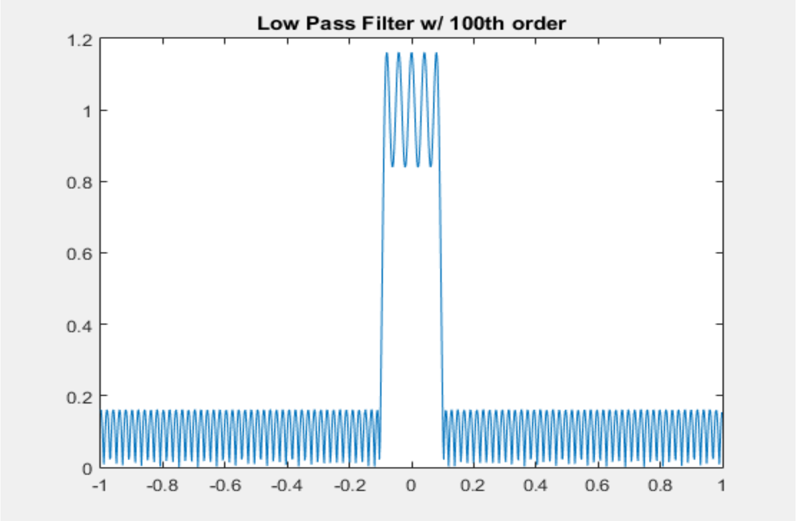


Figure 4.8: The 100th Order Parks-McClellan Linear-Phase FIR Low Pass Filter

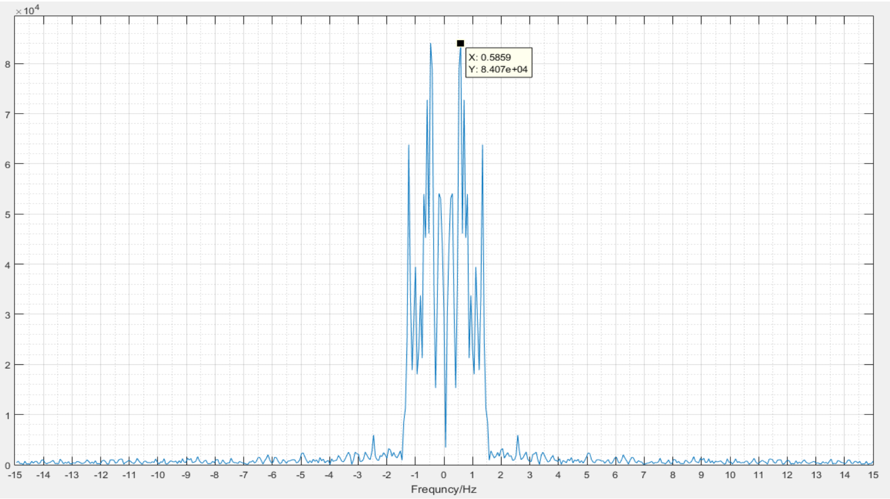


Figure 4.9: Frequency Domain Plot After Low Pass Filter

A threshold level was determined by analyzing the magnitudes of the frequency plots from the thirteen different videos. If the magnitude of the frequency plot exceeded the threshold level that indicates the respiration rate in the video is normal and the system will keep on working. If the magnitude falls below the threshold level, that indicates that the respiration rate from the video is not normal and an alarm should be generated. Based on looking at frequency plots from videos with breathing and videos of just noise a magnitude threshold of 8000 was chosen. Figure 4.10 and 4.11 are both plots from videos with breathing, with magnitude differences due to different light conditions in the videos. Figure 4.12 is significantly smaller and is a plot from a video with no breathing and falls under the chosen threshold level.

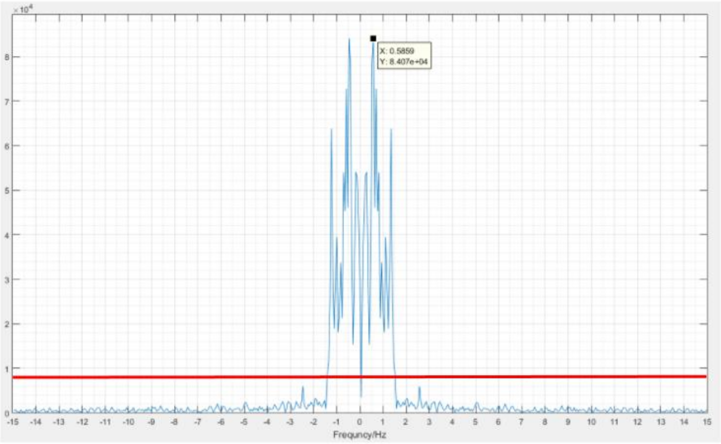


Figure 4.10: Large Magnitude Breathing Frequency Plot with Threshold Level

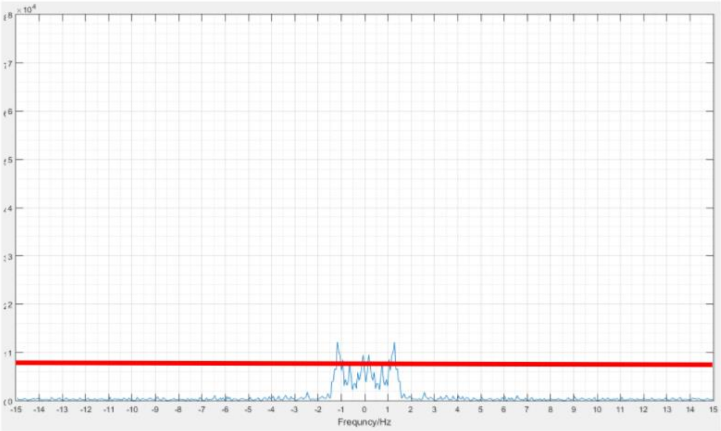


Figure 4.11: Low Magnitude Breathing Frequency Plot with Threshold Level

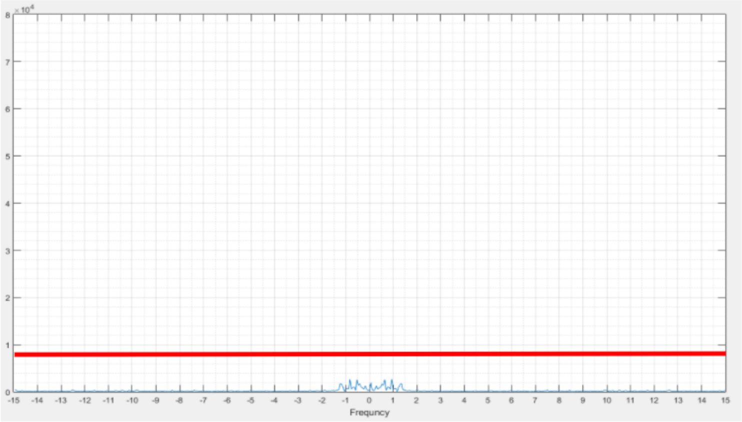
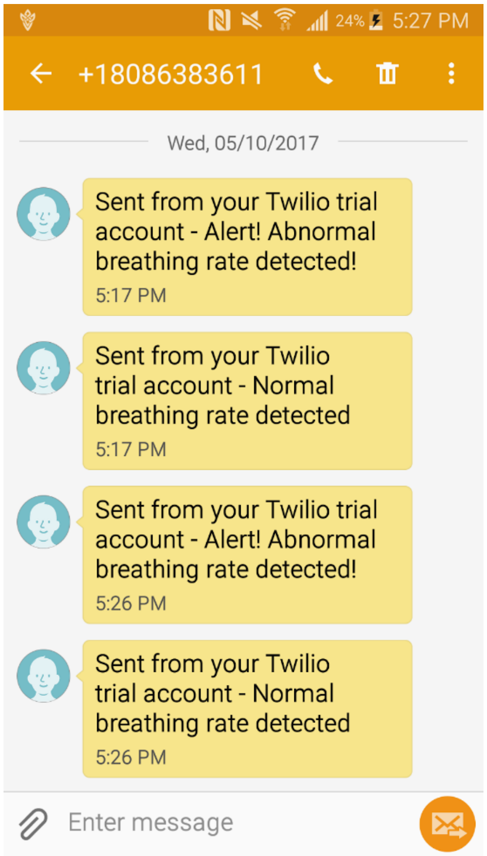


Figure 4.12: No Breathing Frequency Plot with Threshold Level

4.5 Using Twilio for Alarm Generation

By utilizing the threshold level a text file is able to be generated from the video indicating the state of the baby. If the baby is breathing okay then the text file would contain a “1” and if an emergency is detected then the text file would contain a “0”. With some outside help the team was able to come up with Java code that would read the contents of the file and utilize Twilio in order to send a message to a desired phone number. The code was run in the program Eclipse, which is the most commonly used Java Integrated Development Environment. Upon running the code a text message would be received to the desired phone number indicating if normal or abnormal breathing was detected, as shown in figure 4.13. Sending messages when normal breathing is detected would not be necessary, but was done during testing to see if there was proper functionality.



24% 5:27 PM

+18086383611

Wed, 05/10/2017

Sent from your Twilio trial account - Alert! Abnormal breathing rate detected!
5:17 PM

Sent from your Twilio trial account - Normal breathing rate detected
5:17 PM

Sent from your Twilio trial account - Alert! Abnormal breathing rate detected!
5:26 PM

Sent from your Twilio trial account - Normal breathing rate detected
5:26 PM

Figure 4.13: Text Messages Indicating Normal and Abnormal Breathing

Chapter 5

Professional Issues and Constraints

5.1 Ethics

Ethics is ultimately one of the main driving forces behind engineering. The goal of engineering is to use science and math principles in a way that will improve the lives of others. However, not all engineers will use their mental capabilities in a manner that is good for the race, which brings upon the importance of having ethical consideration and discussion. Stopping for a moment to consider the ethical impacts of a product may actually end up changing the way the product is designed. If one is not sure about the ethical implications of a product there is also the possibility to have an ethical discussion with fellow engineers. Engineering is not just a one person field and there are many people around willing to have these types of discussions. Ethical consideration is important because there is possibility that even the best product can be misused in the wrong hands.

5.2 Ethical Justification

The subject of SIDS is sometimes a difficult matter to discuss as it can appear to happen out of the blue and is often unexplainable, causing much grievance among the family. While the project cannot guarantee SIDS prevention, it can shorten parent's response time in the occurrence of an episode, perhaps leading to a saved life. In that light the project is more of a reactive measure than a guaranteed solution to the problem. People should be educated to understand that a complete solution to SIDS may not even be possible, but also understand that taking these preventative measures is never a waste of effort.

5.3 Sustainability

Successful businesses and practices are distinguished from unsuccessful ones by their entrepreneurial skills and the quality of their product. To understand some of the defining aspects of entrepreneurship and quality and how to ensure them it helps to look at a seemingly unrelated topic, sustainability. There are three different aspects of sustainability: environmental, social, and economic, and all three are equally important links between entrepreneurship, quality, and success. If a product was noticeably environmentally unsustainable, it would likely be boycotted in the market. If a product was socially unsustainable, then consumers would have no desire to purchase the product as it does not improve upon their daily lives. Likewise, if a product is not economically sustainable people would not purchase it due to its unaffordability or the company producing it would go out of business. Sustainability factors are very crucial to the success of any product or project.

5.3.1 Environmental Sustainability

As an engineer it is also irresponsible to release a product that is environmentally unsustainable as it is part of our duty as human beings to take care of the planet for ourselves and for future generations. A video based baby monitoring system has good environmental sustainability as it is not a detriment to the environment. The Artik board needs to be connected to a wall socket to be powered and connected to a computer for communication with the camera receiving power from the board. There are no additional power requirements necessary to run the project, excluding having access to a powered phone.

As long as none of the major components are severely damaged then the project will likely have a long lifespan compared to the time the project is actually in use. Due to the nonviolent nature of the usability of the project frequent disposability should not be an issue. Since the Artik 10 is a relatively newly released product it is hard to estimate its lifespan but is likely similar to that of the raspberry pi, which is two to three years. For the times when the product does need to be disposed of, many of the components can be turned into a plant that handles and recycles circuit boards.

5.3.2 Social Sustainability

Social sustainability is an equally important aspect in any project or product as it is the driving force behind people’s willingness to use or purchase the project or product. Hopefully people will understand that the project is for the social purpose of saving babies lives while also bringing parents a better sense of security at night. These are two factors that are hard to put a price on. SIDS cases happen around the world and is a truly terrible occurrence. If our project truly works as intended then there would be no social substitute for it since it is an attempt to reduce the number of lives lost and the heartbreak of the families that follows.

5.3.3 Economic Sustainability

The project is perhaps weakest in the economic sustainability department. The Artik 10 board is new and not very cheap, coming in at $150. The purchased camera was around $50, so the hardware total is around $200. The hardware price is slightly problematic since many commercial baby monitors can fall anywhere in the range of $15 to $180, so the project comes in on the more expensive side. The price of hardware also does not include the price of necessary software subscriptions either, so that is a hidden added cost. With time the cost of the Artik board will hopefully decrease significantly, bringing down the total cost of the project. Cheaper alternative hardware components could also be used if cost really becomes that big of an issue. While the price is quite steep, people will hopefully find it to be worth the cost.

5.4 Health and Safety

The health and safety of the baby is the project's top priority, and therefore causing injury to the baby in any way would mean failure. Since the hardware would be operated out of the baby's reach there should be little choking or strangulation risk involved. Infrared LEDs on the camera for night vision may not be the healthiest for use on young babies, especially when considering how long they will be in use for. Hopefully holding the camera several feet above the baby will help to mitigate this danger, but unfortunately there are few alternatives as video will need to be captured at night. Another major potential issue is generating an alarm when there is no emergency or failing to generate an alarm when there is an emergency. Unfortunately both of these cases are not easy to plan for, so further testing will need to be done to mitigate such scenarios.

5.5 Manufacturability and Usability

The project is relatively easy to manufacture since there are not too many components involved. The setup for the hardware components involves attaching a camera into the Artik board, which is a one step process that any user could do. A more complicated aspect involves stabilizing the camera. Since the team has not created a dedicated stand this is an issue that could be further improved on, but having a stabilized camera is imperative to the success of the project. In an ideal scenario the Artik board and camera would be setup on the top of a baby's crib, with the camera several feet above the baby's chest.

The software does not have to be manufactured more once it is completed since it can just be copied multiple times. However, using the software components is a little more tricky since it requires basic knowledge of Eclipse and MATLAB. Some of the breathing detection MATLAB algorithm is designed to loop through the number of captured video clips in an attempt to make the process easier for the user. The alarm written in Eclipse is also designed to run simply through the use of the run feature after the breathing algorithm has been run. Ideally in the end the whole process will be able to be operated off a single unit, but the team was not able to bring the project that far yet.

5.6 Civic Engagement

The project pertains to the community in the sense that it was designed for the safety and security of families. Modern society works because at the end of the day people have the opportunity to go home to their families where they can feel safe and secure. When the right to familial time is taken away or, in the case of SIDS, threatened, that can have serious repercussion to the functionality of society. By providing this sense of safety and security to families the team hopes that parents will keep their willingness to continue with their civic duties.

Chapter 6

Conclusion and Future Work

6.1 Acceptance Criteria

Unfortunately not all of the requirements initially set by the team could be met. The main requirement that could not be met was having the baby monitoring system run in real time. The system is not ready for use in a real environment since it does not run in real time. As the real time portion of the project was not completed the long duration run time of the system could not accurately be tested or measured either. A work around of capturing short clips was used in order to test the functionality of the rest of the project.

Despite the incompletion of the having an automated system run in real time, the goal of detecting breathing in a video was successfully accomplished. Being able to track and monitor a person's breathing rate with a video camera has potentially huge applications within the medical field. In addition to monitoring the subject's breathing rate for abnormal patterns the team was also able to generate a text message in the event of an emergency. A breath detector would not be very useful in its own right if it constantly had to be monitored, so utilizing SMS smoothens the process

6.2 Future Work

As stated above the main feature that needs to be worked on is the automation and real time performance of the system. In addition to the real time and automation another issue that needs to be dealt with is testing the system on babies. Getting access to and testing on babies is an issue that was avoided by testing the system on the team members. The principle concept remains the same, but some threshold values for breath detection will likely need to be changed due to anatomical differences in newborns.

A major limitation holding back the real time process is the lengthy run time of Eulerian magnification. It takes approximately a minute and thirty seconds to process a thirty second video with MATLAB. The long run time hurts the viability of the project, but can hopefully be improved on in time. Improving the runtime of Eulerian magnification is certainly not an easy task and will likely require a great amount of research into the entire process and probably a dedicated team.

Additional features could also be added to the baby monitor in order to improve accuracy and functionality while utilizing more of the features of the Artik board. The main example is the addition of a microphone to be added in tandem with the video processing to act as additional monitor on the baby's condition. A separate alarm could be generated if the baby is making loud noise or making noise for a long period of time. Another feature that could be worked on is having an amplified video of the baby streaming in real time, as the team did not prioritize getting this feature to work.

Finally, the entire system would ideally operate on one contained unit. If it were possible for the board to run Eulerian magnification, the algorithm for breath detection, and generate an alarm to the user's phone then the project could be considered truly complete. Although the team did not complete all of the originally intended features they have hopefully provided a strong framework to see the rest of the project to completion.

6.3 Lessons Learned

The team learned invaluable lessons working on a project with such a large scope. As the senior design project was the first project both members have worked on that took place over an entire year it would be an exaggeration to say that the entire process went smoothly. One lesson learned from the process involved the importance of setting goals and appropriately changing said goals if they cannot realistically be met. The initial scope of the project was found to not be feasible within the team's technical ability so the scope had to be changed, which ended up being in the project's best interest.

In addition the team learned about the importance of giving precise presentations. On different occasions through the quarter the team had to give two intermediary presentations lasting fifteen minutes each and one final presentation lasting twenty minutes. There is a vast amount of technical details and information that could be given, but a truly great presentation is able to convey the most important points in a concise manner. The team also learned about the importance of practice, as it is certainly a rarity in life to get something right on the first run through.

References

[1] "Sudden Unexpected Infant Death and Sudden Infant Death Syndrome." *Centers for Disease Control and Prevention*. Centers for Disease Control and Prevention, 17 Apr. 2017. Web. 20 May 2017.

[2] "Fast Facts About SIDS." *Eunice Kennedy Shriver National Institute of Child Health and Human Development*. U.S. Department of Health and Human Services, n.d. Web. 20 May 2017.

[3] 28, 2017 Kelvin Claveria | April. "13 Stunning Stats on the Internet of Things." *Vision Critical*. N.p., 28 Apr. 2017. Web. 31 May 2017.

[4] Wu, Hao-Yu, Michael Rubinstein, Eugene Shih, John Guttag, Frédo Durand, and William Freeman. "Eulerian Video Magnification for Revealing Subtle Changes in the World."ACM Transactions on Graphics 31.4 (2012): 1-8. Web.

Appendix A

MATLAB

```
clearvars;
clc;

myDir = pwd; %gets directory
myFiles = dir(fullfile(myDir,'vid*.avi')); %gets all txt files in struct

for vid_num=1:length(myFiles)

    v = VideoReader(eval(sprintf('''vid%d.avi''', vid_num)));
    %FFT length.
    fft_len = 512;

    %Video rate is 30 frames per second.
    vid_rate = 30;
    %Get number of frames in the video file.
    vid_len = v.NumberOfFrames;

    %Generate arrays of zeros.
    aa = zeros(1,fft_len+1);
    ab = zeros(1,fft_len);

    %Loop through every frame and calculate a sum for each frame.
    for ii = 1:fft_len+1
        video1 = read(v,ii);
        video1bw = rgb2gray(video1);
        %frame_val = sum(sum(video1bw));
        frame_val = sum(video1bw(:) > 200);
        aa(ii) = frame_val;
    end
    %Loop through and calculate the difference between frames.
    for ii = 1:fft_len
        video1 = aa(ii);
        video2 = aa(ii+1);
        ab(ii) = video1 - video2;
    end
```

```
%Calculate x-axis values -15Hz to 15Hz.
dW = vid_rate/fft_len;
W = 1 : 1 : fft_len;
W = W - .5*fft_len;
W = W*dW;
%FFT of difference calculation.
X1 = abs(fftshift(fft(ab, fft_len)));
%Create low pass filter with cutoff of 1.5Hz.
B = firpm(100, [0 .09 .1 1], [1 1 0 0]);
[H,WD]=freqz(B,1,1024,'whole');

%Filter difference data.
filt_out = filter(B, 1, ab);
X2 = abs(fftshift(fft(filt_out, fft_len)));




figure(1);
plot(aa);
xlabel('num of frames');
ylabel('count of pixels value > 200');
grid on;
hold on;


figure(2);
plot(ab);
xlabel('Num of frames');
ylabel('Normalized pixels count');
grid on;
hold on;

%{
figure();
plot(W, X1);
ylim([0 max(X1)]);
xlabel('Frequncy/Hz');
grid on;
grid minor;
set(gca,'xtick',[-15:1:15]);
```

```
    %ylim([0 80000])


    figure();
    plot((WD-pi)/pi, abs(fftshift(H)));
    title('Low Pass Filter w/ 100th order')
    %}

    figure(vid_num);
    plot(W, X2);
    ylim([0 max(X1)]);
    xlabel('Frequncy/Hz');
    grid on;
    grid minor;
    set(gca,'xtick',[-15:1:15]);
    ylim([0 80000]);

    trigger = max(X2);

    if(trigger) > 8000;
        disp(' Breathing Detected.');

        fp = fopen(sprintf('breath%d.txt', vid_num),'w');
        fprintf(fp, '1');
        fclose(fp);
    else
        disp('No Breathing Detected!');
        fp = fopen(sprintf('breath%d.txt', vid_num),'w');
        fprintf(fp, '0');
        fclose(fp);
    end

end
```

Appendix B
Twilio

```
package santaC;

import com.twilio.Twilio;
import com.twilio.rest.api.v2010.account.Message;
import com.twilio.type.PhoneNumber;

import java.io.IOException;
import java.io.FileReader;
import java.io.BufferedReader;

public class sendSMS {

     public static final String ACCOUNT_SID ="ACca0c11ecdf5922a8be6f79f08ce7080b";
     public static final String AUTH_TOKEN = "867cf67acecbd34a6d3463af5214f628";

     public static void main(String[] args) {
         readFromFile();
         System.out.println("Done.");

    }

    static int readFromFile(){
        try{
            for (int incr = 1; incr < 10; incr ++){
                String path = 
"C:\\Users\\Kyle\\Desktop\\santaC\\src\\santaC\\breath";
                FileReader fr = new FileReader(path+incr+".txt");
                BufferedReader readerFile = new BufferedReader(fr);
                String str = readerFile.readLine();
                int val = Integer.parseInt(str);
                System.out.println(str);
                if(val == 0) sendAlertSMS(); //send SMS alert if file value is 0.
                if(val == 1) noAlertSMS();
            }
            }catch (Exception e){}
            return 0;
      }

      static void sendAlertSMS(){
        Twilio.init(ACCOUNT_SID, AUTH_TOKEN);

        Message message = Message.creator(new PhoneNumber("+18083893235"),
              new PhoneNumber("+18086383611"),

          "Alert! Abnormal breathing rate detected!").create();

        System.out.println(message.getSid());
      }
      static void noAlertSMS(){
        Twilio.init(ACCOUNT_SID, AUTH_TOKEN);

        Message message = Message.creator(new PhoneNumber("+18083893235"),
              new PhoneNumber("+18086383611"),

          "Normal breathing rate detected").create();

        System.out.println(message.getSid());
      }
}
```