Addressing SIDS: Detecting presence of infant respiratory rate using image processing and machine learning

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Introduction

Sudden Infant Death Syndrome, or SIDS, is similar to, yet a subdivision of sudden unexpected infant death, or SUID. SIDS is a term assigned to the unexpected death, whether explained or unexplained, of an infant. It is the most predominant cause of death in infants ages 2-4 months (Kinney, Hannah C, and Bradley T Thach, 20 Aug. 2009). In the United States alone, according to the CDC, there were 1,400 deaths from SIDS, about 1,300 deaths due to unknown causes, and about 900 deaths from accidental suffocation and strangulation in bed in 2017 (CDC 13 Sept.2019., Figure 1). Aside from SIDS, the only illness that can cause infant deaths is SUID.

There is currently one baby monitor that performs this task, which is the Nanit Plus, but it requires a strap to be placed around the infant, which could make the infant uncomfortable and, if placed too tight, suffocate the infant. Nanit breathing wear is a smart gadget to help monitor the respiratory rate for newborns. Nanit has two different accessories, the swaddle and the band. Both the Swaddle and Breathing Band are easy to put on, made of 100% cotton, and contain no electronics, wires, or sensors. Breathing Wear is an innovative new line of babywear. Both the swaddle and the band have custom-designed to enable the Nanit Plus camera to accurately track your baby's Breathing Motion in real-time without any electronics or sensors on your baby or in their crib (nanit.com/about).

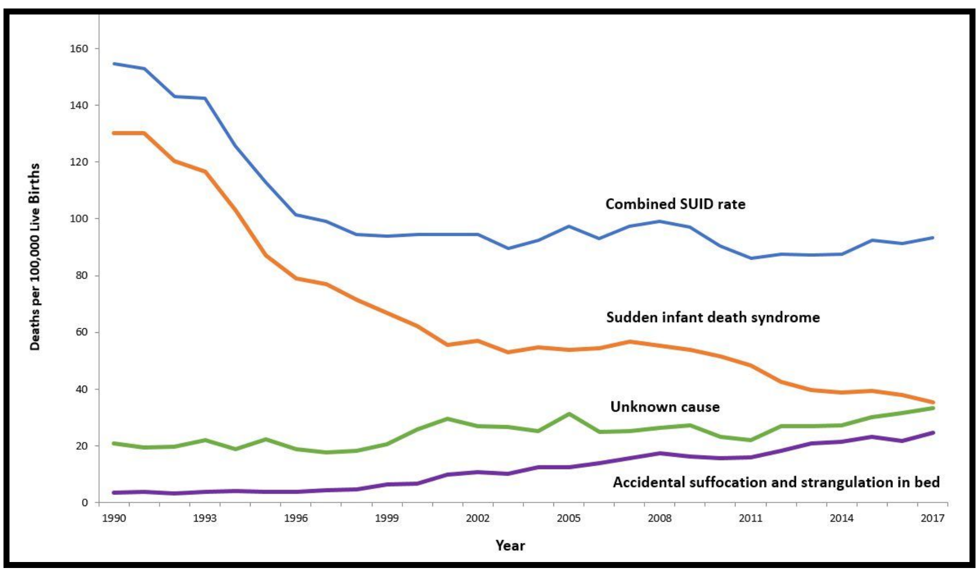

Figure 1: Rate of deaths due to SUID, SIDS, accidental suffocation and unknown causes since 1990
While infant deaths caused by SIDS has decreased since 1990, accidental suffocation and strangulation in bed rate has seen a gradual increase since roughly 1999, thus calling for new and improved research and development to prevent infant deaths of this cause, which we have addressed in our research. (CDC, 2019)

Figure 2: Nanit Plus Camera with Breathing Wear
Display of the Nanit application in use. The wearable strap can be seen on the infant. The large, thick, heavy, and uncomfortable appliance can potentially cause suffocation and impair their breathing. (nanit.com)

When unable to declare the infant's cause of death after thorough investigation, the term SIDS is referred to as the cause of death. The sudden death of an infant can also be associated with suffocation, asphyxia, entrapment, infection, ingestions, metabolic diseases, arrhythmia-associated cardiac channelopathies, and trauma, according to the American Academy of Pediatrics (*AAP.org, 2007)*. While the main cause of SIDS is currently unknown, SIDS occurs typically when an infant sleeps on his or her stomach and can occur without warning. It is therefore recommended that children sleep on their backs as opposed to the side or on the stomach to avoid the risk of suffocation during sleep.

Thus, our team designed and implemented an algorithm and technology for a novel baby monitoring system, named The Smart Crib. The Smart Crib will aim to reduce the amount of deaths due to SIDS. It will continuously monitor baby by incorporating image processing techniques to determine the motion of the chest and if the infant is on its back or stomach using a simple open source facial recognition algorithm. In correlation with a threshold which will be determined with testing and the normal breathing rate for infants, which is 30-60 breaths per minute for an infant 0-12 months of age (ACLS Medical Training, figure 3). The app will immediately alert the parents if irregular breathing is detected, therefore saving the infant from suffocation before it is too late. It also has options to use flash or to reverse the camera, as well as an option to disable the camera if not in use for privacy.

Age Category	Age Range	Normal Respiratory Rate
Infant	0-12 months	30-60 per minute
Toddler	1-3 years	24-40 per minute
Preschooler	4-5 years	22-34 per minute
School Age	6-12 years	18-30 per minute
Adolescent	13-18 years	12-16 per minute

Figure 3: Normal Respiratory Rates in Children
The normal respiratory rates of infants, the age category that we are addressing in our research, is 30 to 60 breaths per minute. Any rate above or below this threshold is abnormal, which is what we are trying to detect and prevent in our research in order to prevent infant deaths. (ACLS Medical Training)

Materials and Methods

Experiment 1

1. For both the control and experimental group data collection, participants were laying down on a flat surface (cot in the nurse's office) 18 inches away from the laptop webcam. The laptop used was a 2015 Macbook Air with a 720p built-in webcam. There were no windows in the room, and therefore the environment is well controlled in terms of lighting. The data was collected at a distance of 18 inches from the participant to the webcam and the webcam was tilted at an angle of 105 degrees (see figure 4)
   At the start of the experiment, student researcher #1 lied down on the cot. A protractor and tape measure was used to measure the angle of the webcam and distance from the participant.
2. Student researcher #2 pressed run when #1 was ready, and gave directions to #1 as the code collected the data through the webcam of the laptop. During the first three seconds (when the code is first run), the participant was directed to continuously breathe. Data is collected and interpreted by the algorithm during a three second window during a total period of 30 seconds, in 1 second intervals (as described next). 3 clicks of not breathing, 3 clicks of breathing, 15 pictures for each subject (3x15). The entire data collection per participant was 900 seconds.
3. During seconds 3-6, the participant was told to hold their breath.
4. This process was repeated so that there were 15 data collections of “breathing,” and 15 data collections of "not breathing."
5. Experiment was repeated for Student Researcher #2 and #3.
6. The data was then analyzed and a threshold which determines the average breathing rate for a high school student in correlation with the app was determined and eventually scaled down to correlate with the average breathing rate of an infant.

Experiment 2

1. Over the course of two several nights, each student collected data during their sleep with ambient light in the vicinity. The algorithm was modified to take pictures and record the average brightness per still every three seconds and automatically stop after two hours. The

data was then used to determine the functionality of the algorithm in low light and the validity of the threshold.

App Development

7. The code, once all tests were successfully completed, was exported in the form of an Android SDK and exported to an Android mobile device. That device printed the average brightness per frame in real time and also allowed users to activate/deactivate the camera and flash. The app uses the Ketai processing library which permits the app to use the device's sensors, such as the camera.
8. An SMS algorithm was built using the Processing SMS library and, once tested for accuracy, integrated into the app. The app asks the user to input a phone number and, if a breathing rate is detected below the threshold, an SMS message was sent to the user immediately.

Algorithm Development

1. Using Processing 3 on the aforementioned Macbook Air, an open source IDE which supports Java and Android app development, an initial algorithm was developed which uses two stills in a video feed and subtracts the pixel value of both and determining the average brightness of each still which correlates with the amount of movement in each still. The macbook had an Intel Core i5 processor, 4 GB of onboard storage and an Intel integrated HD 6000 graphics processor. Some coding was also done on a homemade PC, which had an AMD Ryzen 7 2700x processor, MSI MPG X570 wifi-enabled gaming edge ATX motherboard, MSI Geforce GTX 1660 ti graphics card, 32GB of Corsair Vengeance Pro 3000mhz DDR4 RAM, 1 TB Samsung Evo SSD and 2 500 MB Crucial M.2 SSDs.
2. The code took dimensions of the video and saved them into float variables p0, p1 and p2, as well as the RGB values.
3. The RGB values were then constrained to be between 0 and 255.
4. The algorithm used these dimensions to calculate the pixel density within the stills of the video.
5. The determined value was then printed in a screenshot which is taken every three seconds automatically. An Alternative version of the code was made which will only produce a screenshot when the mouse is clicked.
6. The algorithm was then exported as an Android SDK using the Kentai library to access the camera. Additional code was added for flash as well.
7. An SMS function was added using the Processing SMS library.
8. Forty-five images of infants lying on their stomach or lying on their back/side that were labeled for reuse were entered into an IBM Watson image recognition data set. 15 of the images were entered into the stomach class, which contained images of infants lying down on their stomachs. A negative class of 15 images was created and images of infants lying down on their back or side were inputted. A test case of 15 additional images of infants lying down on their stomach and back or side was used as a test case to test the IBM Watson data sets.

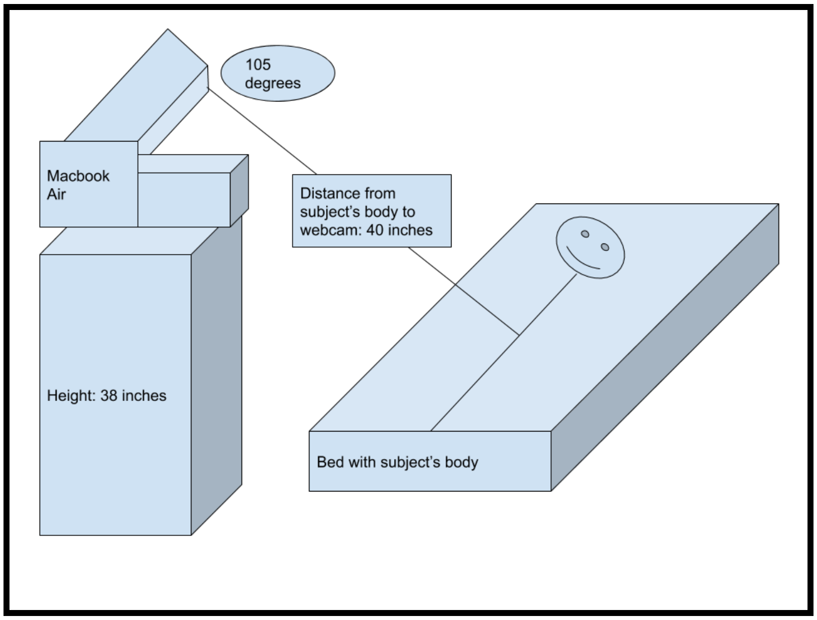

Figure 4: Diagram to illustrate how data was collected during the first trial. Each researcher was used as a test subject, and for their trial, would lay down on the nurse's cot and breath normally for 30 seconds while their motion is being recorded through Processor. They would then hold their breath for two intervals of 15 seconds while their motion is being recorded through Processor. They data collected by Processor would be further assessed and interpreted by the group to record the breathing rates of each subject, breathing and not breathing, according to how their motion was captured by Processor.
(Image created by Jeremy Bernstein)

Results

a. App Design

The app was designed to determine the average pixelation per two stils of a video feed, which it accomplished successfully. The values obtained by the app were similar to those obtained using the processing algorithm which is also embedded into the app. The SMS algorithm was also successful when used with a Google Voice phone, even though compatibility is available with any valid phone number.

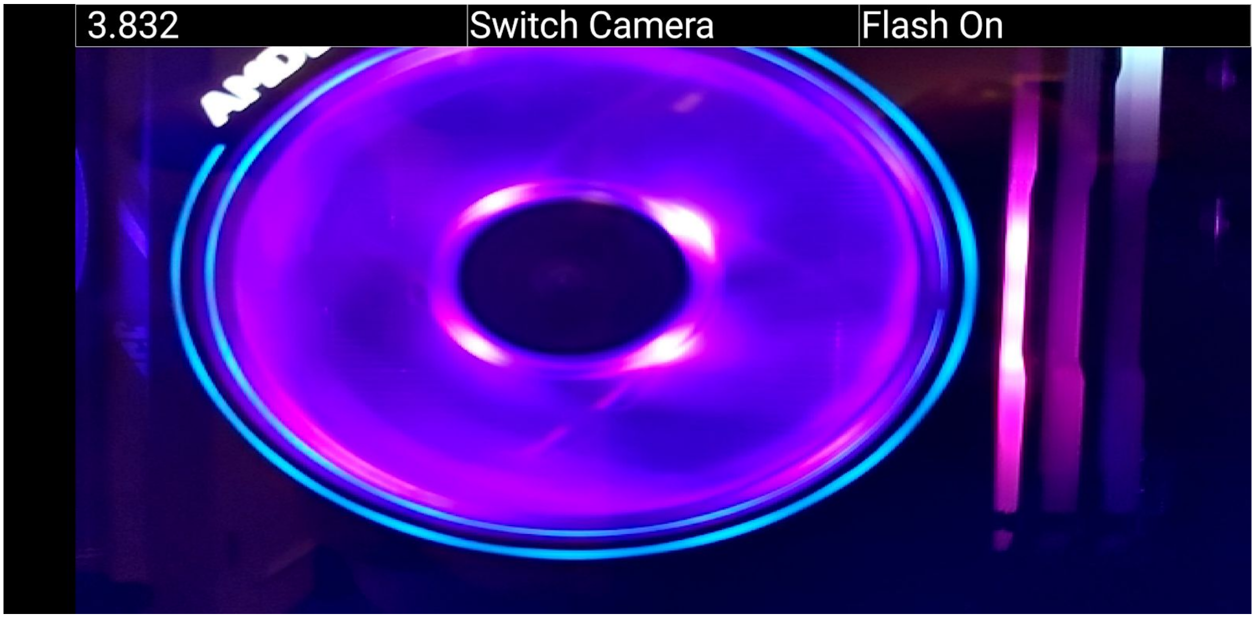

Figure 5: The app is tested on a CPU fan in a gaming PC on minimum load, movement (top left) is detected by the app (rear camera, no flash)

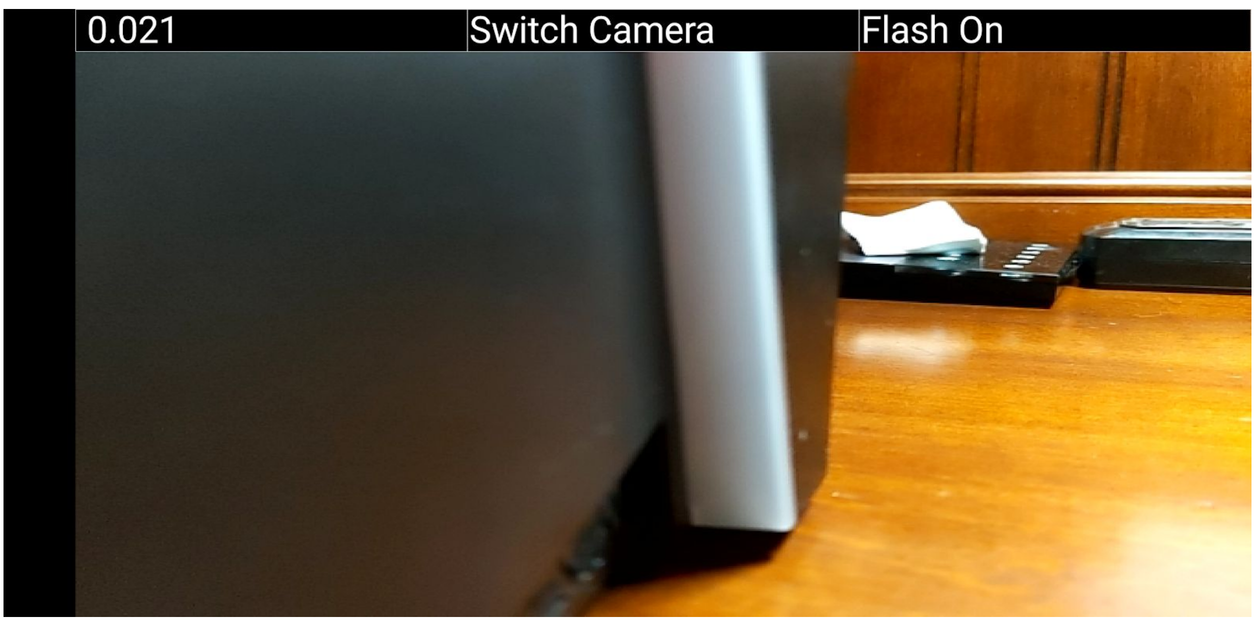

Figure 6: The app is tested on a flat desk and detects movement from the screenshot being taken (rear camera, no flash)

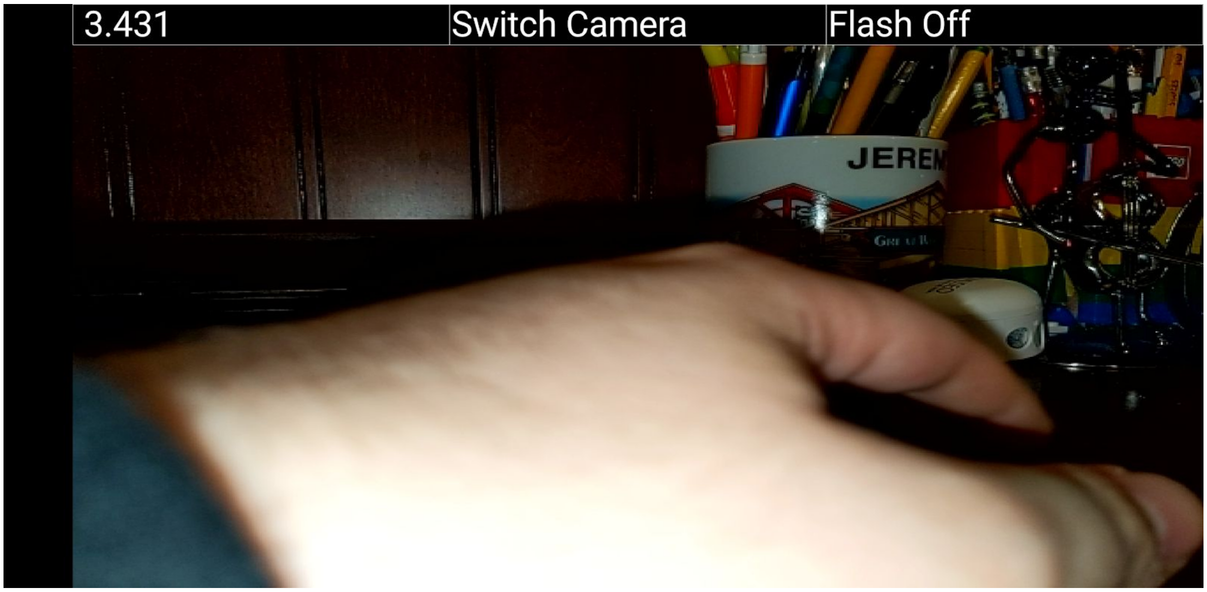

Figure 7: The app is tested on a moving hand in the dark (rear camera, flash on)

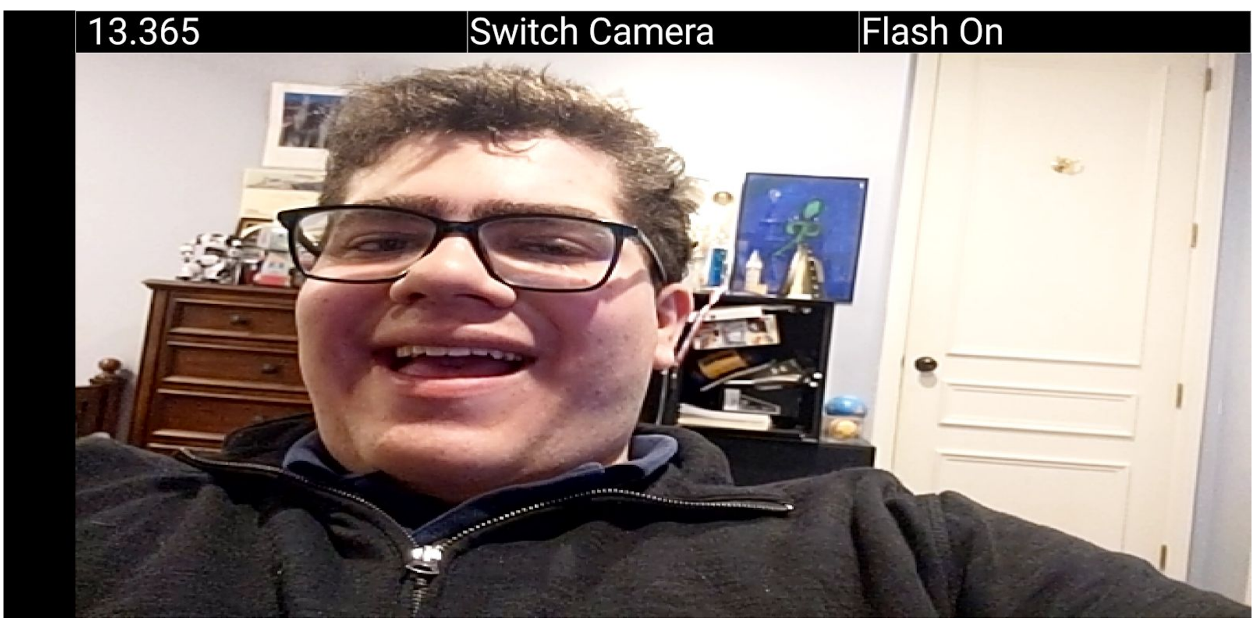

Figure 8: The app is tested to detect my head shaking (front camera, no flash)

- **Proof of Concept**

To determine if the infant was in the crib and on their stomach, images labeled for reuse were entered into an IBM Watson data set. 15 images were inputted into the stomach class of infants lying down on their stomach. A negative class was also created with 15 images of infants lying down on their back or side. 15 additional test case images also labeled for reuse were entered as a test case for testing and the average confidence was 92% of all images.

- **Experiment 1: Breathing for 10 seconds**

After the experiment, the algorithm detected breathing correctly over 50% of the time compared to not breathing. Breathing was determined to be any motion value over zero, while non-breathing was determined to be zero. Between breathing, a value of zero is expected. The unique part of the smart crib app is that an alert is only sent if six seconds passes without a positive motion value. After data collection, the motion values from the experimental breathing group were averaged together, resulting in 0.02285106383, with a standard deviation of 0.04137368347.

Breathing	Not Breathing
0.131	0
0	0
0	0
0	0
0	0
0.094	0
0	0
0	0
0	0
0	0
0	0
0	0
0	0
0	0
0.064	0
0.034	0
0.035	0
0.072	0
0.001	0
0.041	0

0.011	0
0	0
0	0
0.1	0
0.003	0
0.1	0
0.038	0
0.18	0
0	0
0	0
0.009	0
0.019	0
0	0
0	0
0	0
0.039	0
0	0
0	0
0	0
0.089	0
0	0
0	0
0	0
0.007	0
0.001	0
0	0
0.006	0

Figure 9: Motion values recorded during breathing test

The above values represent the motion of the breathing test subject detected by the algorithm by calculating the difference in pixels between two frames. The zeroes represent periods during which the subject was not breathing or in between breaths.

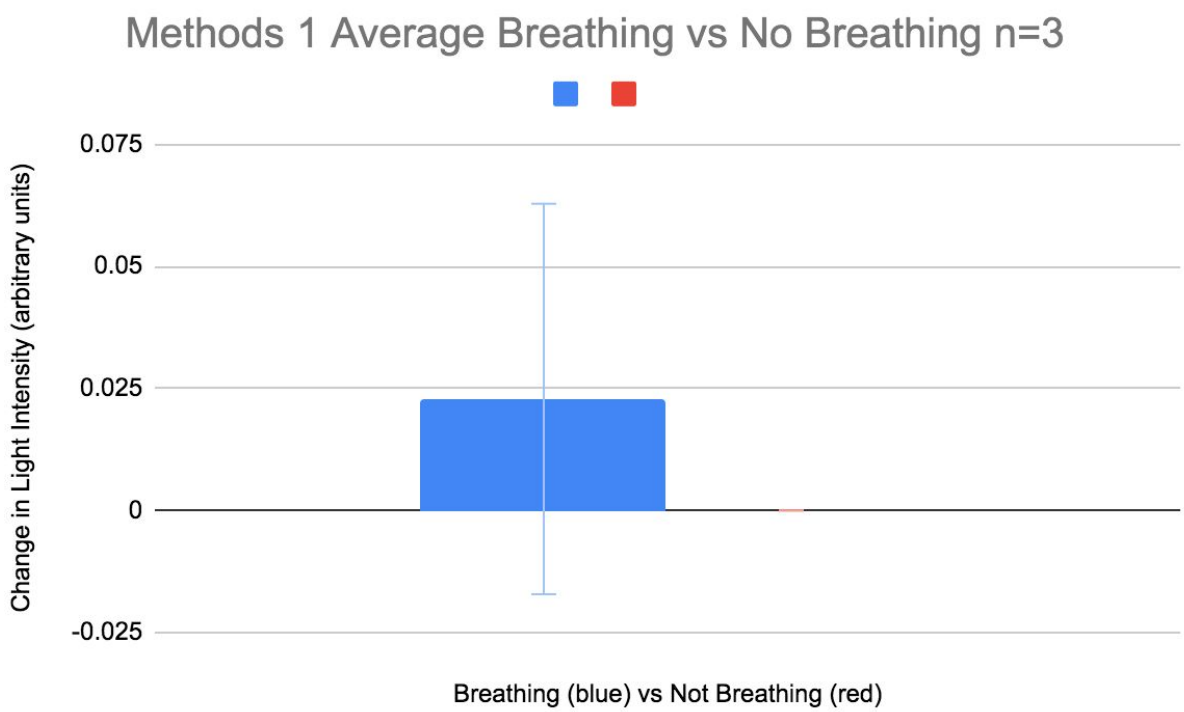

Figure 10: Methods 1 Average Breathing vs No Breathing n=3
The algorithm had zero false positives for no breathing after the three participants were monitored for the presence of a respiratory rate over the course of 900 seconds.

Discussions and Conclusions

The results determined through experimentation were expected and therefore has proved the hypothesis correct. The algorithm was able to successfully detect breathing overnight and during the trial in the nurse's office, as well as when the subject was not breathing. The concept was also proven to work correctly which prompted further research and experimentation. Through this data, the algorithm will be able to detect breathing irregularities in infants.

IBM Watson's image recognition software was first used to determine if the project would be a viable execution. Photos taken with the Processing image algorithm were sorted into breathing and negative (or non-breathing classes) of 15 images, and then an additional group of photos taken with the same algorithm were used as the test case. Once tested, each of the 15 test case images returned correctly with an average of 92% confidence. The app was then tested directly through overnight and short time-period testing, the threshold was determined to be 0.02285106383 percent brightness per two frames. The standard deviation for breathing was also 0.04137368347. However, for the non breathing, the average threshold percent brightness per two frames and the standard deviation were both determined to be zero.

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