UNIVERSITY OF WISCONSIN-MADISON
DEPARTMENT OF BIOMEDICAL ENGINEERING
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DEVICE FOR TRACKING HEAD MOTION IN AN MRI SIMULATOR

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ABSTRACT

While performing medical procedures on patients there is often a great difference between individual subjects. Medical professionals much overcome these differences to conduct the procedure correctly and obtain accurate and reliable results. One difficulty that these professionals and researchers might encounter, as is the case with our client, deals with the difference between the abilities of their patients to hold still long enough to perform the procedure correctly. Young children have difficulty focusing and lying in one spot without moving while an MRI machine scans their brain; they must be trained to hold almost perfectly still while the scan is taking place. Using patient feedback and stopping a movie or other attractive feature for the patient when they move past a certain desirable threshold can perform this. Our device will detect very slight patient movements and stop playback when a threshold is exceeded.

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Problem Statement

The goal of this project is to design and build a system to track a subject's head motion in an MRI simulator and link this to a video display. When the subject moves his/her head, a displayed video (movie) is turned off; when the subject stops moving his/her head, the video resumes. Our goal is to use this device to train children to keep their head still when undergoing an MRI scan. Ideally, this device and software should be user-friendly. The system should be capable of detecting at least 0.2mm and 0.2 degree head motion at 30 Hz or better. The subject will be lying in a simulated MRI scanner, so access to the subject is somewhat spatially limited.

Background

The client for this design project is Dr. Rasmus Birn. He is doing research on the organization of the brain during childhood development. The two main areas that his lab's research is focused on is methodological improvements for resting- state functional connectivity and changes in functional connectivity during childhood and adolescence [1]. This is done through Magnetic Resonance Imaging, MRI, of children's heads as they age.

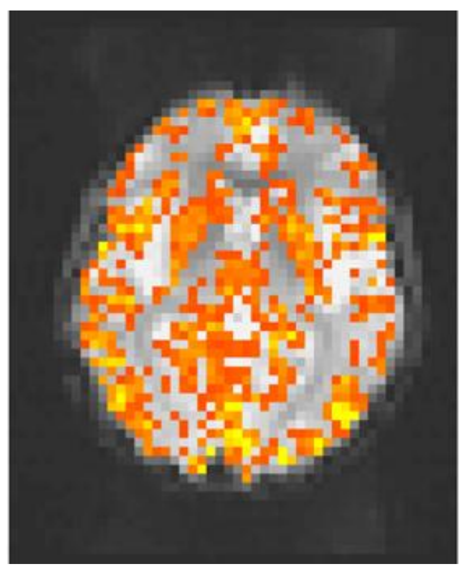

Figure 1 – An image from an fMRI during the subject taking a single deep breath [http://www.radiologyinfo.org/en/info.cfm?pg=fmribrain].

MRI is a technique used to produce detail images of internal structures of the human body. This is done by an MRI machine producing a powerful magnetic field to cause the protons in the body to align themselves. Next, radio waves are produced and sent to the body for the

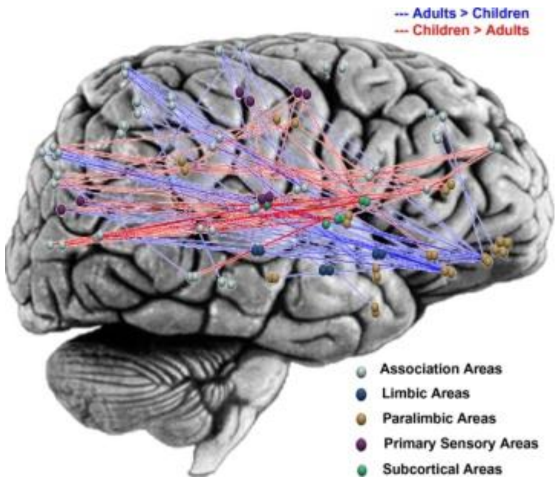

Figure 2 – A graphical representation of the changes in connectivity of brain areas as development occurs [Uddin et al., 2010].

protons to absorb, causing the protons to start spinning and emit energy that is picked up by the coil of time MRI machine [2]. This creates image slices of the part of the body that is being scanned which are sent to a computer that is able to produce a final three dimensional image. Thus, accurate brain images can be created using MRI scans. Particular brain activity can be measured using function MRI (fMRI). This is a type of MRI which detects changes in blood flow related to energy use by brain cells, also known as the hemodynamic response [3]. Figure 1 is an example of an fMRI image that could be used for research. Images of patient as they become older allow researchers to see the difference between the children and adults brains. An example of major locations being identified for comparison can be seen in Figure 2. For this research to be done, multiple scans must be taken from a large subject pool that will produce clear usable images.

MOTIVATION

Figure 3 – A MRI simulator used to prepare patients for an MRI procedure [http://www.pstnet.com/hardware.cfm?ID=92].

For accurate scans and clear images to be created, the subject in the MRI scanner must remain still. This is because movement that occurs during scanning can result in image distortion. In fact, movement of 1 mm translational or 1˚ rotational will cause image distortion. If larger movement occurs, the image can be distorted to the point that it is no longer able to be used which wastes money and resources; therefore, an MRI simulator is used to train patients to remain still during the scanning process. The MRI simulator, Figure 3, is currently be used to try and get the patient to feel comfortable in an MRI scanner in hopes that they will then be used to remaining still during a scanning period. However, there is no way for the patient or the doctor to know if the patient is remaining still in the simulator or if small movement is occurring. Therefore, a device is need that is able to detect head motion. This device should also be able to give feedback to both the patient and the MRI operators when movement occurs. For the patient's feedback, it could be visual images or a video that is turned off if movement above a threshold occurs. The MRI operators' feedback could be a constant monitoring of the head in three dimensional space for movement under the threshold and an additional alert if movement occurs above the threshold.

EXISTING DEVICES

Currently, there is a device that is commercially available to work in MRI simulators that can track head motion. This technology was developed by the Psychology Software Tools, Inc. and is called Mo Trak® Head Motion Tracking System. Mo Trak is software that uses Ascension Technology's Flock of Birds sensors. These are magnetic sensors that are attached to the patient's head that can locate the position of the head in space. The Mo Trak system, Figure 4, is able to track translational and rotational movement in the MRI simulator. It is also able to give visual

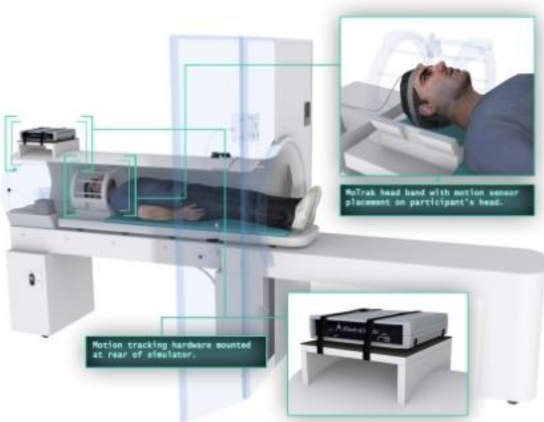

Figure 4 – Diagram of the MO Track system and how it tracks head movement in MRI simulator [http://www.pstnet.com/software.cfm?ID=96].

feedback of the patient's motion as well as auditory feedback to the participant when movement above the threshold has occurred [4]. The downfall to this device is that it is out of our client's budget as it cost approximately $8,000.

CLIENT REQUIREMENTS

A number of requirements were given by the client that the system must meet. Firstly, the head tracking device should detect movement in 6 degrees of freedom: in all three planes of translational movement and rotationally around each of those three axes. The translational measurements must be accurate to 0.1 mm and the rotational measurements must be accurate to 0.1°. This precision is necessary to ensure that the image output by an MRI is not distorted or blurry. According to the clients, movement of 1 mm or 1° can significantly affect the image.

Apart from the measurements which will be taken, the size of the device also needs to be taken into consideration. After taking several measurements of the current simulator setup, a distance of 17.8 cm remains unused between the subjects face and the inner surface of the simulator. Moreover, there exists an additional round cage which is 10.2 cm from the subjects face. The device must be designed to work within these confines when considering the design alternatives.

The visual feedback to the subject must also be altered when a movement threshold of 1 mm or 1° is breached. Children have short attention spans by nature, so it is paramount to limit their movement within the simulator. By having real-time feedback, the subject will be alerted when they are not remaining still enough for the MRI to capture a clear and ultimately useful image.

It is also worth noting that we are only working with an MRI simulator which does not use actually magnetic resonance. Therefore, ferrous materials can be used in the final design.

DESIGN ALTERNATIVE: IR SYSTEM

One design alternative considered involves using LEDs and an IR camera to track head motion. The LEDs will be secured to the head of the subject in a fashion which will allow for the tracking of movement in six degrees of freedom. As the head then moves, so will the LEDs. The IR camera will take in the image projected by the LEDs onto a mirror above the subjects face and be able to triangulate the position of the head, given an initial reference point. The voltage output of the camera will then be sent through a USB microcontroller to a processing program on a computer. The program will display the six measurements described above and allow the user monitoring the subject to know how still the subject is.

IR cameras, similar to the camera used in a Wii remote, have the capabilities to track position within 0.1 mm. The rotational accuracy is more unknown, and testing would be needed to ensure its adequacy for this accuracy requirement.

A USB microcontroller, most likely Arduino, is used to allow for easy interfacing between the device and the computer. Furthermore, a programming language will need to be settled on in order to talk to the microcontroller.

Figure 5 shows the orientation of the IR camera, mirror, and the surface of the LEDs on the subject. By using a mirror to project the LEDs position, the restriction of size within the simulator is partially solved, since the camera will be place outside of the simulator.

DESIGN ALTERNATIVE: CAMERA TRACKING SYSTEM

The second design alternative is similar to the first one but instead of an IR camera this design uses a video camera. The setup will be similar to the diagram in Figure 5 with the mirror extending the field of view and allowing the camera to focus of the entire face of the subject in the MRI simulator. This system works through a web camera recording images. These images are then sent to a computer where imaging software, such as Free Track, processes the images to determine if movement occurs. Movement is detected by differences in images on a frame to frame comparison [5]. If there is a difference in the images, then movement has occurred. The images recorded by the video camera will appear similar to those in Figure 6. The image processing software will be programmed to use the camera's pixel resolution to determine how large of a movement occurred.

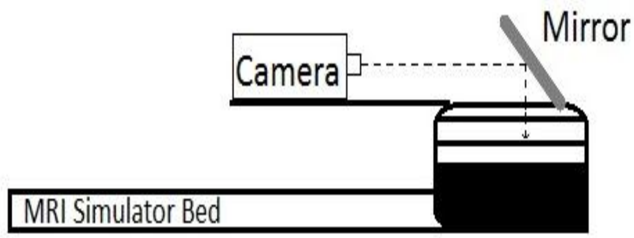

Figure 5 – Diagram of the layout of the camera tracking system.

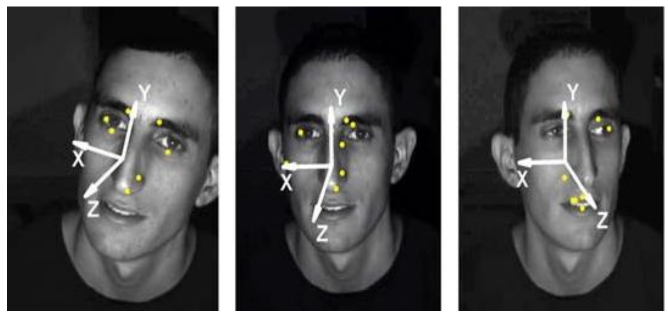

Figure 6 – Images being recorded by video camera and how they would appear before processing by software [http://www.free-track.net/english]

Two different camera setups can be used to allow for six degrees of freedom tracking. The first is using a single web camera like in Figure 7. This setup will need to use Light Emitting Diodes, LEDs, like how the IR Camera System did. That is, four LEDs will be used. The LEDs will be placed in the three planes making up three dimensional space [5]. The LEDs will then be placed on the

Figure 7 – A web camera that could be used in this tracking system [http://www.free-track.net/english].

subject's head to use as reference markers. The camera then records the LEDs and tracks their movement which is the same as the patient's head.

The second camera system would use two different cameras, Figure 8 that record images simultaneously. The images are then recorded together on particular computer software that produces three dimensional images [6]. This system works similar to how humans' eyes allow them to see depth and in 3D. This system requires more complex image processing and could be affected by the use of the mirror. Further research or testing would need to be done if this system is selected to be used.

Figure 8 – DynaSight stereo- camera system [http://orin.com/3dtrack/dyst.htm].

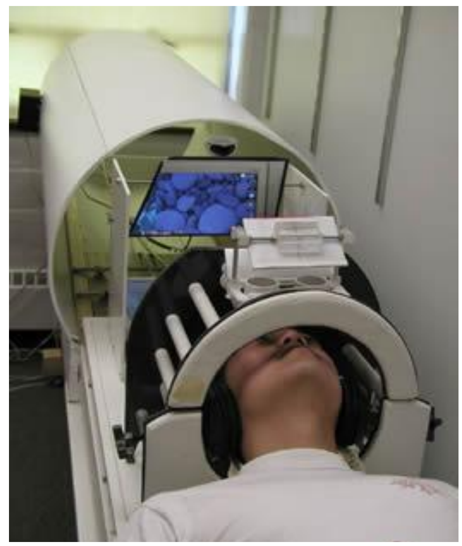
Figure 9 – MRI simulator video camera head tracking setup at the University of Washington [http://depts.washington.edu/idl/mockmri.htm]

The image processing software will be able to give real time feedback for the MRI operators to watch visually. A second program can be created to work alongside the imaging processing program to send feedback to the subject in the simulator when the movement threshold is reached. The subject's feedback could be a video display seen using the mirror that turns off when the movement threshold is reached. This setup would be similar to the one in Figure 9 that researchers at the University of Washington are trying to develop.

DESIGN ALTERNATIVE: ACCELEROMETER SYSTEM

Accelerometers measure displacement by detecting the acceleration of the sensor. It measures tilt through static acceleration, or gravity, and direction through dynamic acceleration. Accelerometers can be either analog or digital and can detect motion along one, two, or three axes. For the specifics of this design project, a three axis digital accelerometer may be the best option to reduce the amount of calibration necessary. Figure 10 shows one example of a triaxial accelerometer. By selecting a digital model a microcontroller can also be used in conjunction with the accelerometer. In addition to these differences in models, the way in which acceleration is measured varies from model to model. In some models, a hot gas bubble is located in the chip along with a number of temperature sensors around the edge. As the chip moves the bubble moves, redistributing the temperature. The temperature sensors pick up these changes and are then related to acceleration [12]. Other models contain microscopic crystal structures which forces due to acceleration stress and cause voltage generate. This changes the capacitance which is then measured. Other less common methods of measurement include use of piezoresistive effects and light [13].

Figure 10 – An example of a three axis accelerometer [http://www.dimensionengineering.com/accelerometers.htm].

Interfacing the accelerometer with the subject feedback system would be accomplished with a simple circuit. At the specified threshold (i.e. 1 mm) a switch like mechanism would turn the video feed off until the subject stops moving.

DESIGN MATRICES AND EVALUATION

The design matrix was split up into 6 different categories; cost, accuracy and sensitivity, programmability, MRI compatibility, size, and manufacturability. Figure 11 illustrates the point breakdown for each of the individual categories. The first category of the design to be analyzed was size of the design and its fit into the imaging tube. As the ability of the design to fit into the tube and perform its necessary operations must occur for the device to be functional it received a slightly heavier weighted value of 22% of the whole. In this category the accelerometer received a perfect score. There are no worries about the ability of the accelerometer to fit in the necessary space, as it will simply be attached to the subject with cords to transmit the signal to a processing unit. The infrared unit received a slightly lower score of 20, as it requires the use of one camera, a mirror, and LED lights attached to the subject. The optical design received an even lower score of 17, as it requires two cameras for six degrees of freedom, and a mirror to transmit the image to the cameras. Figure 12 illustrates the point breakdown for each design for size, manufacturability, and accuracy/sensitivity.

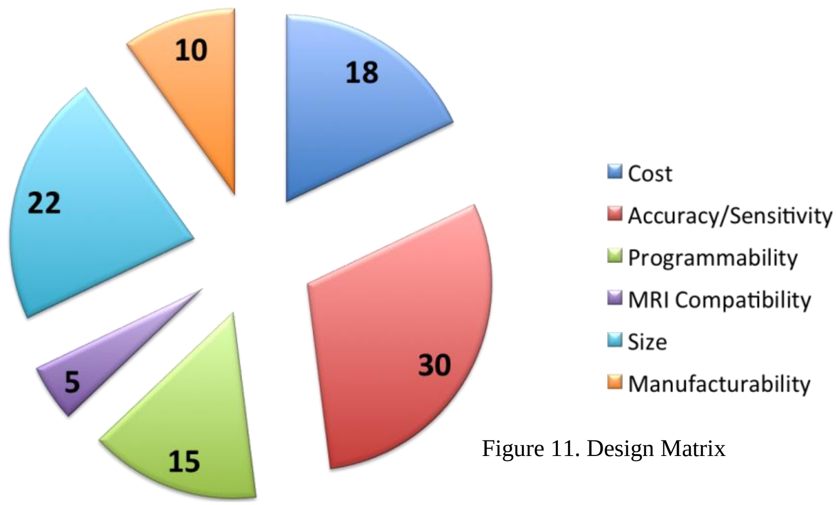

Figure 11. Design Matrix

Manufacturability is the next variable that was evaluated and received a total of 10% of the total weight. All of the designs will be relatively simple to manufacture so the scores are fairly similar with the accelerometer scoring the highest. The accelerometer will have wires attached to it that pose some manufacturing problems that prevent it from receiving a perfect score but it still comes in at an 8 out of 10. The optical and infrared designs will both require the use of mirrors to reflect the image of the subject in the MRI simulator back to them as there is not enough room in the imaging tube for the lenses and reading devices to focus in their optimal range. The optical design requires more precise mirror placement and will be more difficult to pick up the image variation than the LED position so it received a 4 while the infrared received a 5.

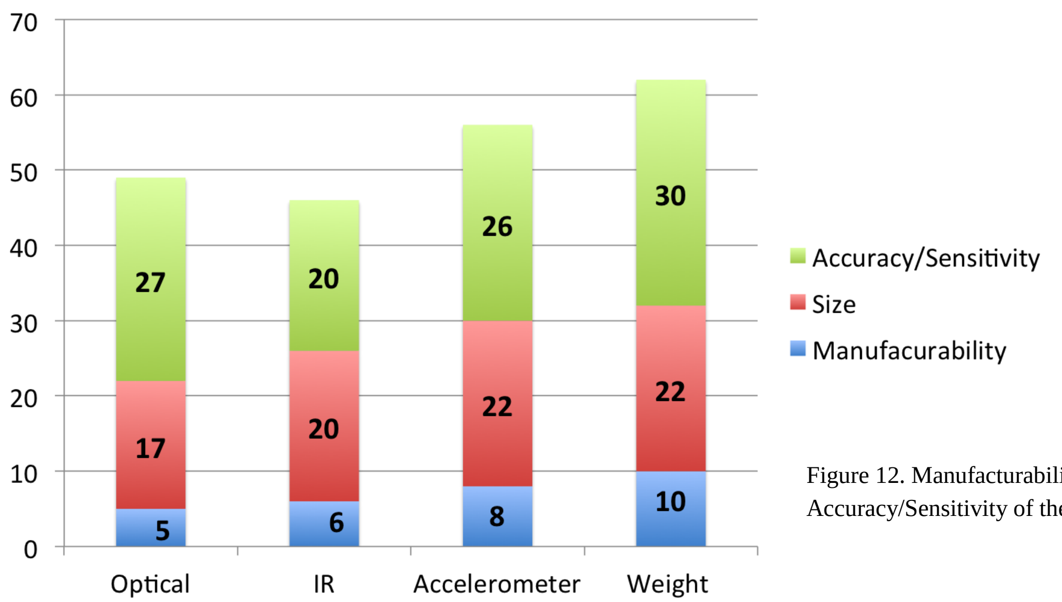

Figure 12. Manufacturability, Size, and Accuracy/Sensitivity of the device.

The category that received the highest ranking was the accuracy and sensitivity of the design. The project is meant to help train small children to hold still in an MRI simulator in order to train them for actual imaging in an MRI machine. If the children move more than 1 mm in any direction it will skew the results and render them useless. To prevent this from happening our device must have a much smaller detection value. The accelerometer will be the most accurate of the devices, as it will detect very slight movements as long as they occur in a relatively rapid manner. This works well for the kids being trained as they are much more likely to move fast than they are to move very slowly. The optical device will also work quite well as it simply records the difference between the images it is receiving and has the ability to detect very small differences in the picture such as orientation, shadow and size. The infrared model received the lowest score in this area as the detection of the LED's attached to the subject will not give nearly as accurate of results compared to the other models. It cannot detect changes on as small of scale and also requires the most amount of objects to be attached to the test subject.

The next category to be analyzed, cost, received a ranking proportional to 18% of the total. Cost is a necessary part of the design as the clients have requested to keep the cost as minimal as possible. We have been given a budget of $500 and all of the designs should stay well within this range, leading to its average power ranking. The accelerometer received the highest score for the cost category of 18 as the accelerometer and other necessary components will be very inexpensive. The optical and infrared designs both received very similar rankings for the cost. They are slightly more expensive than the accelerometer design and therefore received slightly lower scores. The optical design requires more parts and setup and therefore received a 14 while the infrared scored

15. Figure 13 illustrates the point breakdown for each design in the cost, MRI compatibility, and programmability.

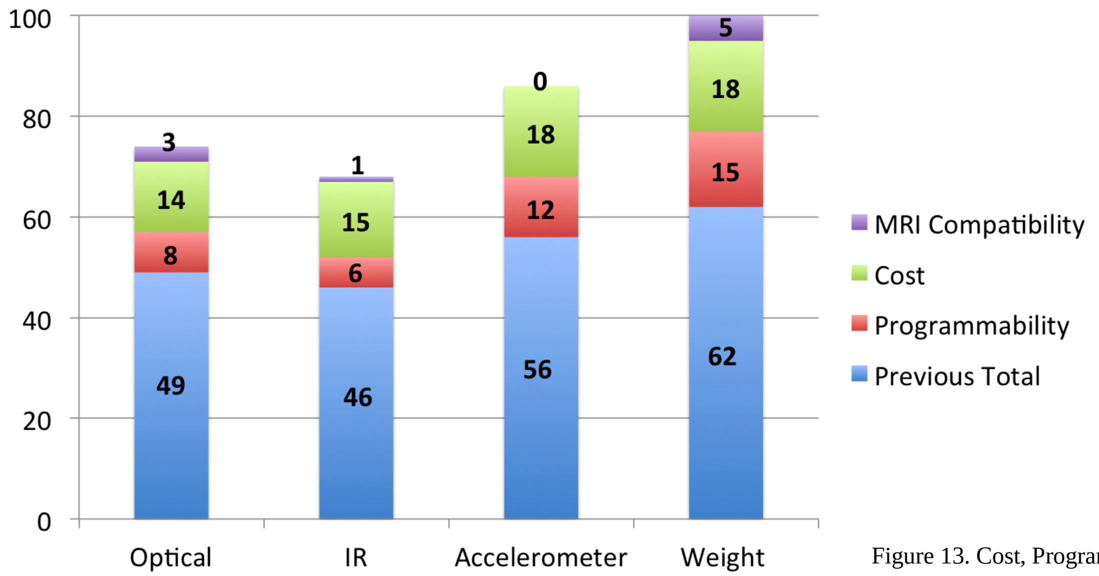

Figure 13. Cost, Programmability, and MRI compatibility of the device.

MRI compatibility is another area that was examined for each of the designs, yet it only received a ranking of 5% of the total available points. It received such a small ranking due to the fact that our client has not included it in the design requirements. The device we will produce will only be used in an MRI simulator and not an actual MRI device, but it would be beneficial to have the ability to use it in the actual machines. This led to its inclusion in the design matrix with its very small value. The accelerometer received a rank of 0 as there are many ferrous components to the device that prevent it from ever becoming MRI compatible. The infrared design received a score of 1 as if LED's can be produced using non-ferrous material it might be possible to manufacture a design that is MRI compatible. The optical design received a score of 3 as the cameras will be placed outside the actual MRI and look into the tube through a series of mirrors.

The fact that it is removed from the actual imaging tube gives it the opportunity to function without interfering with the imaging equipment.

The programmability of the devices was the last section that came under scrutiny for our design. This area was weighted for 15% of our total points available. The accelerometer will be the easiest design to work with and received a value of 12 as it utilizes a microcontroller and digital or analog input that could easily be interpreted and converted into a useful output. The optical system received a ranking of 8 as it would come with the necessary software for reading the input from the device. The software language would have to be manipulated with thresholds and recoding to help it perform the necessary functions. The infrared design received the lowest value of 6 as there would be extensive coding and programming necessary to interpret the input from all three LED's. The input from all three units would have to be combined and used as a whole to determine the orientation and movement of the individual.

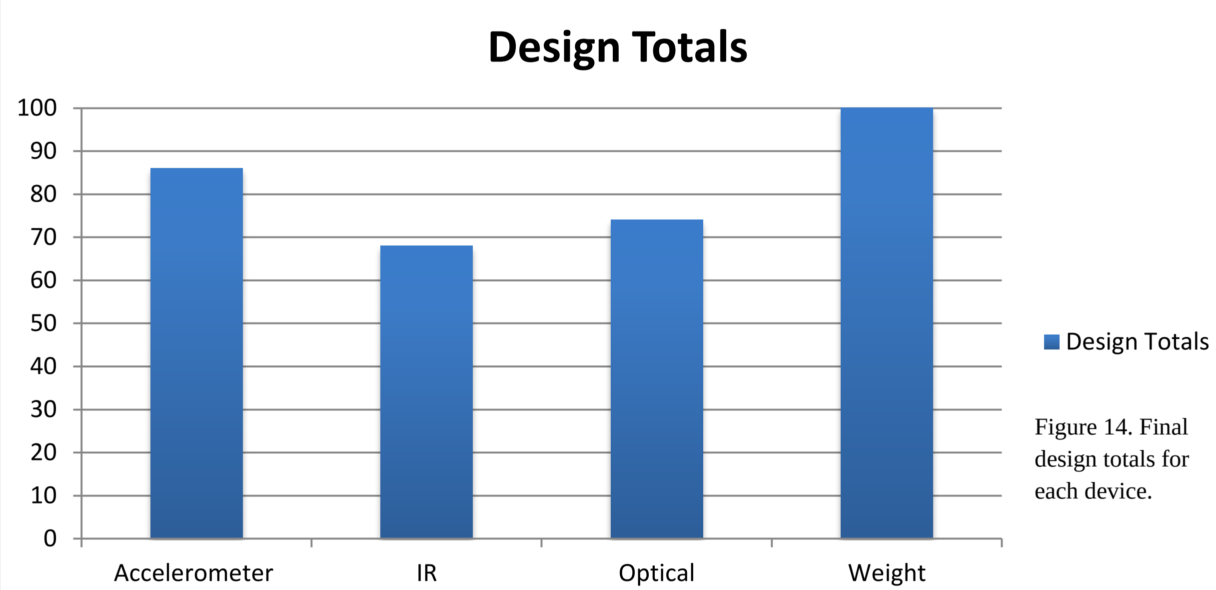

Figure 14. Final design totals for each device.

FINAL DESIGN

After the design matrix was completed the points each design had accrued were totaled. The accelerometer was the clear winner of the process with the optical and infrared designs scoring relatively close to each other. Each design had desirable attributes but the accelerometer scored the highest in important areas such as cost, size, and accuracy/sensitivity that were worth a majority of the total points. However, after further considerations the accelerometer was not used for the final design. The team decided to go with an option that was not previously thought of for the design matrix, an inclinometer. The inclinometer will easily fit in the space available without using mirrors, the parts necessary to complete the design easily fit into the proposed budget, and it requires very little programming and will therefore fit our ease of manufacturing category. As it is a two-axial inclinometer it will only detect movement in the X and Y planes but this was deemed acceptable, as subject movement perfectly in the Z plane will be greatly restricted by the MRI simulator bed and supports. A single LED patient feedback stimulus has been implemented that lights up when the subject moves beyond a degree of tilt beyond the average of the previous 10 readings. This design accommodates all of the client's requirements and solves the problem presented to us. The final design can be seen in Figure 15.

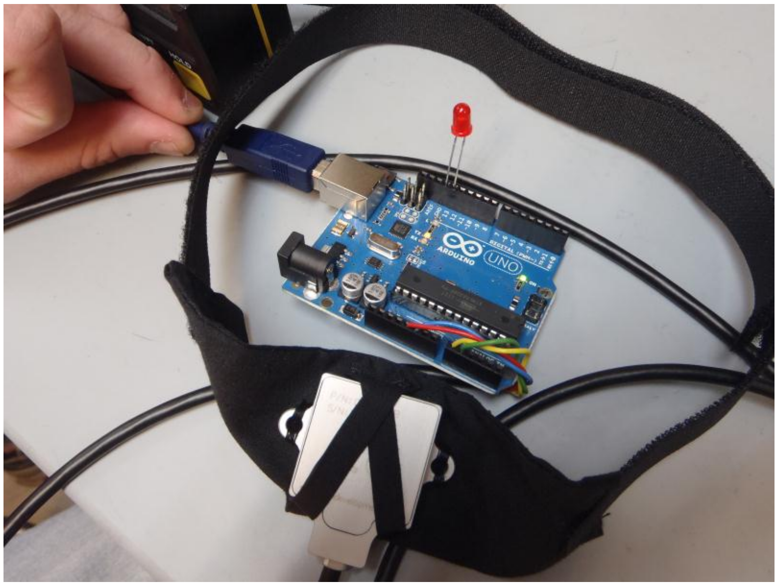

Figure 15: Final design, including: Arduino microcontroller, inclinometer, and headband.

BUDGET

Since the only current commercially available device is $8,000 and well out of the client's budget, any reduction of this cost would be greatly appreciated. Initially a flexible budget of $500 was given to the team with the willingness to pay up to $1,000 for design components of superior quality. Additionally, the client strongly emphasized that the primary use of the system will be for training in the MRI simulator only, allowing the team to purchase relatively cheap components. Total, the final design cost approximately $170. Majority of this cost came from the inclinometer, which cost about $150. The Arduino microcontroller selected cost $17. The headband was made from extra fabric and Velcro and therefore was a no cost item. The LED used for subject feedback was also a no cost item as an extra one from was given to the team from the electronics lab. A computer is needed to power and adjust the threshold setting of the feedback system. The programming language necessary for the microcontroller is a free download, and thus another no cost item. There is currently a computer stationed in the lab with the MRI simulator and therefore the cost of the computer was not figured into the budget for this project.

FABRICATION

The sensor we selected to use for our final design was an inclinometer, particularly the SCA121T-D05 Dual Axis Inclinometer. An inclinometer is a device used for measuring angles or tilt of an object with respect to gravity. The sensor is only able to detect two degrees of motion

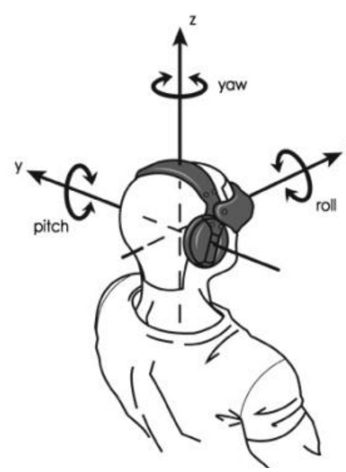

Figure 16 – Layout of the six degrees of freedom [http://electronics.howstuffworks.com/gadgets/other-gadgets/VR-gear.htm].

instead of the six degrees our client required; however, the major motion that a patient in the MRI simulator will be able to do is in the yaw and pitch directions as seen in Figure 16. This is because the patients head will be placed in a U-shaped mock head coil as pictured here in Figure 17. So the motion that can occur is nodding, movement in pitch, or shaking side to side, movement in yaw. Translational motion in the X, Y or Z direction is very restricted and would need to occur perfectly about one of the axes without the motion be detecting by the inclinometer. Also, perfect rolling head motion can rarely occur without some yaw or pitch motion occurring as well; therefore, the dual axis inclinometer will be able to detect most of the motion that is occurring and should be sufficient to meet our client needs.

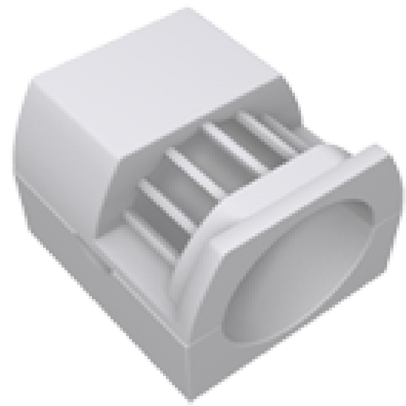

Figure 17 – GE style mock head coil for MRI simulator [http://www.pstnet.com/software.cfm?ID=96].

In order for the inclinometer to detect motion in the yaw and pitch, the sensor must be able to be placed flat on the forehead of a patient in Figure 18’s layout. To get the inclinometer in this positioning a head strap that the inclinometer can be securely attached to must be fabricated. This was done by sewing the inclinometer to a piece of fabric that consists of Velcro straps. The Velcro straps allows for head strap to be adjusted to various patients head sizes. It also

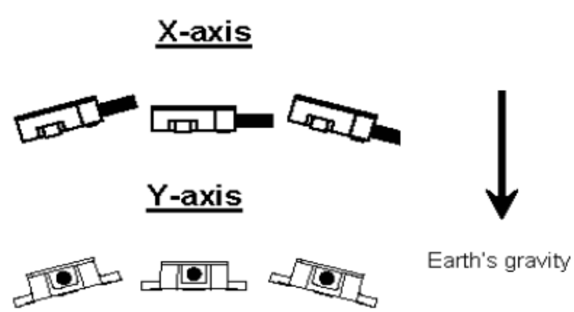

Figure 18 – Layout of inclinometer that will allow for detecting angular positioning in of yaw (Y-axis) and pitch (X-axis) [http://www.vti.fi/sites/default/files/documents/sca121t_inclinometer_datasheet_82127400a.pdf].

creates a secure tight fit to the patients' forehead leading to accurate angular positioning readings. This created head strap can be seen in the final design figure.

For the dual axis inclinometer to function and detect if motion is occurring above a threshold, an Arduino microcontroller to perform data processing is needed. The Arduino microcontroller also powers the inclinometer by the plugging the red wire into the 5 Volt pin and the blue wire into a ground pin. The inclinometer then sends two analog outputs to the Arduino via the yellow and green wires. The X-axis or pitch output is in the yellow wire and the green wire is the Y-axis or yaw output. These outputs are sampled by the Arduino program at a rate of 100 Hz. For theses outputs to become useable, an equation is necessary to convert this analog output to an angular positioning. This equation was given on the inclinometer data sheet to be $\propto = \frac{Vout - Offset}{Senstivity}$, where Vout is the current voltage output, offset is the voltage output when the inclinometer is at zero degrees and the sensitivity is a constant of 35 milliVolts/degree [16].

With this equation able to convert outputs to angular positioning in the Arduino program, the program then needs to be able to determine if motion greater than the threshold of 1° has occurred. To do this, the program needs to have a reference points to compare the current values to. The references values is a running averages of the previous ten sensor reading values. The program keeps two different averages for both the X and Y axis angles. It is important to use running averages rather than constant calibration values for this program for several reasons. The first is that this allows the program to calibrate quickly to different patients. The next is that small movement under the threshold can occur. If the new head positioning is not update, more small movement can occur to cause the threshold to be reached when it shouldn't have been. This causes a false negative reading to occur. Lastly, if movement above the threshold does occur, the patient should remain at the position they moved to instead of causes more movement to occur by shifting back to the original location. Therefore, the running averages are needed to update to the new position once movement has ceased.

The Arduino program sends feedback to the patient by a Light Emitting Diode, LED, lighting up when the current angle position in either the X or Y axis is a greater or less than a threshold from the average X and Y angles. This is determined by the program using a formula of the absolute value of current angle minus average angle. If that value is greater than the threshold value, then too large of movement has occurred. This causes the LED to turn and remain on until the formula falls back below the threshold. As was stated earlier, the threshold for patient feedback to occur is 1°. This is because movement of this magnitude can cause MRI image distortion. The code for this whole design to work can be found in the Appendix. To verify this design is working correctly and accurately determining the angles, testing of the system must be preformed.

TESTING

As required by the client, the device was to have accuracy to 0.1 degrees in both the x and y-directions. To test for this, we used a SmartTool digital angle finder, quarters, and the device and its corresponding Arduino software. The device and the angle finder were secured together using the Velcro strap holding the inclinometer. Then after determining the reference angles of both the device and the angle finder, the angle was changed by using quarters to raise the device at equal increments. The difference between the raised angle and the reference angle were then record for the device and the angle finder. Each angle recorded was test independently three times and the average was recorded to be used in analysis. Figure 19 shows the testing setup.

Figure 19: Accuracy testing set up.

Figure 20: Default angle testing set up

The range for each direction was determined by placing the device on a subject's forehead while lying flat on the floor, as shown in Figure 20. The default angle for the x-direction was between 5 and 10 degrees, depending on the subject, and the default angle for the y-direction was 0 degrees. Therefore, using these default angles, the testing range for the x-direction was determined to be -5 to 25 degrees, and the testing range for the y-direction was determined to be -15 to 15 degrees. Figure 21 shows the comparison of the device angle reading to the digital angle finder reading in the x-direction. Figure 22 shows the comparison of the device angle reading to the digital angle finder reading in the y-direction.

In the x-direction, the deviation at any angle along the range of use of the device was found to be 0.096 degrees. In the y-direction, the deviation at any angle along the range of use of the device was found to be 0.097 degrees. Both of these deviations are within the criteria laid out by the client. Additionally, the device was found to be equally as accurate at all angles tested.

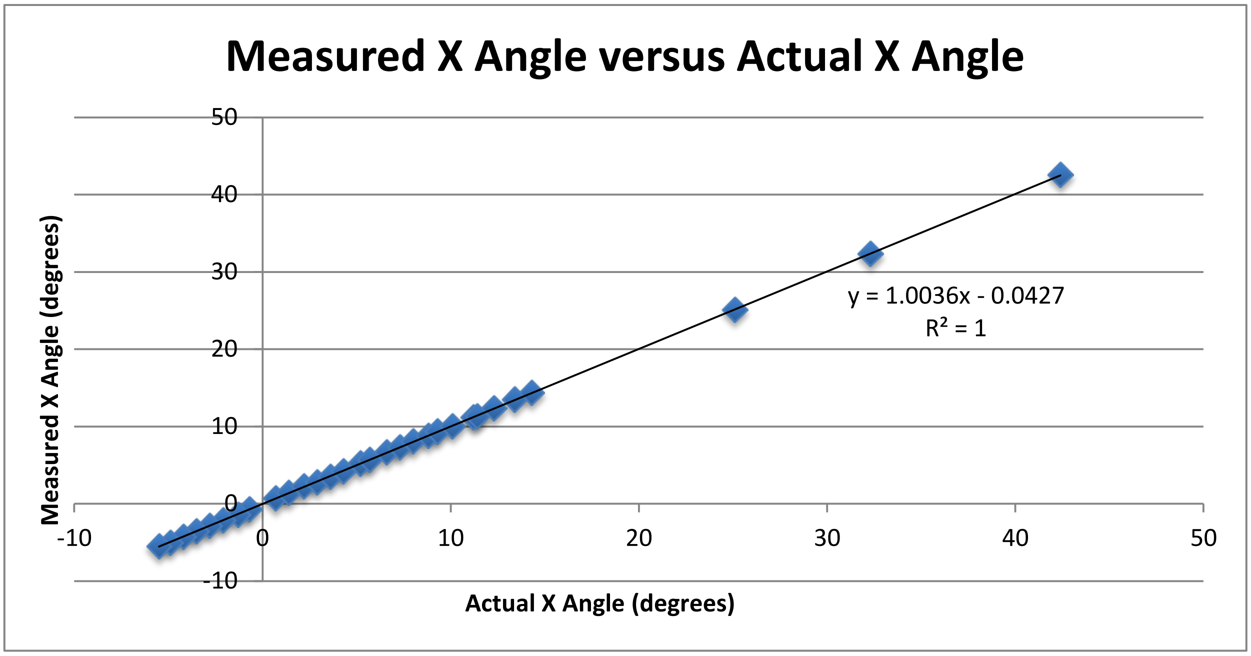

Figure 21: Comparison of device angle reading to digital angle reading in the x-direction.

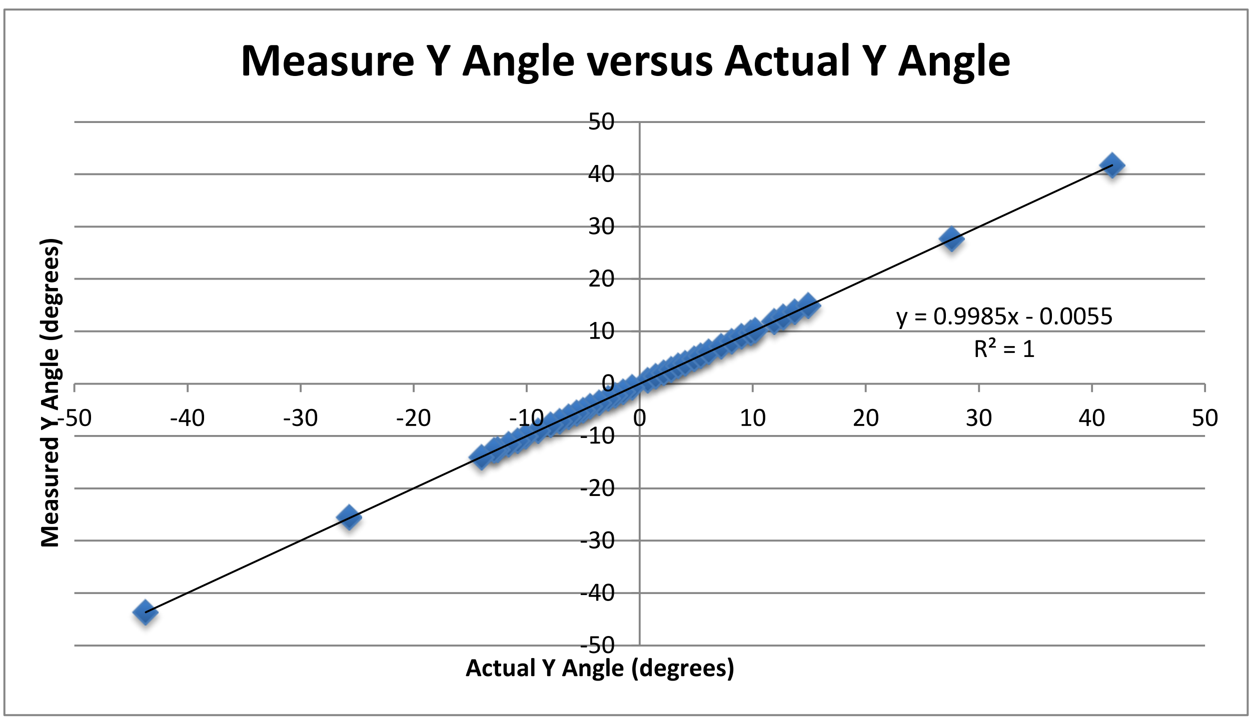

Figure 22: Comparison of device angle reading to digital angle reading in the y-direction.

Ethical Considerations

Since part of the system will be in contact with the subject in the MRI simulator, the device will need to be safe for the subject. The method of attachment to the subject must be comfortable when worn for a significant amount of time. Lastly, the device will not need to be tested using human subjects and therefore the team does not need to be certified for human subjects testing.

Future Work

While the system can be used to accurately detect motion and provide the subject with feedback, a few areas could be improved to make the design even more user-friendly. Although the dual axis inclinometer will detect majority of the subject's head motion, it would be even better in a tri-axial sensor is used. An accelerometer would accomplish this, but this would come with a number of programming changes that would need to be made. Additionally, a graphical interface for the researcher would make the system easier to read. This would provide the researcher with information on how much the subject is moving and when. Lastly, the subject feedback system should be upgraded to turn off a video feed when the subject's head movement exceeds the threshold as opposed to simply turning on an LED. This would provide more incentive for the children to stay focused on their program and remain still.

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APPENDIX A: PRODUCT DESIGN SPECIFICATIONS

Device for tracking head motion in an MRI simulator

May 1st, 2012

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Problem Statement

The goal of this project is to design and build a system to track a subject's head motion in an MRI simulator and link this to a video display. When the subject moves his/her head, a displayed video (movie) is turned off; when the subject stops moving his/her head, the video resumes. Our goal is to use this device to train children to keep their head still when undergoing an MRI scan. Ideally, this device and software should be user-friendly. The system should be capable of detecting at least 0.2mm and 0.2 degree head motion at 30 Hz or better. The subject will be lying in a simulated MRI scanner, so access to the subject is somewhat spatially limited.

Client Requirements

- Have the ability to detect movement in 6 degrees of freedom
- Fit into the MRI simulator, approximately 4 cm size restrictions
- If the project does eventually end up being used in an actual MRI scanner non-ferrous materials must be used
- Accuracy of detection as small as 0.1 mm or a tenth of a degree of rotation
- Feedback to the patient so they can tell when they are moving and need to stay still

Design Requirements

1. Physical and Operational Characteristics

   a. Performance Requirements: Device should be capable of withstanding repeated use without breaking, It needs to fit with the patient inside the MRI scanning simulator.

   b. Safety: The device will be used on human subjects so precautions must be taken to ensure nobody is harmed from using the device. Also it must not interfere with other medical equipment or devices that are to be used in conjunction with it.

c. Accuracy and Reliability: A high level of accuracy is required from the design as very slight movements on the part of the subject can greatly alter the image the MRI is producing. Movement detection should be as precise as 0.1 mm or one tenth of a degree of head rotation.

d. Life in Service: The device should be able to withstand repetitive use and last for an extended period of time while still operating correctly. It should last for thousands of uses if necessary.

e. Shelf Life: The shelf life of the system should be an indefinite amount of time. All components should maintain working order with minimal component replacement.

f. Operating Environment: The device will be placed on the exterior of the patient’s body. It will be used indoors in a stable environment. There should be very little human contact to cut down on possible breakage of the device or its components.

g. Ergonomics: The device should experience very little human contact; only minimal forces should be applied for slight adjustments for positioning.

h. Size: The device needs to be able to fit inside the MRI simulator along with the human test subject. Only the sensor that must be attached or removed from the subject must be mobile but will remain within close proximity to the simulator.

i. Weight: The total device should not exceed 20 kg. The sensor or the part of the design that is placed on the human subject should be less than 2 kg.

j. Materials: The materials used in the design that come into human contact must be hypoallergenic.

k. Aesthetics, Appearance, and Finish: Functionality is more important than appearance in this project. If the device works correctly the appearance of the device should be made as professional as possible.

2. Production Characteristics

a. Quantity: Only one device is needed at this time.

b. Target Product Cost: Target cost is approximately $500. This is flexible based on necessary components.

3. Miscellaneous

a. Standards and Specifications: Device must comply with OSHA regulations.

b. Customer: Client prefers that current MRI simulator set up remain unaltered, however nonessential components can be altered if necessary.

c. Patient-related concerns: The sensor must be easily sterilized and should be comfortable during extended use of the system. All materials used must be hypoallergenic.

d. Competition: There currently exists a head tracking device (MoTrak) used in MRI simulators made by Psychology Software Tools, Inc.

APPENDIX B: ARDUINO CODE

```
const int analogInPinX = A0; //Analog input pin x-axis
const int analogInPinY = A1; //Analog input pin y-axis
 unsigned char idx = 0; // Initializes the running average to start at 0 for X axis
 unsigned char idy =0; // Initializes the running average to start at 0 for Y axis
float xSensorValue[10]; //Stores ten previous x values
float ySensorValue[10]; //stores ten previous y values
int led=13;             // pin number for power(long) leg of LED
const int threshold=1;  // Sets the threshold to an integer of 1 degree of movement


void setup()
{
 Serial.begin(9600);
 pinMode(led,OUTPUT);
 for (int i=0; i<10;++i){
 xSensorValue[i]=analogRead(analogInPinX); //Fill array with current sensor x reading
 ySensorValue[i]=analogRead(analogInPinY); //Fill array with current sensor y reading
 delay(10);}
}

void loop()
{
 float currentXReading;
 float currentYReading;

 float avgXReading=0;
 float avgXangle=0; //Average of ten previous X angles
 float currentXangle;
 float avgYReading=0;
 float avgYangle=0; //Average of ten previous Y angles
 float currentYangle;

 //Get current readings
 currentXReading = analogRead(analogInPinX);
 currentYReading = analogRead(analogInPinY);

 //Calcuate average of last 10 readings
 for (int i=0;i<10;++i){
 avgXReading +=xSensorValue[i];
 avgYReading +=ySensorValue[i];
 }
 avgXReading = avgXReading/10;
 avgYReading = avgYReading/10;
```

```
 //Replace Oldest entry in past 10 Readings
 xSensorValue[idx]=currentXReading;
 idx=(idx+1)%10;
 ySensorValue[idy]=currentYReading;
 idy=(idy+1)%10;

 //Calculation of angles
 avgXangle = ((asin((avgXReading-(512))/407))*(180/3.14));
 currentXangle = ((asin((currentXReading-(512))/407))*(180/3.14159265));
 avgYangle = ((asin((avgYReading-(512))/408))*(180/3.14));
 currentYangle = ((asin((currentYReading-(512))/408))*(180/3.14159265));

 Serial.print("avg X Angle ="); Serial.print(avgXangle);Serial.print(" X current
=");Serial.print(currentXangle);  //Print values to serial moniter
 Serial.print("  avg Y Angle ="); Serial.print(avgYangle);Serial.print(" Y current
=");Serial.println(currentYangle); //Print values to serial moniter

 //Turn LED ON if angle difference is greater than 1
 if ((abs(currentXangle-avgXangle))>threshold){

 digitalWrite(led,HIGH);}
 else if ((abs(currentYangle-avgYangle))>threshold){

  digitalWrite(led,HIGH);}
   else {digitalWrite(led,LOW);  //Turns LED off when the difference between the current
reading and running total is less than 1
 }


 delay(10); //Delay 10 milliseconds between readings
}
```