User Studies

There was a series of user studies designed for this thesis, at different levels of complexity and completion. Early in the process, I realized it would be advantageous to quickly iterate through different setups while trying to understand and discern the key concepts that would make up the design tree for Digital Synesthesia. The iterations would concentrate on testing different ways of conveying the data to the body I call this Testing the Feedback. Another variable for the studies was the type of signal I wanted to detect. Lastly, every test would change the amount of contextual information the user would have about the test.

Testing the Feedback

The studies were created in order to test the best pairing of sensed data and feedback to be felt by the body. I wanted to test temperature, sound and vibration as feedback so three setups were created. The transducer can be used for either vibration or sound depending on where on the body it is located, on study used vibration to represent data from a proximity sensor worn by the subject in the palm, the transducer was placed in the thumb of the same hand. Sound was used to translate data from a temperature sensor and this was used in two user studies, the sensor was worn on the forehead looking outwards and the transducer was behind the sensor and against the forehead. Temperature as feedback was used in one study, the peltier device was worn in the nape and it responded to the location signal of the glass infrastructure around the Media Lab.

Testing the Signals

I tried to find different types of signals to carry out the studies. The first distinction in the type of signals was either analog or binary. I chose as a binary signal a location based experience where the user would sense a feedback every time they walked in front of one of many screens at the lab that can recognize people via RFID. The analog signals I used were given by a proximity sensor and an IR sensor; these signals would slowly ramp up or down depending on the behavior of the user.

Changing the Contextual Information

Lastly, the final variable was the amount of contextual information given to the subject. By contextual information I mean the knowledge that the subject could have about how the sensor, actuator and activity worked. A study with a lot of contextual information was done with a proximity sensor and an actuator worn in the hand. During this test, the user was told how the system worked, they could see were the sensor and the actuator were located on their bodies, they could assess their performance on the test by taking off a blindfold and looking at the correct answer and they were told other details like the sensitivity level to be used and the group of correct choices from which to venture a guess. All of these details amount to contextual information that helps the user understand their artificial sensory experience.

A test with very little contextual information was done where the examiner would only have to make sure that the user felt the actuator feedback and would give no more information to the user. The user then had fifteen minutes to explore and determine what the artificial sense was responding to.

Summary of User Studies

Study	Type of Feedback	Type of Signal	Contextual Info.
Proximity	Vibration on the thumb	Analog	High
Temperature	Sound through bone conduction	Analog	Medium
Cell Sensors	Sound through bone conduction	Analog	Low
The Foodcam	Smell	Binary	High
Stress	Sound through bone conduction	Analog	Medium
Location	Temperature on the back of the neck	Binary	Medium

USER STUDIES (THE SUCCESSFUL ONES)

Sensory substitution studies have proven that the brain is capable of interpreting data from one sensory input that is responding to another sensory input[26]. I am interested in understanding how not only the brain but the user is able to use these new sensory experiences in daily life. The distinction between brain and user implies that the user is also aware of what all the other senses are saying and of the previous knowledge around their present state and situation. Digital Synesthesia uses the power of the brain not to understand an isolated input but to interpret the aggregate of information of which one part is the artificial sense. If we allow the brain to understand an input in relation to the position of the sensor in the body, the position of the body itself, the speed at which the user is moving, what other conditions are being sensed by the body and what the user knows of the context in which they are, the experience with an artificial sense will be rich, easy to understand and immediately applicable in the users activity.

The user studies were based on a very simple haptic feedback, a vibration that would change its frequency according to the data received by the sensor. The idea was to give the user a minimal amount of data that came directly form a sensor with minimum processing, hoping that the user would be able to discern noise from signal and be able to understand the signal within the experience.

To this end, the 3 user studies used a feedback signal with only one affordance, frequency, and gradually took away the contextual cues in order to create a more isolated experience that the user would have to navigate through.

Proximity to Vibration

This study used “proximity” as the artificial sense. The test was designed to be redundant to vision. This means that the subject was able to corroborate through vision what they were feeling through the artificial sense.

Preparation

The system would randomly pick which hand was to be used by the subject. Then the subject would wear an ultrasonic sensor on the palm, of the selected hand, and a transducer on the thumb of the same hand.

Hardware

The system for the first stage and first user study implemented an Ultrasonic Range Finder LV-MaxSonar-EZ0 that interfaced with a IOIO OTG board through the analog interface. Both the sensor and the IOIO Board where worn by the subject. A two finger wood ring was made so that the sensor could be attached and the subject had a good enough understanding of the direction the sensor was facing, by moving the middle fingers. Different sizes were made to accommodate different users and give all the users the same amount of control over the sensor. The IOIO Board was inside a fabric wristband that also housed the 9V battery for power. The IOIO was connected via USB to the Android device, in this case a Sony Table S. The output of the IOIO was fed to the transducer that was attached to the thumb of the same hand that had the sensor.

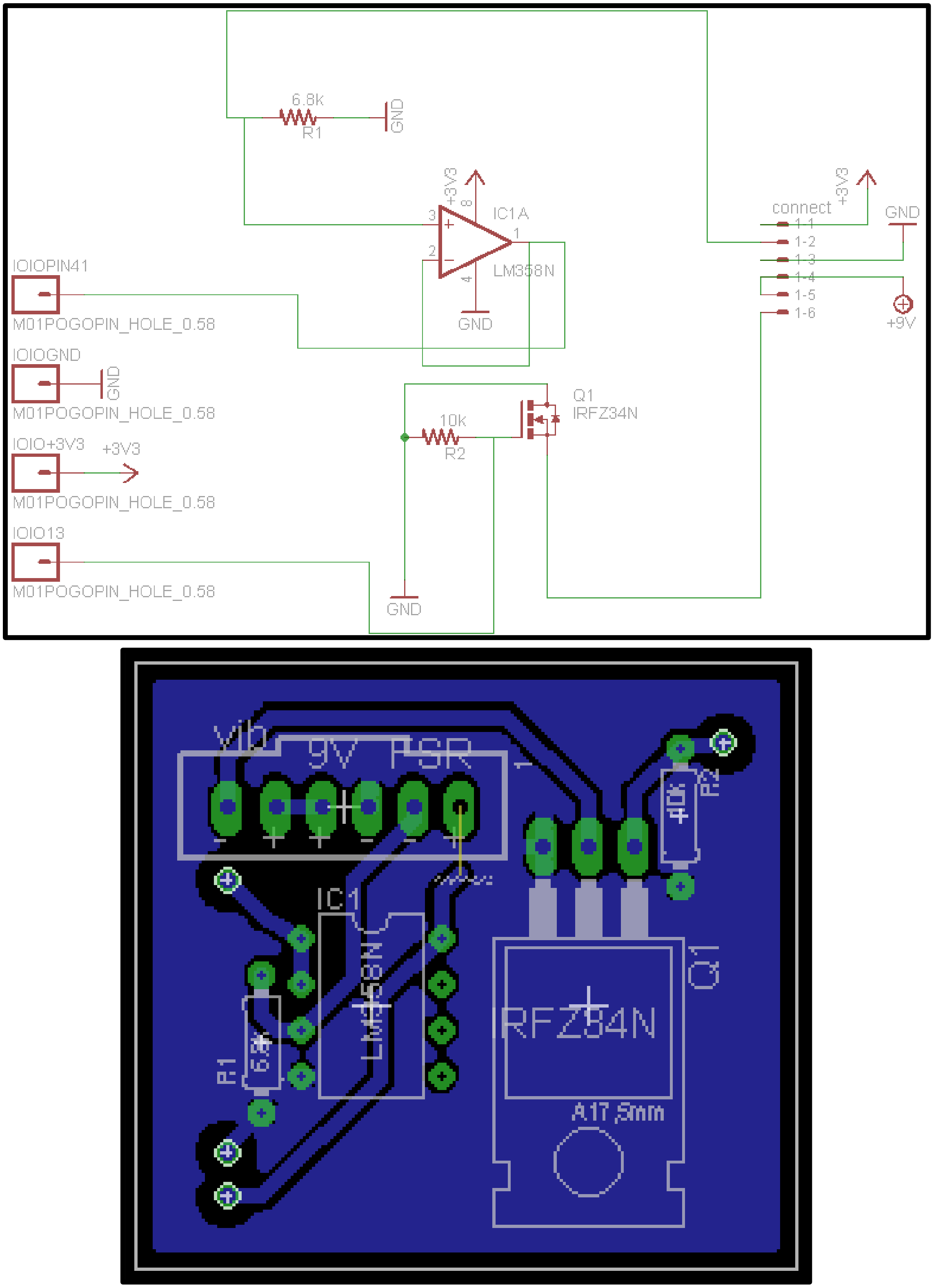
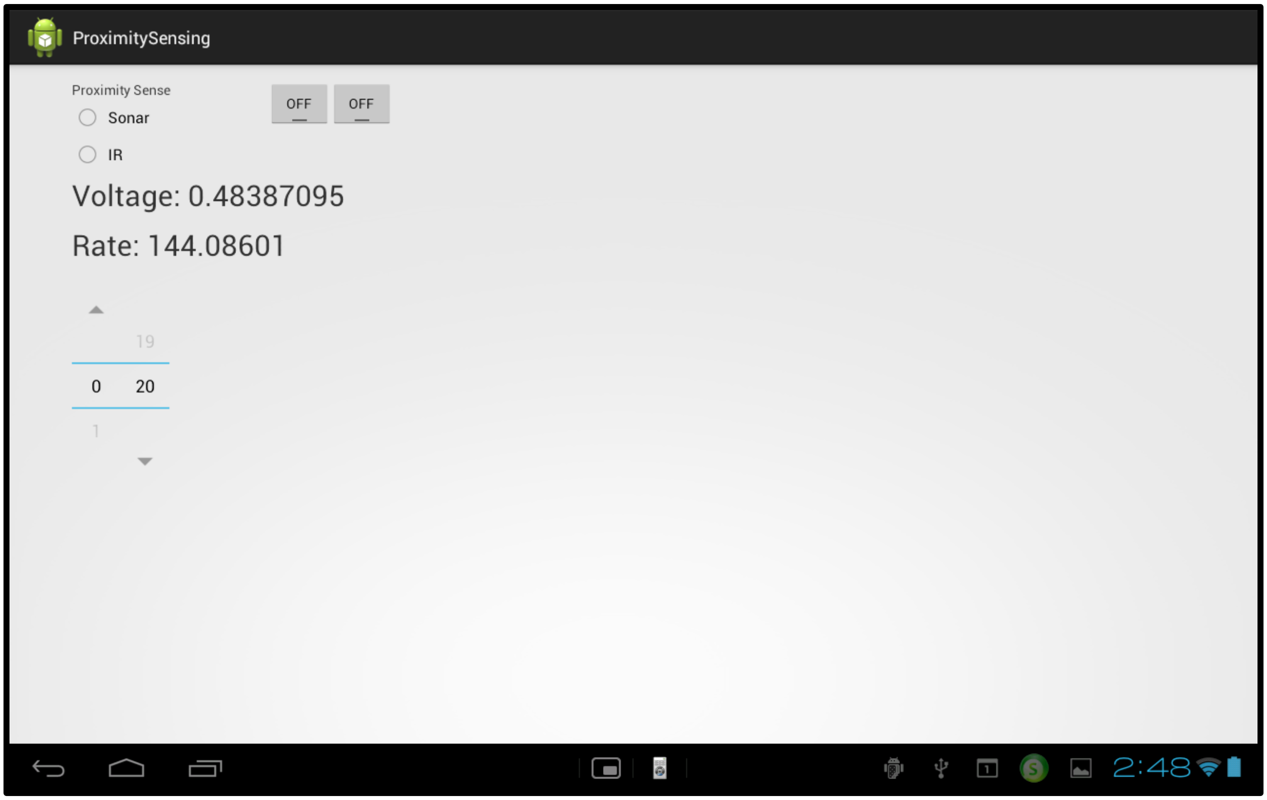


FIGURE 1 – SCHEMATIC AND BOARD

SOFTWARE

The software side for this study was written to be used only by the examiner. In it they were able to see the numerical value coming from the sensor and the resulting frequency of the transducer after being mapped. Two number pickers gave the ability to change the sensitivity of the artificial sense.



TEST PROCEDURE

This test was divided in three phases; each phase would follow a similar structure. The subject would wear a blindfold and asked to identify object on the table. In all phases the subject was given two minutes to try to guess. At the end of the two minutes the subject had the choice of venturing and answer or using 2 more minutes.

FIGURE 2 SUBJECT DURING PHASE ONE

PHASE ONE

On phase one I used flat rectangular wooden pieces of 2” by 12” that were placed on the table in front of the subject. The subject’s task was to try to identify how many objects there were. The computer would choose at random any number from 0 to 3 objects that the examiner would place. This exercise was done 4 times while varying the height of the objects and the sensitivity level that was controlled by the examiner. After each try, the subject was allowed to take off the blindfold and compare their answer to the actual number of objects. The iterations were as follows:

First try. Random number of objects, at 2” tall from the table and a sensitivity of 10.

Second try. Random number of objects, at 2” tall from the table and a sensitivity of 5.

Third try. Random number of objects, at 1” tall from the table and a sensitivity of 10.

Fourth try. Random number of objects, at 1” tall from the table and a sensitivity of 5.

FIGURE 3 ONE, TWO AND THREE BARS

The sensitivity values were decided ahead of time and kept the same through the whole study for all users. The values were chosen by finding a mapping that would demonstrate the usefulness of having different sensitivity while demonstrating the balance between sensitivity and noise. With a low level of sensitivity (sensitivity 10) the subject could only feel small changes in the vibration frequency, with High sensitivity (sensitivity 5) the changes were more noticeable but the noise would also be more noticeable. The noise came from the sensor as well as from the stability of the subject's hand.

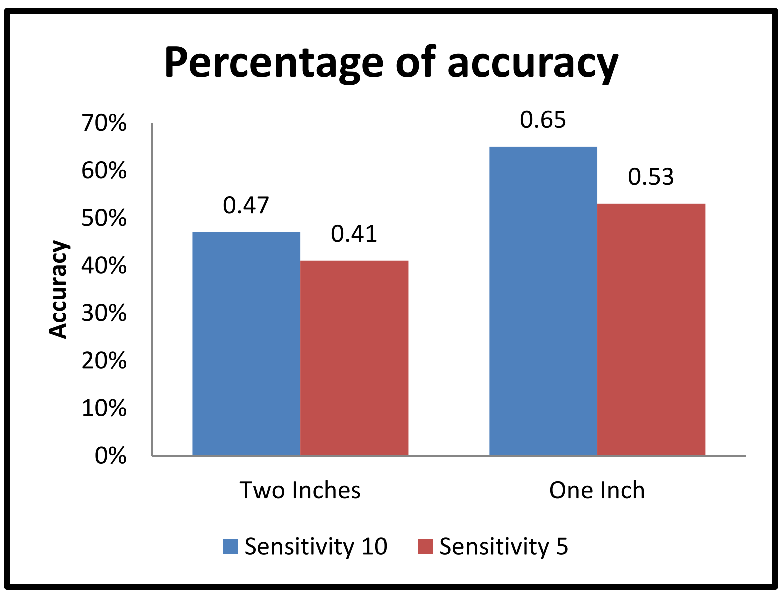


FIGURE 4 ACCURACY ON PHASE ONE

Phase One Results

The results in Table 1 show that the subjects were close to 50 percent accuracy. This was encouraging since it was well above a random distribution that would be close to 25 percent given that the users had one of four choices to make. Table 1 shows the results of phase one.

Totaling the correct answers of phase one in the four tries and ignoring the height and sensitivity difference, we have a total (n) of 68 tries; the result gives a percentage of accuracy of 51%. When we compare this percentage to a random control group of 25% because of having to choose among 4 possible answers, we get a confidence value of $p<0.002$.

Phase One Evaluation

In this first phase the subject needed to only move their hand from side to side in the X axis and up and down in the Z axis (Figure 7). Up and down would allow them to control the base line frequency they were comfortable with while scanning on the horizontal axis.

The users had no experience with this artificial sense except for a five to ten minute training activity in which they would see how the frequency behaved when the hand was waved over objects of different sizes and with different sensitivity levels.

I was expecting an advantage to having a higher sensitivity setting which would be sensitivity 5 but the results show that sensitivity 10 was easier for the subjects. I believe this to be that at sensitivity 5 the experience was vulnerable to unconscious movements of the hand. Some subjects would not notice if the hand went down slowly or small jerks movements that would affect the readings. These small movements were less noticeable at sensitivity 10 which was less sensitive.

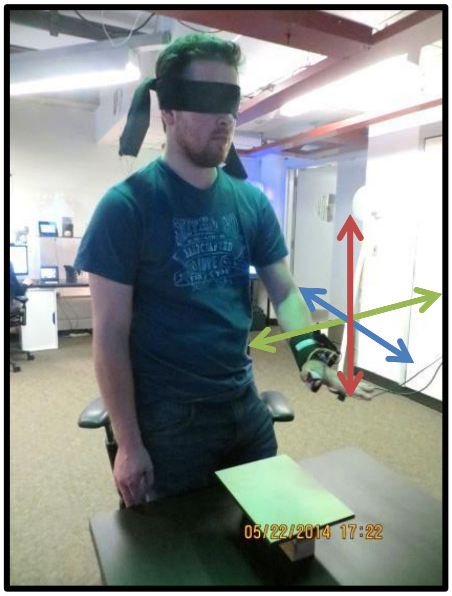


FIGURE 5 X AXIS GREEN, Y AXIS BLUE AND Z AXIS RED

The subjects demonstrated different techniques to accomplish this task. Some subjects would simply scan and try to differentiate between noise and signal but some developed more nuanced strategies such as scanning at different speeds and compare their impressions or scan a different heights and compare. Even more would focus specially on the stability and movement of the hand while others focused on the feedback, tried to get the rhythm and then detect minor changes.

FIGURE 6 DIFFERENT SHAPES FOR PHASE TWO

PHASE TWO

Phase two presented the subject with just one object. The computer would randomly choose between a circle, a rectangle or a triangle. This exercise was made 4 times as follows.

First try. Random object, at 2” tall from the table and a sensitivity of 10.

Second try. Random object, at 2” tall from the table and a sensitivity of 5.

Third try. Random object, at 2” tall from the table and a sensitivity of 10.

Fourth try. Random object, at 2” tall from the table and a sensitivity of 5.

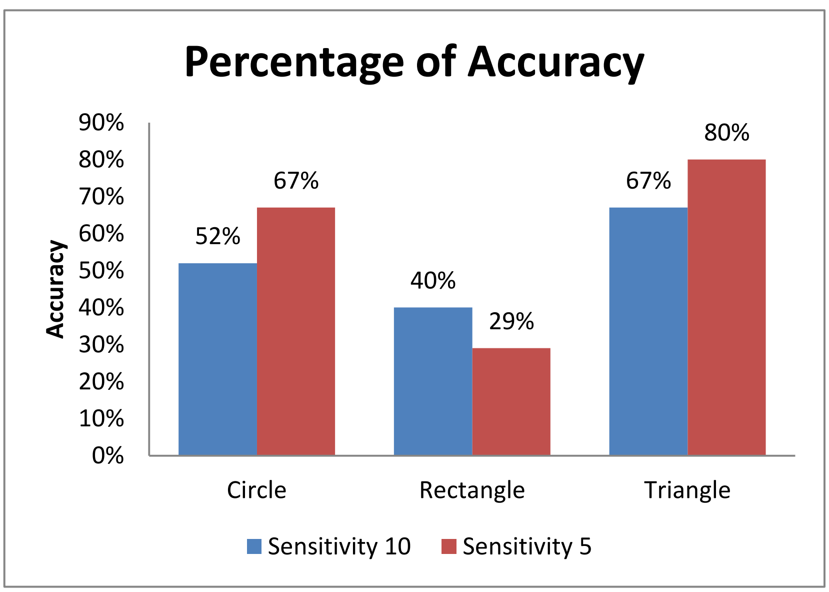


FIGURE 7 PERCENTAGE OF ACCURACY ON PHASE TWO

PHASE TWO RESULTS

Once again the results are well above random, which in this case would be 33 percent given that there were three choices to be made. The object with the largest percentage of correct answers was the triangle, while the Rectangle had the lowest. This time the most sensitive setting of 5 was more successful. Figure 9 shows the results of phase two.

Totaling the correct answers of phase two in the four tries and ignoring the sensitivity difference, we have a total (n) of 68 tries; the result gives a percentage of accuracy of 54%. When we compare this to a random result, which would be 33% because of having to choose amongst 3 possibilities, we get a confidence value of $p<0.02$.

Phase Two Evaluation

Having worked through the first phase, the subjects had a better handle on this artificial sensory experience. This exercise required the subjects to move their hand side to side and also front to back, giving them a 2D field to scan. Because of the first exercise, finding the edges was easy, their job was then to use that information to find a pattern they could compare with their mental expectation of how any of the shapes would feel.

The fact the triangle gave the best results was an interesting finding. Even though I expected this not to be the case given the familiarity of the other shapes, the triangle offers the most drastic change at the corners and made it easy to identify. The circle seems to have had an advantage when people would start inside the shape and then realize how long it took to find an edge.

Two main techniques were used successfully in this task. The most used was scanning the area on the X axis until an edge was found, then moving a bit on the Y axis and scanning again in the opposite way, much like a printer would make a line, advanced the paper and make the next line. The triangle would have a long distance between the edges at the bottom but very small distance at the top. The other technique implied searching for the first definite edge and then bouncing the hand along the edge of the object in an attempt to trace the shape and find the answer.

FIGURE 8 SHAPES FOR PHSE 3. CUBE, SPHERE AND PRISM

PHASE THREE

Phase three was about an object with three relevant dimensions. Since the first two phases had dealt with, essentially, 2D shapes. This phase presented a Cube, a Prism and a Sphere. Everything else was just like phase 2 as follows.

First try. Random object, at a sensitivity of 10.

Second try. Random object, at a sensitivity of 5.

Third try. Random object, at a sensitivity of 10.

Fourth try. Random object, at a sensitivity of 5.

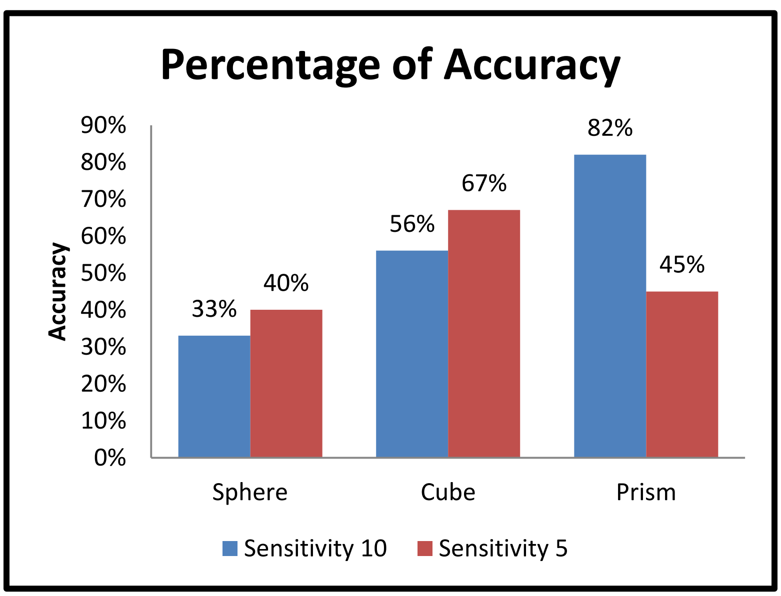


FIGURE 9 PERCENTAGE OF ACCURACY ON PHASE 3

PHASE THREE RESULTS

The sphere shows a success rate barely above random whereas the Prism shows a success rate of more than 80%. Overall the success rate for all three shapes was 55%. The results of phase three are shown in table 3.

Totaling the correct answers of phase three in the four tries and ignoring the sensitivity difference, we have a total (n) of 66 tries; the results give a percentage of accuracy of 54%. When we compare this to a random result, which would be 33% because of having to choose amongst 3 possibilities, we get a confidence value of $p<0.03$.

Phase Three Evaluation

The most surprising result in this phase was the Prism. I expected this shape to be the most unfamiliar and hence the hardest to identify. But it happened that because of the ultrasonic nature of the sensor, the behavior of the feedback was not what the subject was expecting and for that same reason it was the most recognizable once the user knew that was the prism's "signature". What happened is that as the subject approached a side of the prism, the frequency would increase as expected for this and other shapes but once the subjects hand was over the apex of the prism, the wall would not bounce the signal back to the sensor and instead of the frequency being very high, it would jump back to slow, as if there was no object at all. This was confusing the first time the subject encountered but for those that got the prism more than once, it became the easiest shape to understand.

I believe this to be the most significant result because it is the result that shows that it is through the exploration of the artificial sense that we will learn to use it, even if what we feel might seem un-intuitive, as long as it is constant it will behave as a new sense with its own intricate patterns.

Normalization of the Sensor

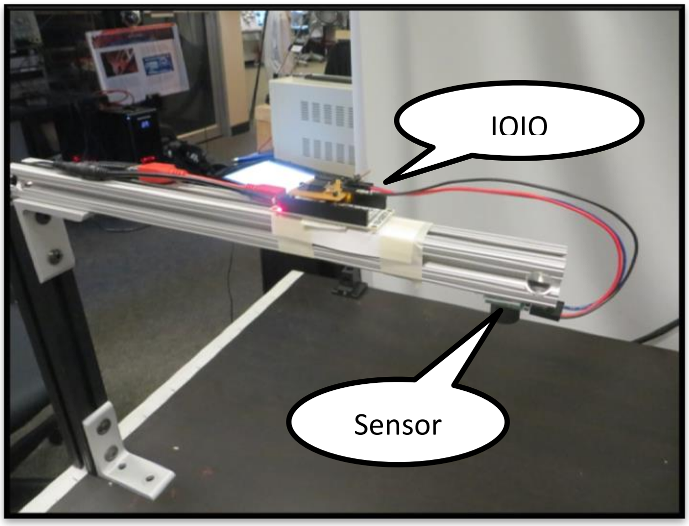


FIGURE 10

A lot of care was taken in order to get accurate raw readings from the sensor in order to determine its specific characteristics.

A rig was built to hold the sensor over the objects at a constant height and completely still.

The rig allowed for adjusting the distance of the sensor to the table and the objects to be sensed and markings on the table allowed for careful alignment of the rig along the sensing area. Ten seconds of readings were taken at twelve positions along the sensing area. The sensor readings were taken at raw, 10 and 5 sensitivity levels. The test was conducted with various objects and at two different heights from the table.

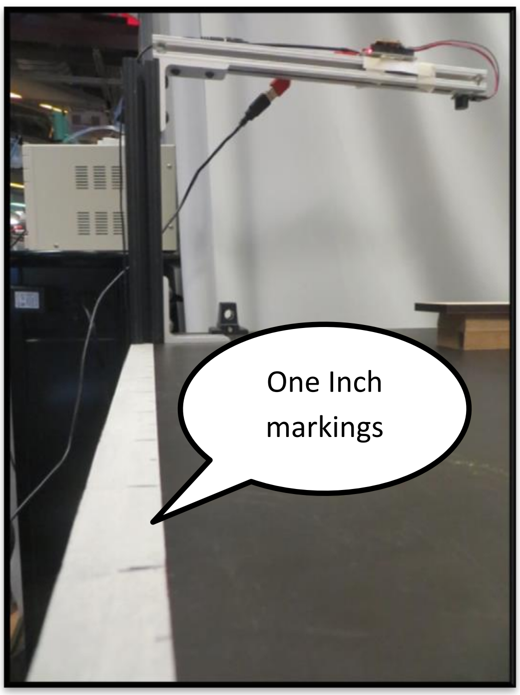


FIGURE 11

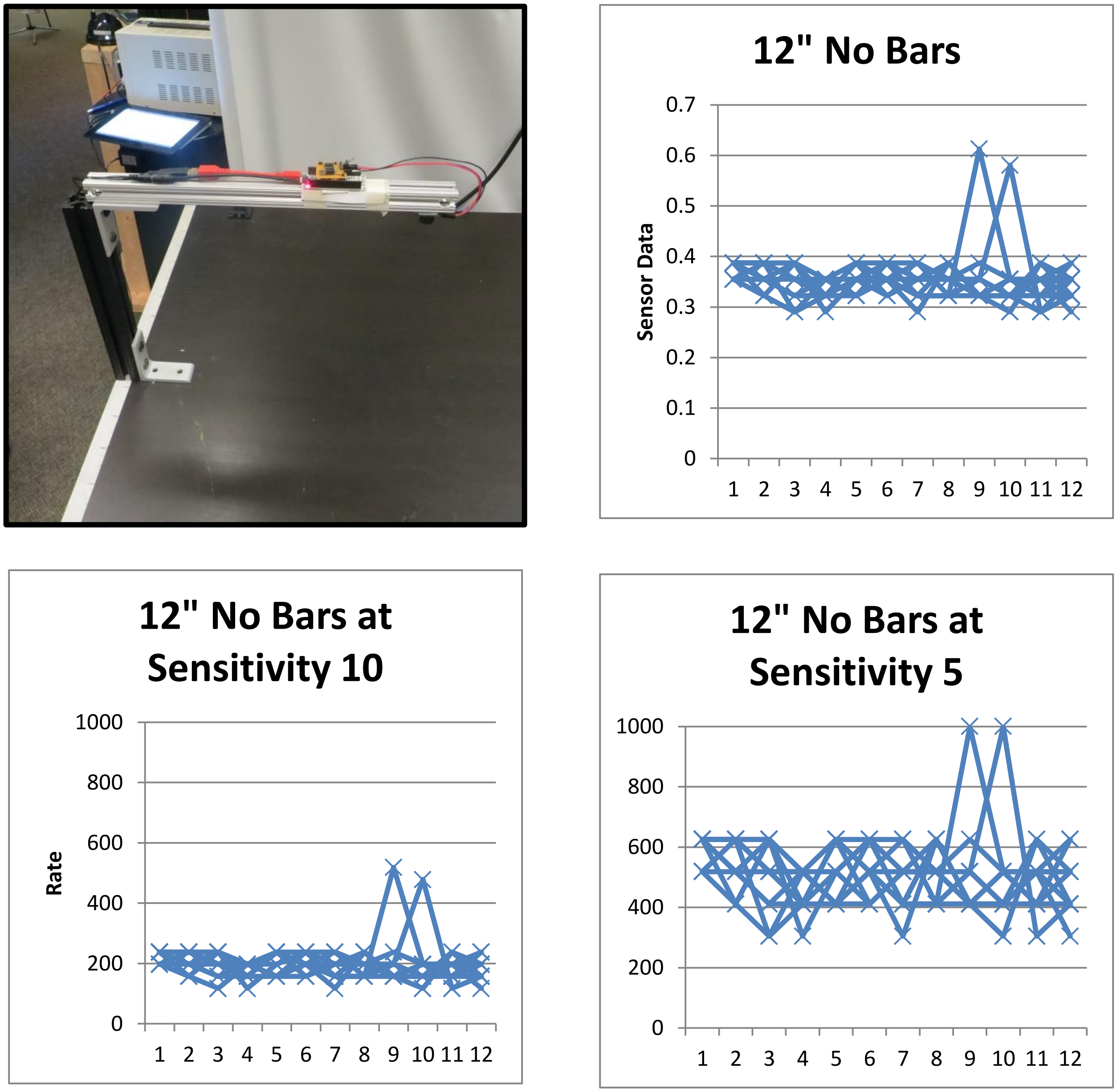


FIGURE 12– CONTROLLED MEASUREMENTS AT 12"FROM TABLE AND NO BARS

Figure 14 shows how the sensor data can be noisy at 12 inches from the table and how this noise is amplified by the sensitivity settings.

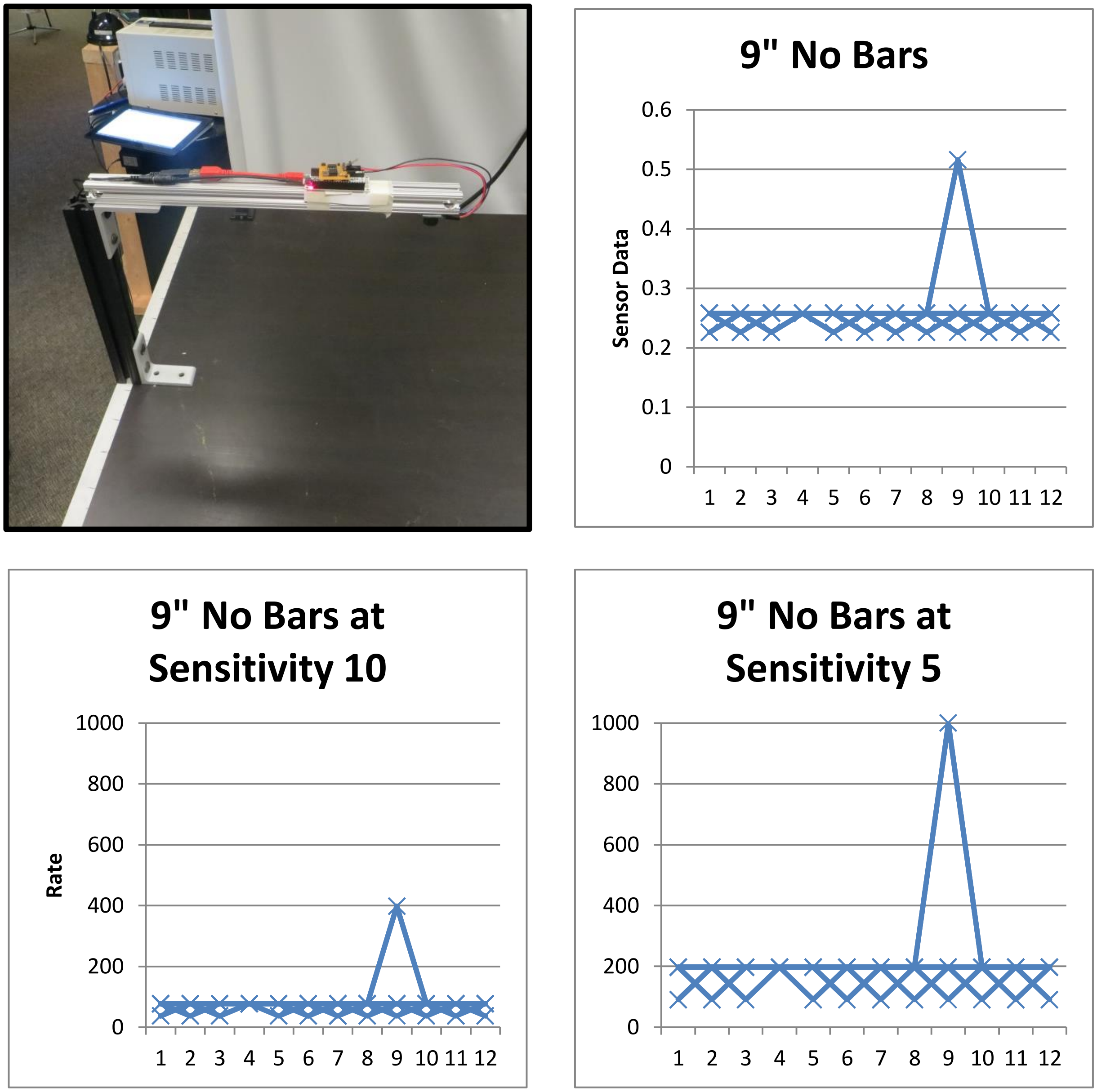


FIGURE 13 – CONTROLLED MEASUREMENTS AT 9"FROM TABLE AND NO BARS

Figure 15 shows the setup and results of the sensor when no objects were on the table. There is a spike that responds to an anomaly of the sensor data. These anomalies are what the user is learning to differentiate from the valuable signal. Compared to the 12" readings, this is a much cleaner signal that is easier for the user to perceive.

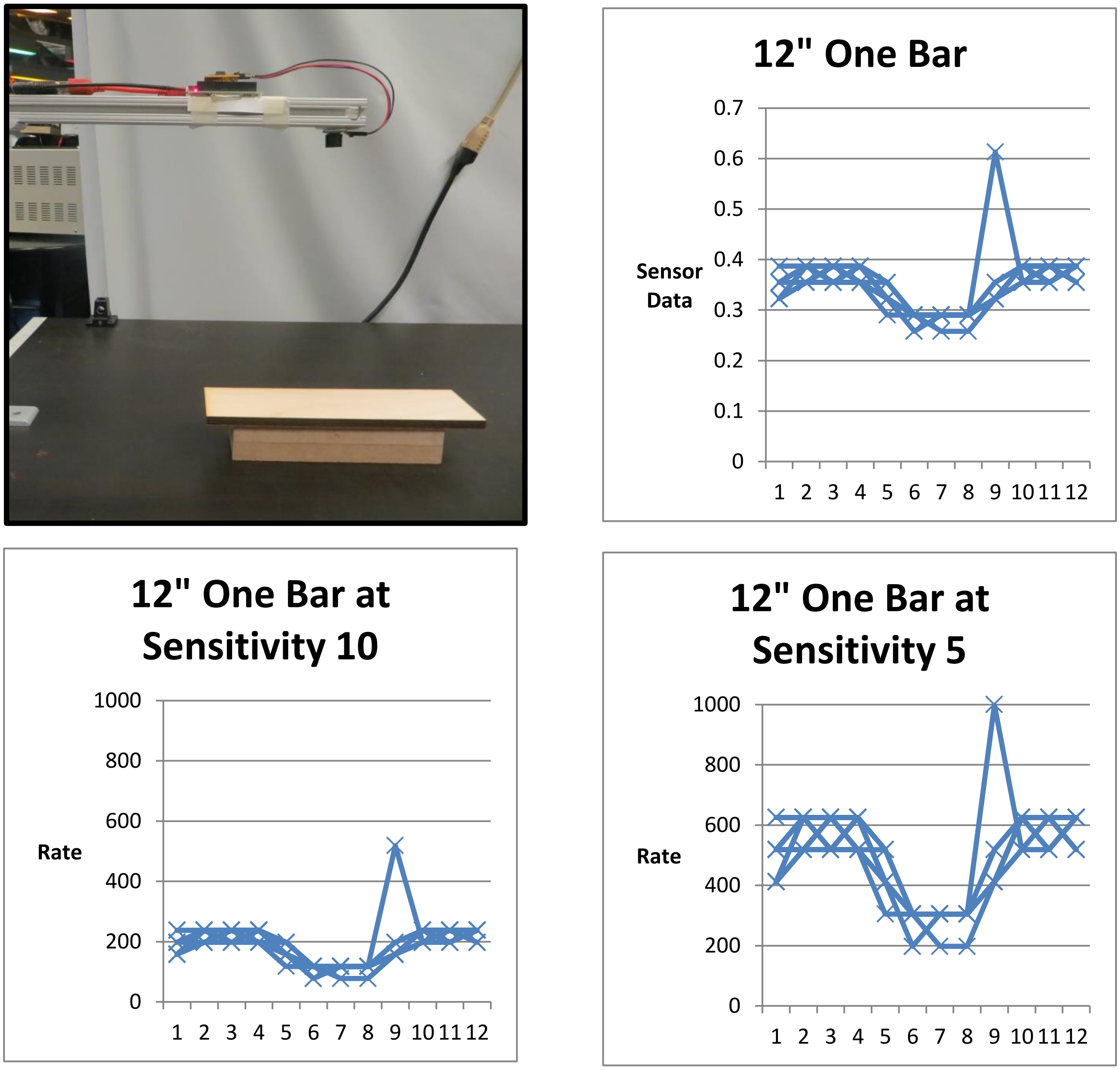


FIGURE 14 – CONTROLLED MEASURMENTS AT 12"FROM THE TABLE AND ONE BAR

Figure 16 shows the measurements at 12"with one bar on the table. Here we can start to see the differences between the sensitivity levels and how the response at 5 might be more drastic but the noise is also amplified.

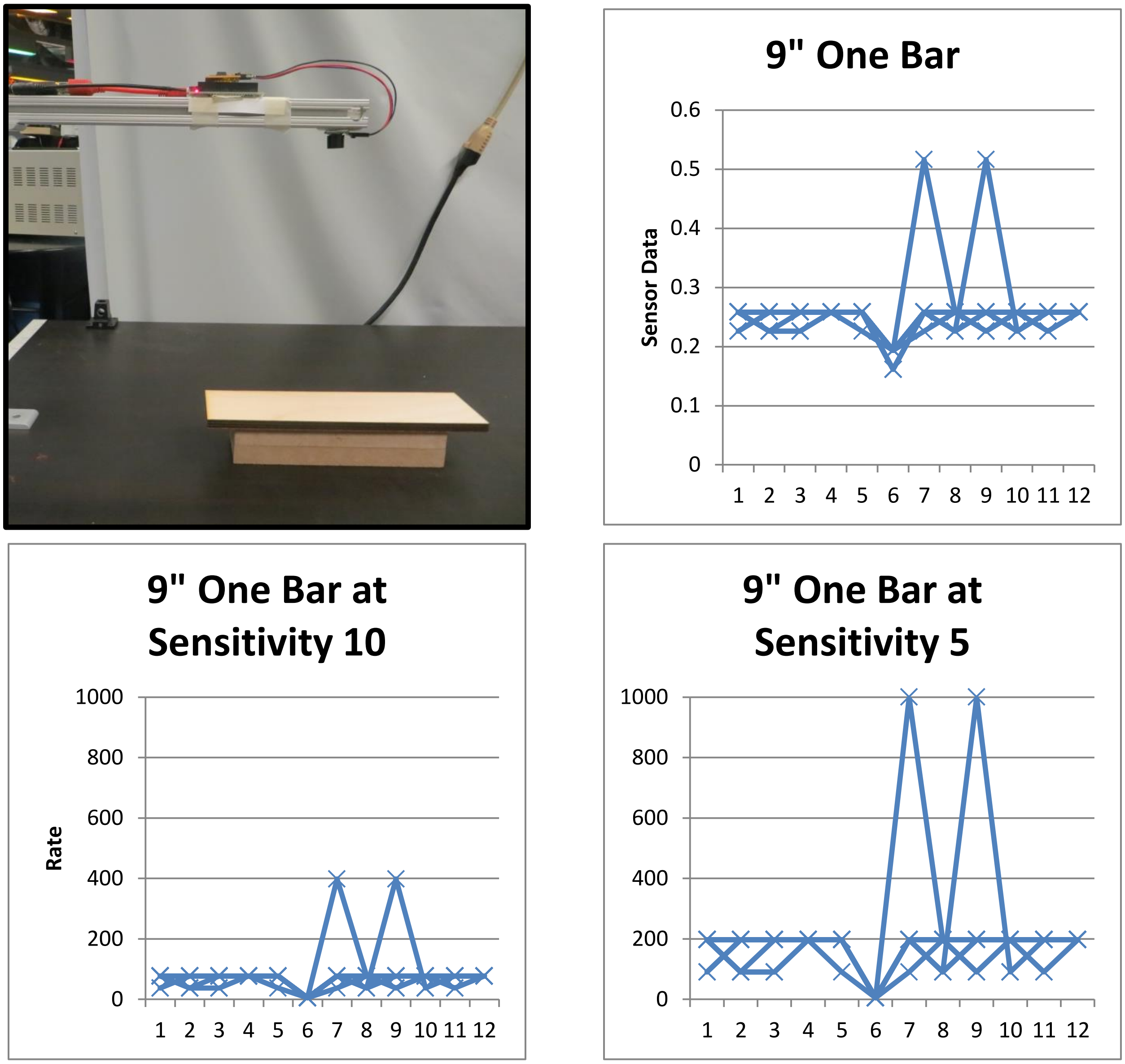


FIGURE 15– CONTROLLED MEASUREMENTS AT 9"FROM TABLE AND ONE BAR

Figure 17 shows the sensor data when one bar is present. Again we can see spikes of bad data and a clear dip at position 6 where the bar was detected.

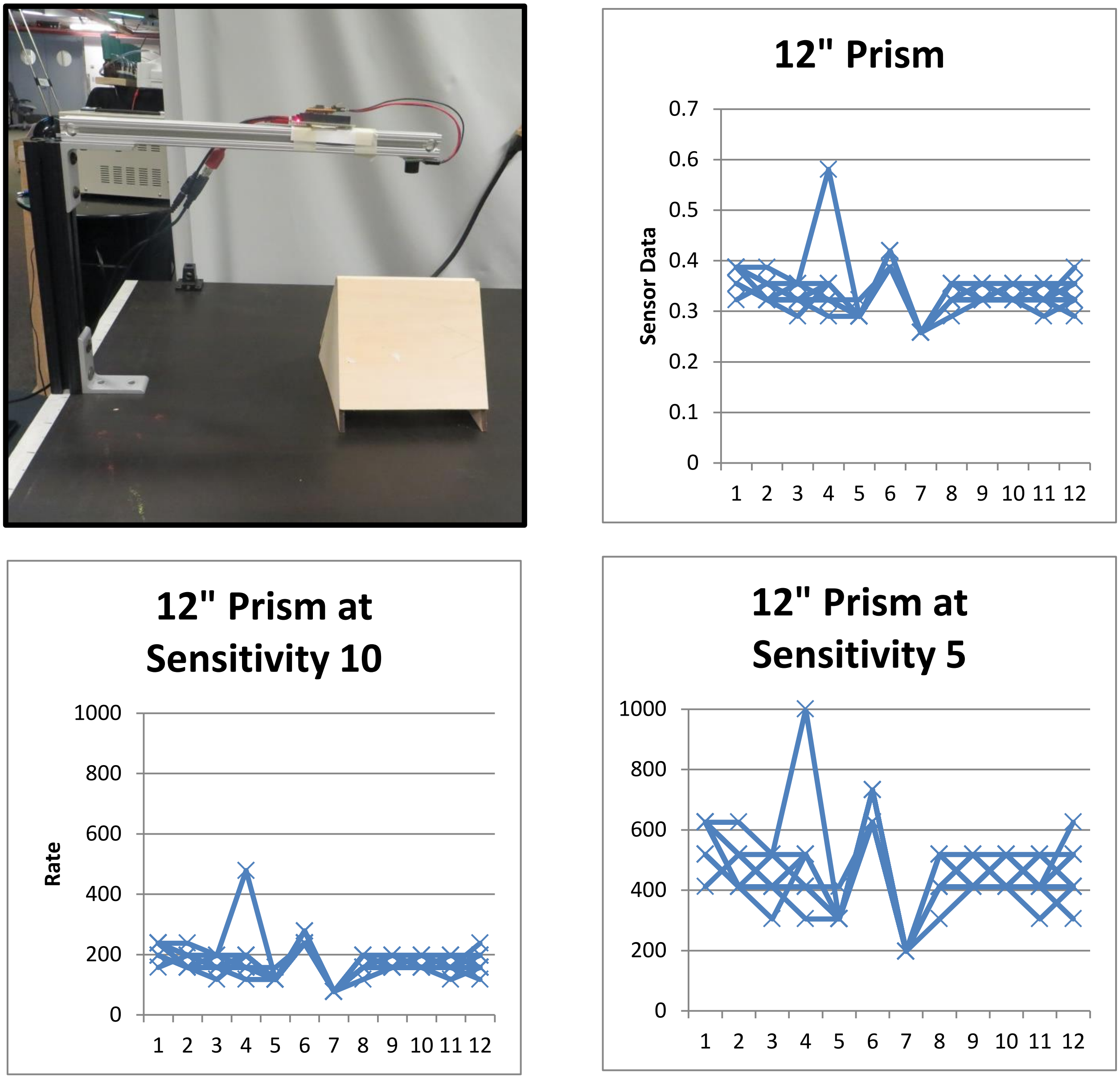


FIGURE 16- CONTROLLED MEASUREMENTS FROM 12" FROM THE TABLE WITH THE PRISM

Figure 18 shows the result with the prism object at 12". I find this measurement to be really important because the pattern is completely different from what the user had learned the sensor would behave up to this point, but given the highly distinct pattern, after only one occurrence of the prism, if the user was presented with it again, there was no confusion an so the accuracy of the prism was of about 80%. We can see that around position 3 the sensor picks up the prism but at 6 the prism "disappears" and comes back in positions 7 to 9.

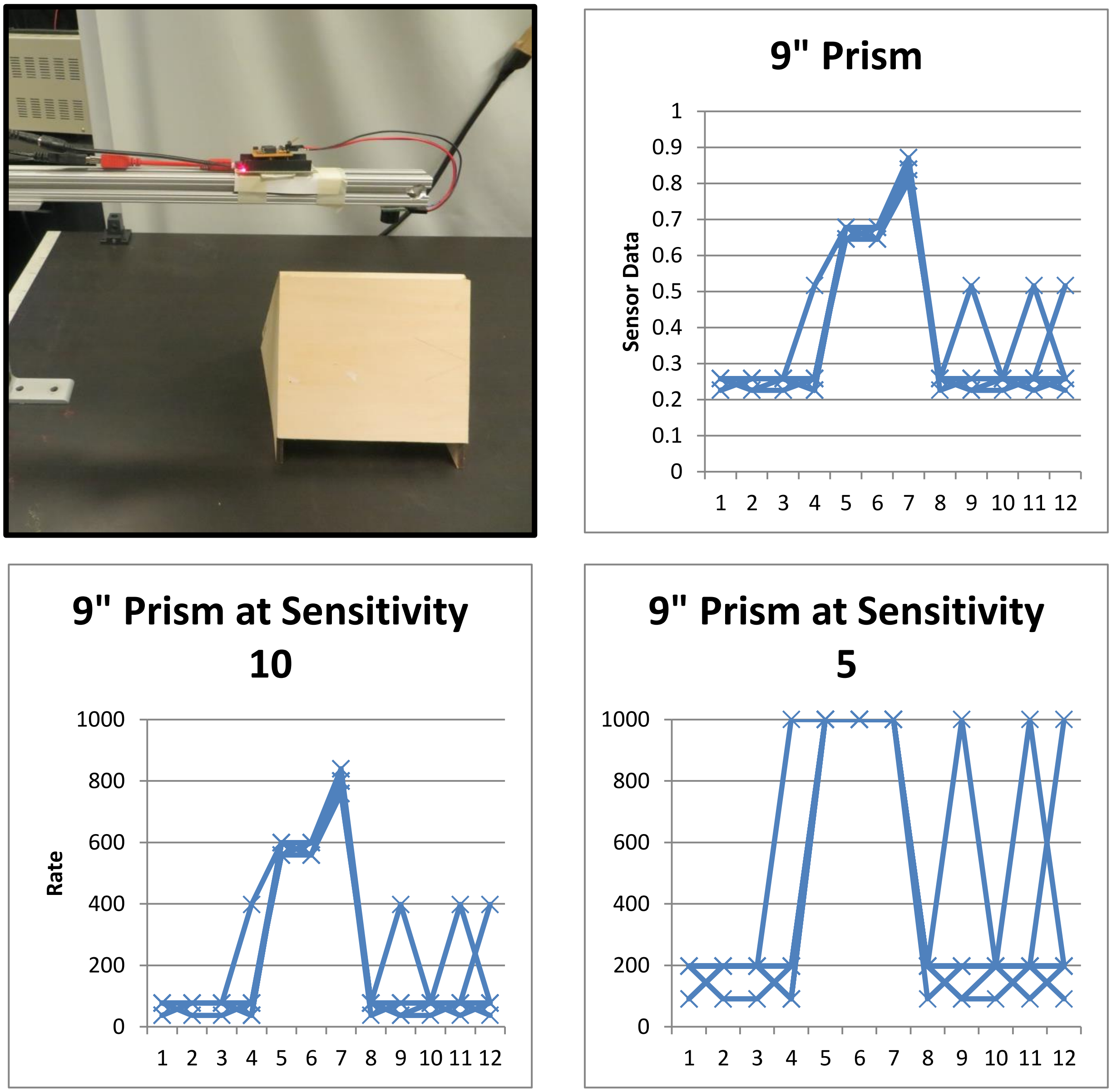


FIGURE 17 –CONTROLLED MEASUREMENTS FROM 9" FROM THE TABLE WITH THE PRISM

Figure 19 shows how different the measurements are from 12" to 9" and also shows how in this case measuring at 12" gave a better reading than at 9".

Temperature to Sound

The objective of this study was to create an artificial sensory experience that was impossible to verify with other senses. In this case the only way to verify would be by touch, which the subjects were not allowed to use. So this study wants to explore the way that the subjects will learn to trust their new sense and if there is a different learning curve when given an outcome feedback or not. These changes in the level of comfort when using the artificial sense would be reflected in the time taken to make a guess.

Preparation

At a desk with a computer monitor, the subject would find 3 peltier modules attached to the monitor at eye level. The tablet device would be placed in front of the subject, this would be the main UI for the test. The subjects were also given a mobile device that would be the UI for their sensory device.

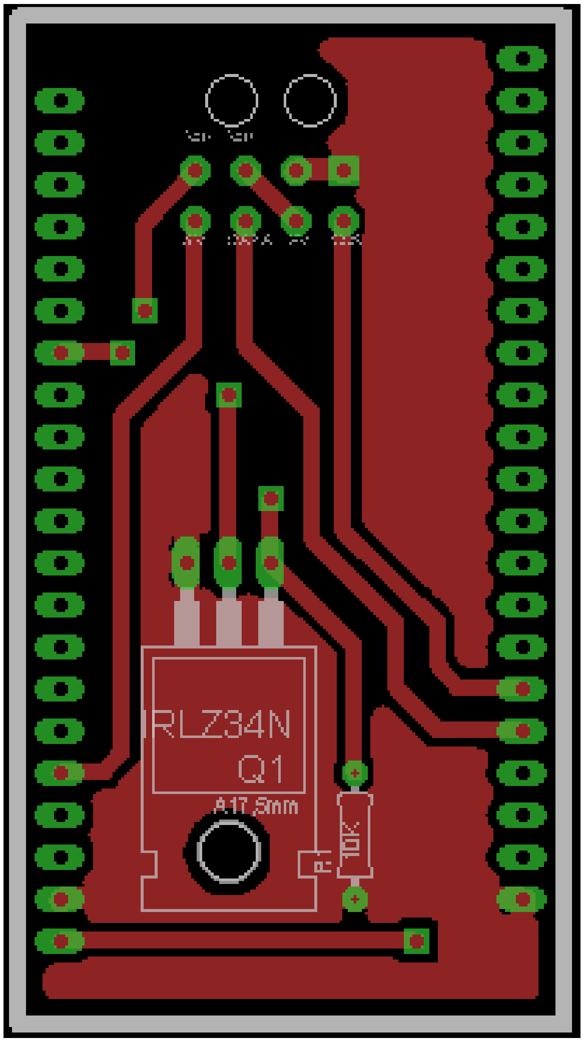


FIGURE 19 BOARD TOP

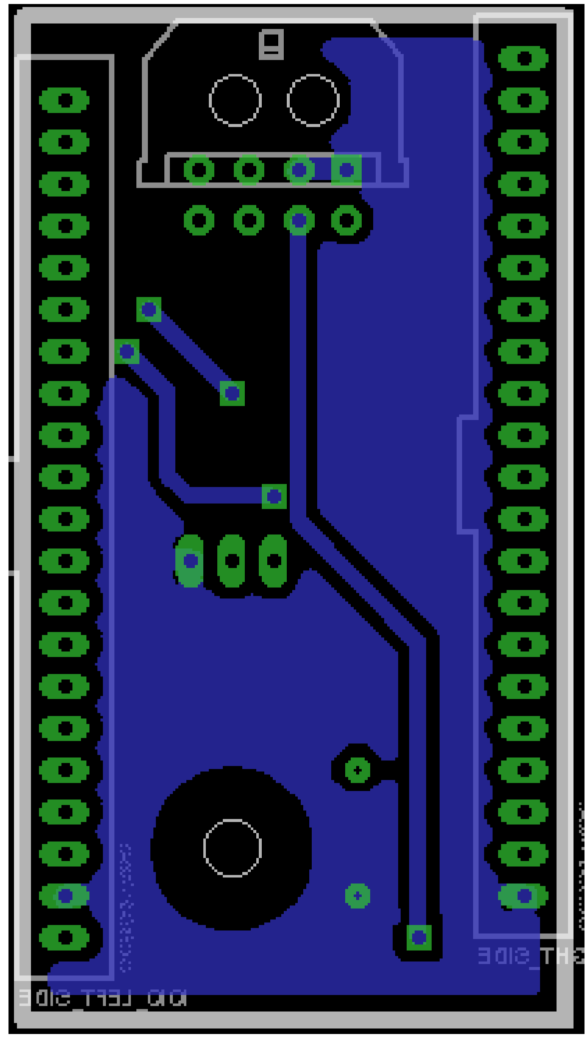


FIGURE 19 BOARD BOTTOM

HARDWARE

There were two systems created for this study. First, the system worn by the subject consisted of an MLX90614BAA to detect the temperature of the peltier module. This sensor was connected via I2C to the IOIO OTG board and the board would connect to the transducer.

The second was to control the peltiers, and record the data. Three peltier modules were used, two 1x1 inch and one 1/2x1/2 inch. The two large peltiers were placed on the sides and the small one in the middle. They were controlled via PWM by a IOIO Board that was hooked up to a Sony tablet S.

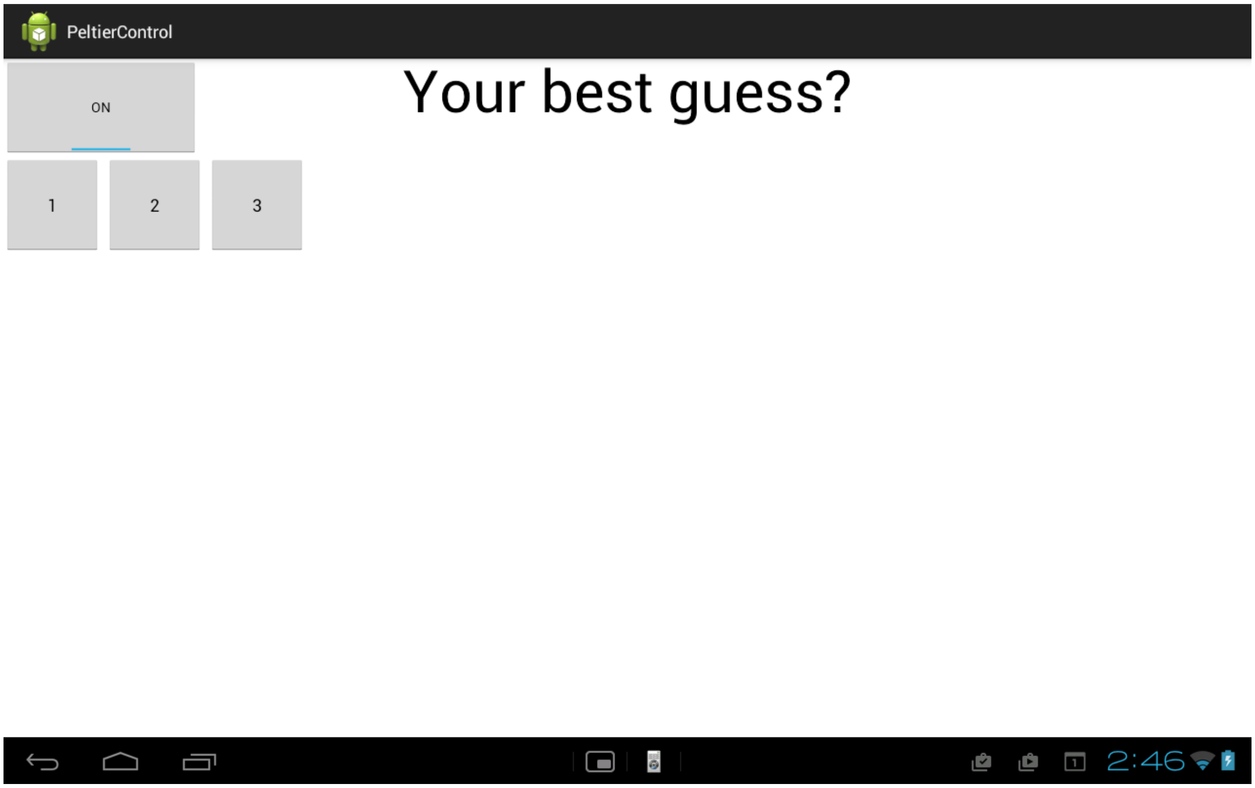


FIGURE 20 USER INTERFACE FOR SECOND STUDY

Software

Similarly, two Android apps were written for this study. One gives the user control of the sensory experience by giving control over the sensitivity range, all other visual feedback was disabled. The second app was written to give the subject control over the test. It was designed to be completely independent of the examiner and so create a double blind test. The app would first randomly decide if there would be a result feedback at the beginning or end of the session. Then it would offer the button to turn on the peltiers and give a countdown of how many turns were left. Three buttons corresponded to the three modules to allow the subject to enter their guess. At the end of the session the app would notify the subject that they were done and would give them the score out of twelve of correct responses.

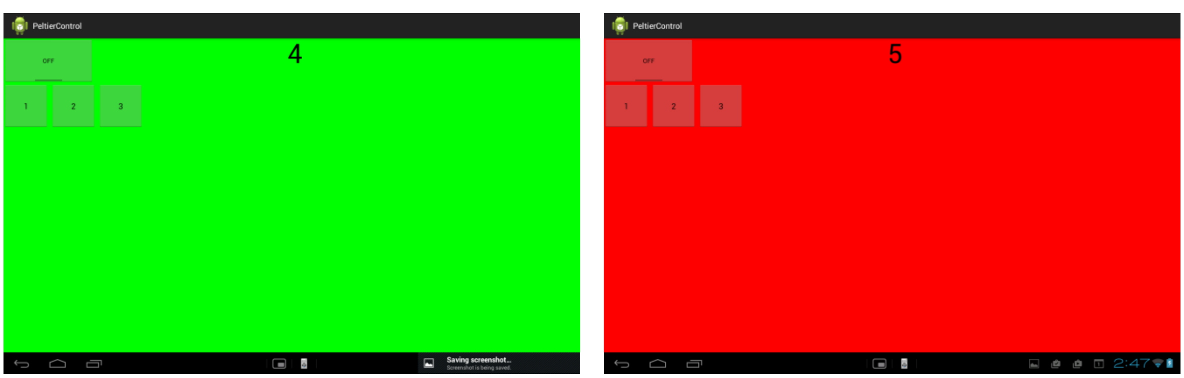


FIGURE 21 GREEN WHEN CORRECT, RED WHEN WRONG

PROCEDURE

The subjects were seated in front of three peltier devices. At a given moment, only one of these devices would be hotter than the others. The subject's task was to guess which device was hot.

The subjects were given a head band that would hold the sensor, transducer, IOIO and power. That IOIO would be connected via Bluetooth to a mobile device that would give sensitivity control to the users. Another device would control the peltier modules so that when a button was pressed, the device would randomly activate one of the peltier modules. The UI peltier control device would offer a button to activate the peltiers and begin timing and three buttons that corresponded to the subject's guess.

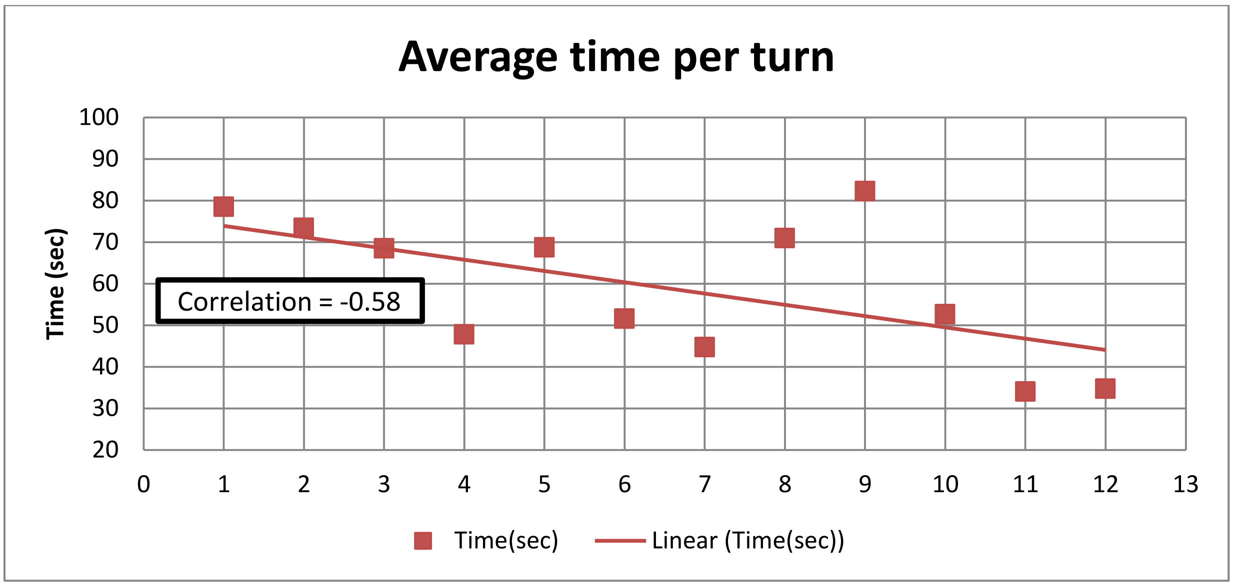


FIGURE 22

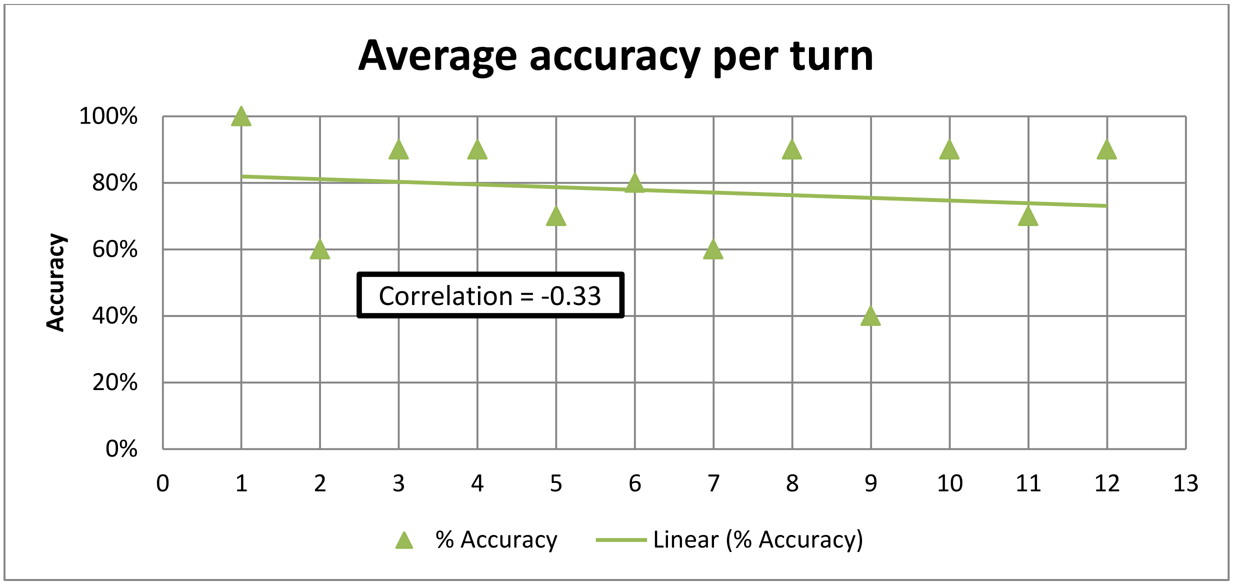


FIGURE 23

The subjects would do this guessing activity twelve times, six times with a visual result that would tell the user if the guess was correct or not and six with no visual result. Whether the visual result would appear on the first or the last six turns was also randomized.

Results

The initial result shows an average of 80% accuracy, but this was not the most exciting result or even the result I wanted to examine. This study was more about the subject's ability to learn how to use this sense and it would be reflected in the time each subject took to make a guess. Overall we see that the time per turn goes down (table 4), and when compared with the average of right or wrong answer, the accuracy tends to remain well above 50%.

Another interesting result was the relation between time and the visual feedback. For 6 of the 12 turns the subject received a green light for correct answers and a red light of wrong answers. The results show that there was no significant advantage to having the visual feedback come at the beginning or at the end. The data was analyzed to compare the average time per turn when the visual feedback came first against when it came second (table 5), then the average time of the 6 turns with no feedback when these came before against when these came after and finally the average time of the last six turns when the feedback came first against

Evaluation

I expected to see the users get better as they performed the task and this is shown by the average time per turn decreasing to an average of little more than 30 seconds. This means that the user learns to understand their sense, but also that they get used to the task. For instance

Time and Accuracy of the last 6 turns, when feedback came first vs. second		
Feedback	**Time(sec)**	**Accuracy**
Feedback first	58.01	66.67
Feedback Second	50.22	83.33

Average time of feedback Vs no feedback		
Feedback	**Time(sec)**	**Accuracy**
Feedback	57.99	80
No Feedback	59.93	75

in most cases the middle peltier which was smaller than the other two was not really checked but chosen when the others were not giving a signal, so by elimination it had to be number two. But as the test advanced, the subjects obtained a better picture of where the sensor was in their foreheads and how to properly align it to the peltier module in question. This is what I was looking for, to see how quickly the subjects would adapt.

I didn't expect to find that there was no significant difference from when the visual feedback was offered. I expected that when the visual feedback came first, it would help the learning curve and then it would make the last 6 turns be faster and more accurate. I found that the average time in the last 6 turns remained at around 50 seconds. Even so, there is an effect to having a visual feedback but this is only in the behavior of the subjects. Having a visual feedback of the result made the experience more enjoyable like a game. This means that the subjects felt more involved in the experience and tried extra hard to get it right, this was reflected in a slight increase in time when feedback was given over when there was none.

Overall the subjects reported the hardest thing to be locating the sensor on their forehead and once located, trying to align themselves again to the same position proved challenging. The use of the sensitivity dials was very consistent over all the subjects; they would search for a comfortable setting and then leave it still for the rest of the test.

Cell Sensors to Sound

This is the main study designed to test the ability of a subject to connect a new signal with its source, or better yet, the ability of a subject to find significance in a signal when compared to their surroundings. This study was geared towards a more qualitative analysis because I was not as interested in the accurate identification of the sensor but in the interpretation that the user would give the signal. These interpretations are the power behind Digital Synesthesia. When we experiment with phenomena that are completely outside of human perception, it will be the ability of the users to find significance in those signals that will bring this project to its fullest potential.

Preparation

I took an old baseball cap and fitted it so it would support the IOIO board, the Bluetooth dongle and power. On the inside close to the left temple the transducer would vibrate next to the skull to generate both vibration and sound through bone conduction. A mobile app would activate a random sensor of the device and map the data inside the sensing range. Via Bluetooth the cellphone would send the data to the IOIO board to control the transducer.

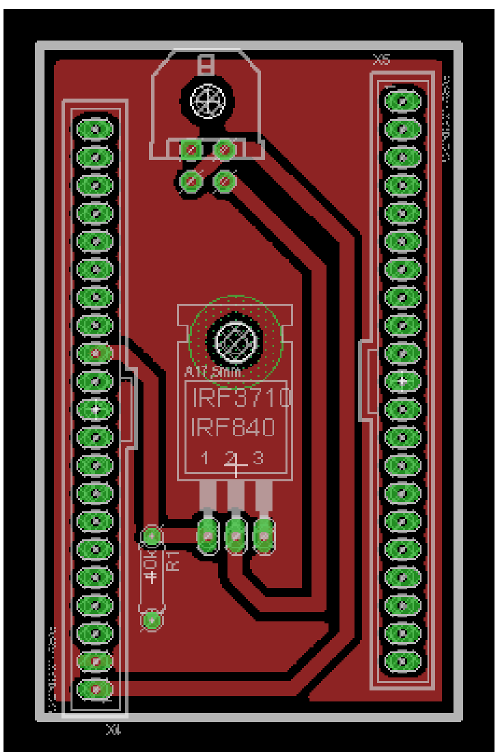


FIGURE 24 - BOARD TOP

Hardware

The hardware designed for this test was more simple that the others because all the sensors were already working in the mobile device. I designed a board (Figure 26) that would connect to the IOIO board and control the transducer. The IOIO would receive the data from the device via Bluetooth and transmit the frequency to the transducer.

Software

I wrote an app that scans the device for any and all available sensors and creates a button for each one as well as WiFi strength and surrounding sound levels. When a sensor is selected, the app gives access to a sliding scale that controls the sensitivity as well as to a numeric feedback of the raw sensor value and the mapped value used as frequency. Finally a real-time scrolling graph gave additional visual feedback (Figure 28).

The app offers an interface to the examiner, which I described above, and a different interface to the subject (Figure 27). This second interface hides all the sensor buttons as well as all the

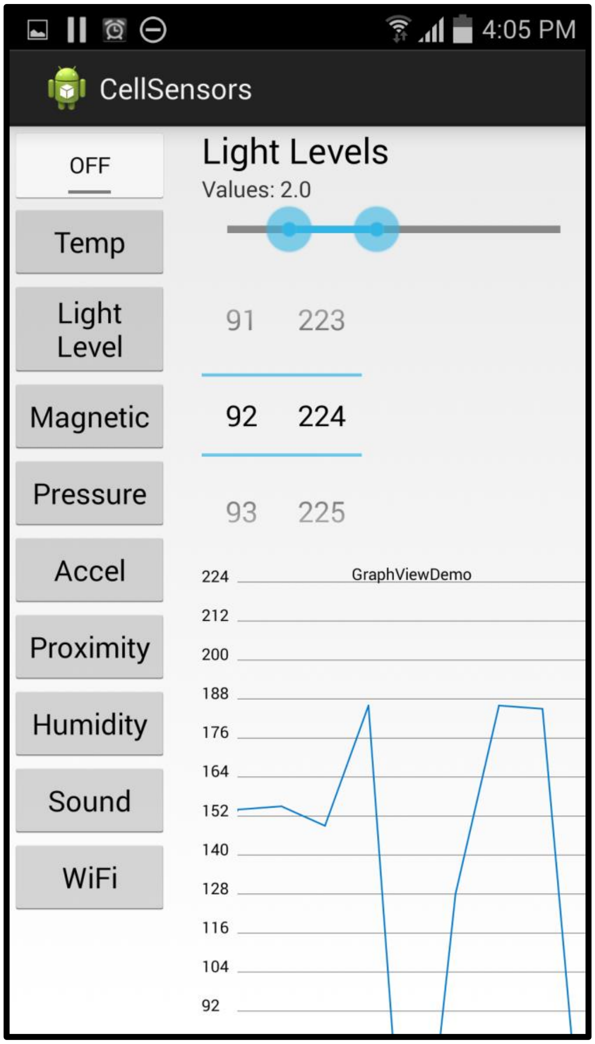


FIGURE 26 - UI FOR THE RESEARCHER

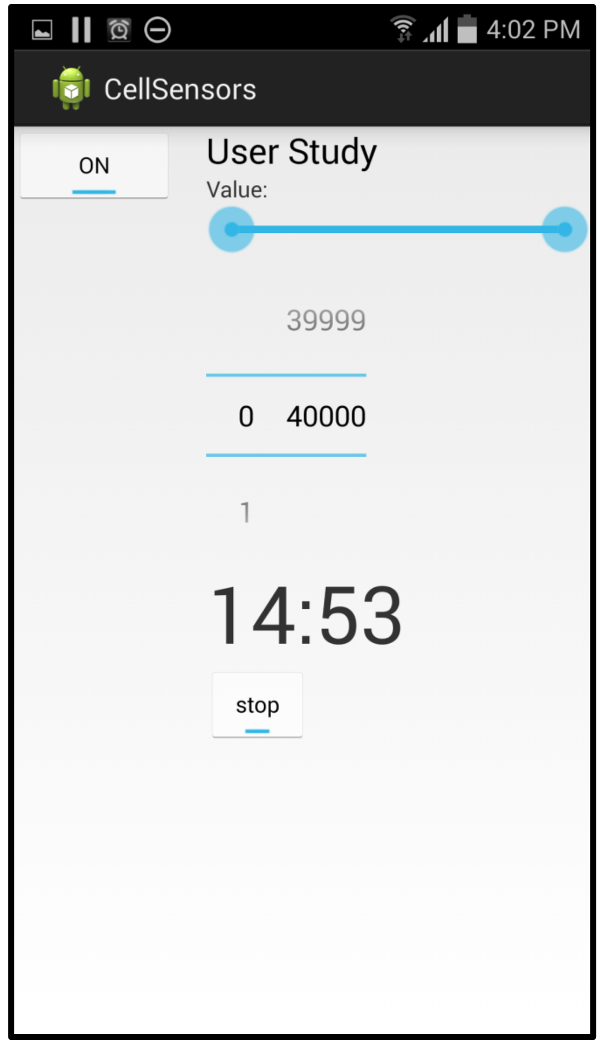


FIGURE 25 - UI FOR THE SUBJECT

feedback information so that the user has no idea what are the possible sensors to choose from. The subject has access only to the sliding scale that controls the sensitivity and a timer set to 15 minutes. After the 15 minutes an alarm sounds and the phone asks the subject to return to meet the examiner.

Test Procedure

The subject would wear the cap and the examiner would pick a sensor to use as an example while the procedure and operation was explained. This explanation was done using the "examiner" interface so that all the visual feedback would help the subject understand the operation of the device and land on some strategies to successfully set the sensitivity values. Once the subject had a good grasp of the operation, the examiner would set up the study but choosing another random sensor and switching to the "study" interface, then give the device to the subject and instruct them to roam around the building for 15 minutes while trying to find a correlation between the signal and their surroundings. Lastly, the examiner ensures that the timer has started and sends the subject on their way.

One of three mobile devices were used, many of the sensors were present in all three. Changing the device would also help so the user would be less familiar with the technology in the device.

Sensor \ Device Model	Samsung Galaxy S4	Samsung Galaxy S3	Huawei Ascend P6
Light Sensor	X	X	X
Tilt Sensor / Accel	X	X	X
Magnetometer	X	X	X
Barometer	X	X	
Temperature	X		
Humidity	X		
WiFi	X	X	X
Sound	X	X	X

Setting sensitivity values

The subjects were instructed in how to set the sensitivity value by having them use the cap and trying to feel the change while looking at the visual feedback. If the change was very small or if there was no feeling of change at all, then the upper value of the sensitivity range was brought down until the frequency was fast. That way you had a good upper value, now without moving the upper value, the lower value was brought up until the frequency would slow down. Finally the user would test the sensor again until they were satisfied by the change being felt.

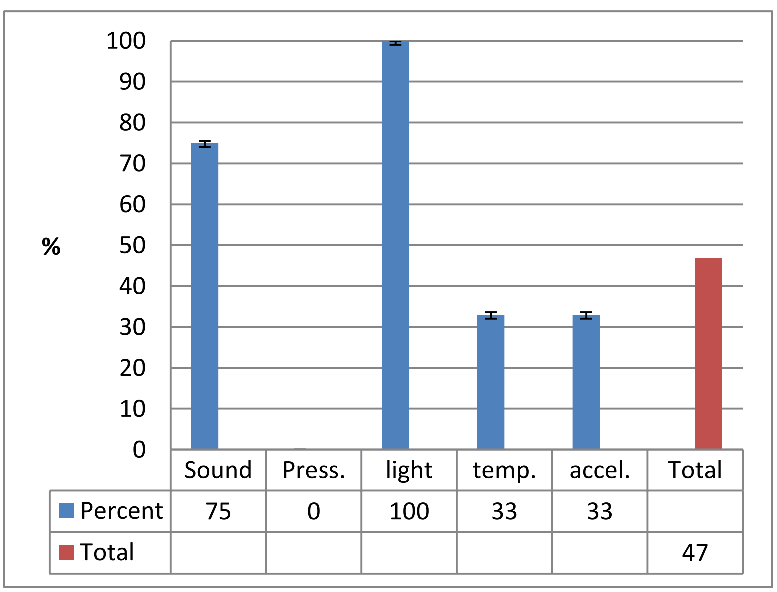


FIGURE 27 – PERCENTAGE OF CORRECT ANSWERS

They were then asked to try and do this without looking at the visual feedback since there was not going to be any during the test.

Results

A total of 17 subjects were tested with a percentage of correct answers of 47%. The total amount of possible sensors in the devices was 9 which give a minimum percentage of random at 11%. The correct results were guessed during the first 10 minutes of the test, with the last 5 minutes used to confirm and “play” with the sensor.

Evaluation

The value of 11% based on the 9 sensors available is somewhat inaccurate. On one hand because the users had no knowledge on how many options there were and they were not picking out of a list presented to them. On the other hand, many of my users were very familiar with mobile technologies and had an idea of what the capabilities of different mobile devices could be. This said, what was important to me on this study was the thought process around finding out the connection between the feedback signal and the experience. In this sense, the familiarity with technology also proved problematic because some subjects would just spend their time going through the sensors one by one in order to simply eliminate possible sensors.

The wrong responses	
Sensor	**Response**
Sound	Wind or weather related
Pressure	Has to do with the stairs. Shape, Distance or Materials
Temperature	No Idea
Accelerometer	Screens or Bluish light

Table 1

The really exciting experiences were given when a user was not sure and came up with possibilities of what the experience was. When users who were feeling the sound level stepped outside of the lab, they would immediately think that the sensor had some environmental connection or that it detected wind speed. This is what I was hoping for, users interpreting in a useful or meaningful way the experience.

The most successful sensor was light intensity. It also created one of the most enjoyable experiences because it had a good range of change that was easy to feel and going from room to room there was always a change, but it wasn’t until the subject went down a hallway when a series of quick changes would happen and it became evident because the subject was walking under a series of light fixtures.

Smell Explorations

Smell is a very difficult sense to work with and to generate experiences with. It is not easy to create costume smells and once a smell is in an area it is not easy to get rid of it in order to replace it with another. So the smell experiences designed for this study were made as a broad exploration of its possibilities and not as a strict user study.

Smell Explorations 1 "The Foodcam"

The media lab has a system set in place to deal with leftover food from meetings and events. All the food is taken to a central location at the lab where there is a table designated for this purpose. Above the table there is a webcam that, when a button is pressed, will capture and image of the table and the food offerings and send this image as an email attachment to everybody in the lab, at which point people will head over to collect some free food.

Preparation

I designed a system that would listen to any activity in the foodcam camera feed and also listen to the emails coming out of the foodcam account.

Hardware

I bought an "Air Wick® Freshmatic | Automatic Air Freshener dispenser and Spray" which is an aroma dispenser that can be programed to release a puff of aroma at a set time frame. It was easy enough to bypass the power, from the batteries to the servo-motor that would press the canister of scent, through a MOSFET so I could control the actuation with a IOIO OTG board. This board would be connected to a Sony Tablet device.

Software

An app was created to regularly look at the foodcam live feed for changes and to listen to the emails being sent. When activity was seen on the camera a signal would be sent to the IOIO to activate the servo for a very small amount of smell to be released. One the foodcam button was pushed the IOIO would send the signal to release a full burst of scent into my office.

Evaluation

The experience of having a smell release when the foodcam was activated was more efficient that waiting for me to actively check my email. As a just-in-time interface it worked much better given that I was in my office. Even if I was near my office I would notice the smell change and know what it meant. There was the problem of lingering smell since after I had gotten the signal of the foodcam the smell was to remain. This would not only be inconvenient but in the cases when the foodcam was pressed in close succession, the second puff of scent would be unnoticeable. But the problem of the lingering smell showed a positive angle when I realized that I could broadly estimate the time passed since a foodcam signal was triggered by how faint the smell was.

Smell Explorations 2 "The smell-mixer"

Another difficulty when working with smells is the creation of new smells. To this end, we[1] created a system of eight bottles and a pump that could be used to mix essential oils in different ratios to consistently create different smells.

Preparation

Based on the science of perfumery, to create a smell you need at least 2 different scents, a base scent and a top scent. We have set up eight bottles to do just that.

Hardware

A regular pump is hooked to all eight bottles with plastic tubing that goes through a solenoid that controls the flow of air. The solenoids are controlled by relays that respond to a IOIO OTG board.

(Insert circuit diagram…)

Software

An app was created to offer a user two choices of bottle, a base and a top scent. Then the user can dial a scroll bar to decide the mix ratio of base to top. Given the choice, the app was programed to take divide ten seconds in whatever ratio was needed so if the ratio was 50:50, both solenoids would be open for 5 seconds. If the ratio was 30:70 the base would open for 3 seconds and the top for 7.

Results

(in progress)

Evaluation

(in progress)

[1] With my advisor V. Michael Bove

USER STUDIES (THE LESS SUCCESSFUL ONES)

STRESS TO SOUND

Working with a IR sensor was one of my biggest curiosities because it gave me the opportunity to experiment with a well know environmental effect as is temperature but also in a way that the body cannot perceive which is optically. So it would be an easy jump for the subject, I thought, as a fits approximation of how an unknown artificial sensory experience might be like.

There is literature that supports how small changes in a person's facial temperature are related to that person's emotional state[27]. Specifically in stressful situation like a high stakes poker game. I intended to replicate one of these studies by creating a game situation in which a player had the ability to detect the emotional state of the other players and use this to their advantage.

In order to test the validity of this thesis, I needed to first test the sensor to see if there would be any discernible change in a players temperature. Given that the players would be at an unspecified distance from each other and I was not going to be able to control where the sensor was pointing and how the subject would use it, I decided to set it up in such a way that it would always face one user. To achieve this I changed the design of the cap and the player who would wear it would have the IR sensor facing at its own face. This way the player was free to move their head and the sensor would remain fixed pointing at that players face. Everything else was kept the same.

PREPARATION

A subject out of 4 to 6 subjects would wear a baseball cap with an IR sensor facing out from the forehead and a vibrating transducer on the temple. A game of Liar's Dice[28] was set up and the rules explained. The group would play until the player with the cap was out and then another session would commence.

HARDWARE

A baseball cap was fitted to support a 9V battery, a IOIO Board, an IR Sensor and a tranducer. The 9V battery was the main power for the whole system. Data collected by the IR sensor would be transmitted to the IOIO Board and then to the mobile device via Bluetooth. The device would transform this signal to frequency and send it back to the board. The IOIO Board would then control the transducer and make it vibrate at the desired frequency.

(Insert images)

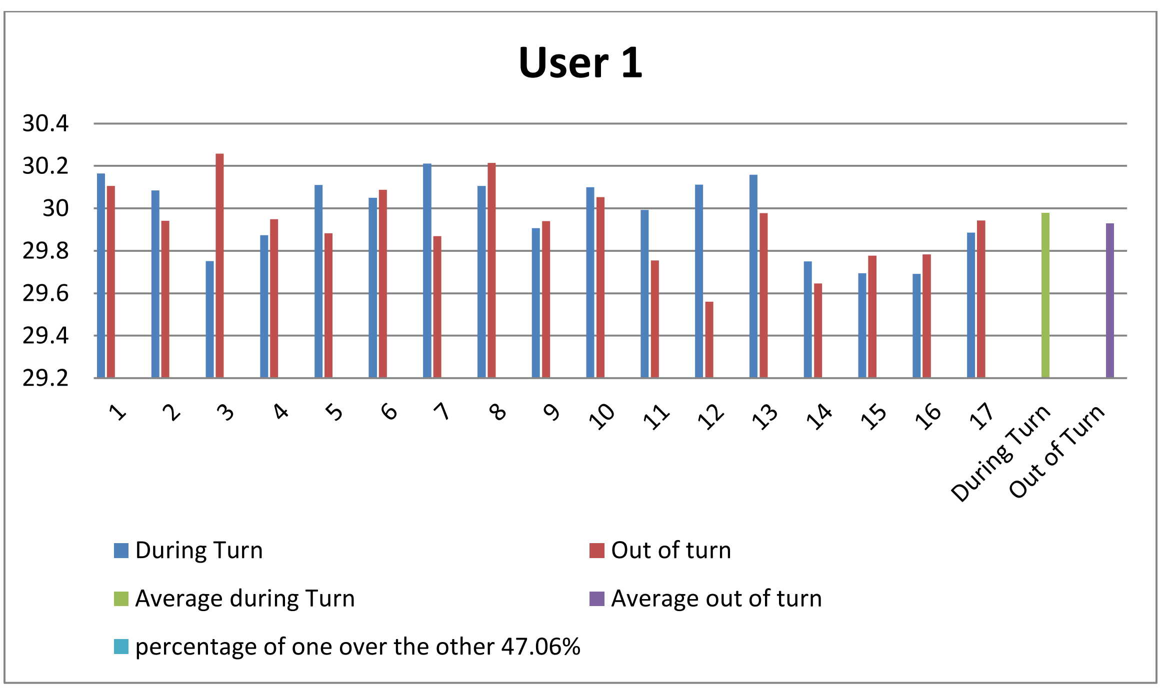
SOFTWARE

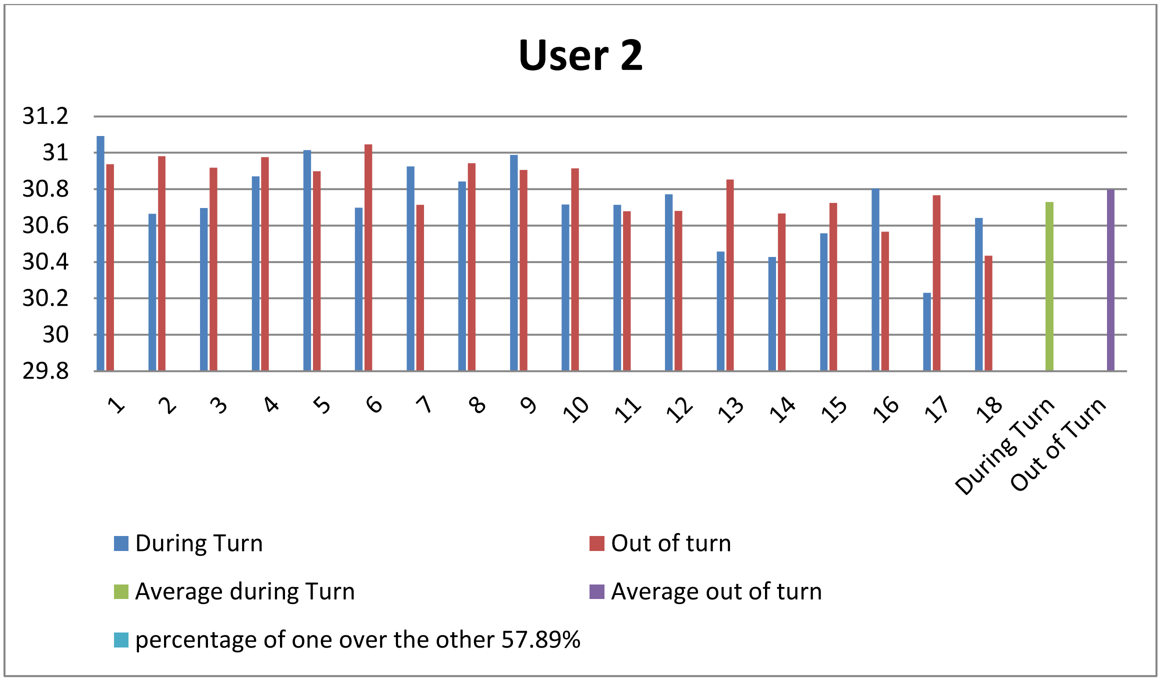
Using and Android device, an app was made to be controlled solely by the examiner. The app would take the incoming sensor data, map it into the range set by the examiner through a couple of number pickers and send the data as frequency to the board. The examiner had numerical feedback of the incoming temperature value, the sensitivity range and the outgoing frequency. Additionally the app offered graphical feedback of the real-time variation of temperature value. A button was created for the examiner to be able to mark the beginning and end of the subjects turn, this mark would appear in the data stream being recorded of temperature so that the data could be analyzed by separating values during a turn and out of turn.

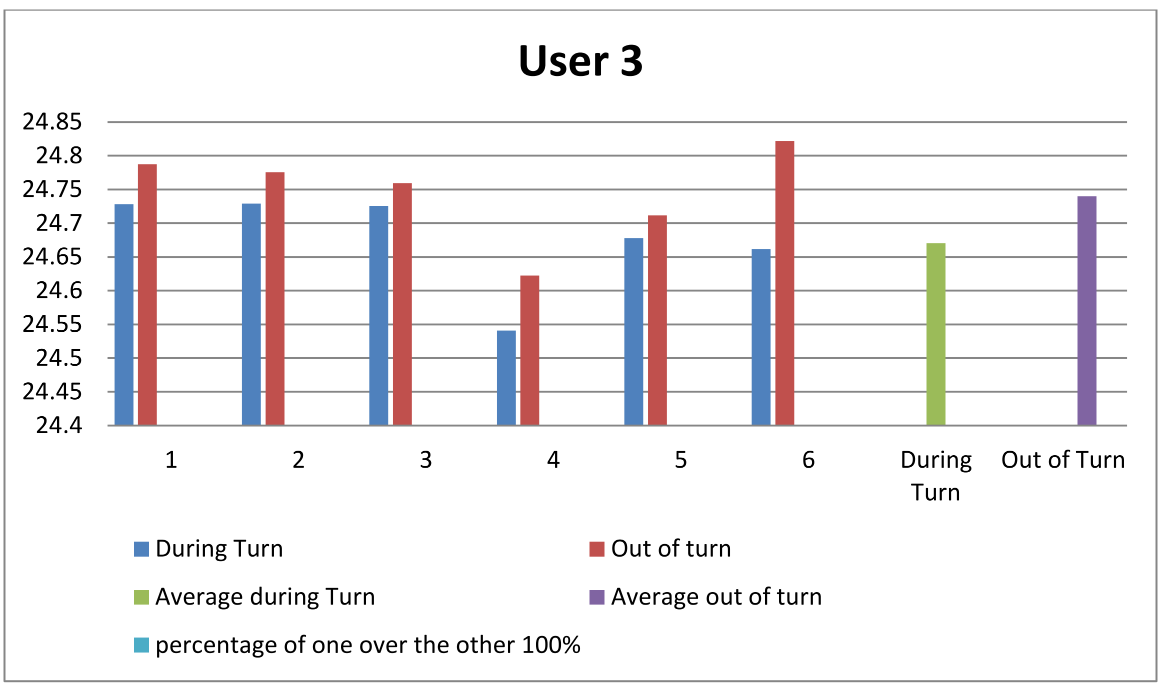
Evaluation

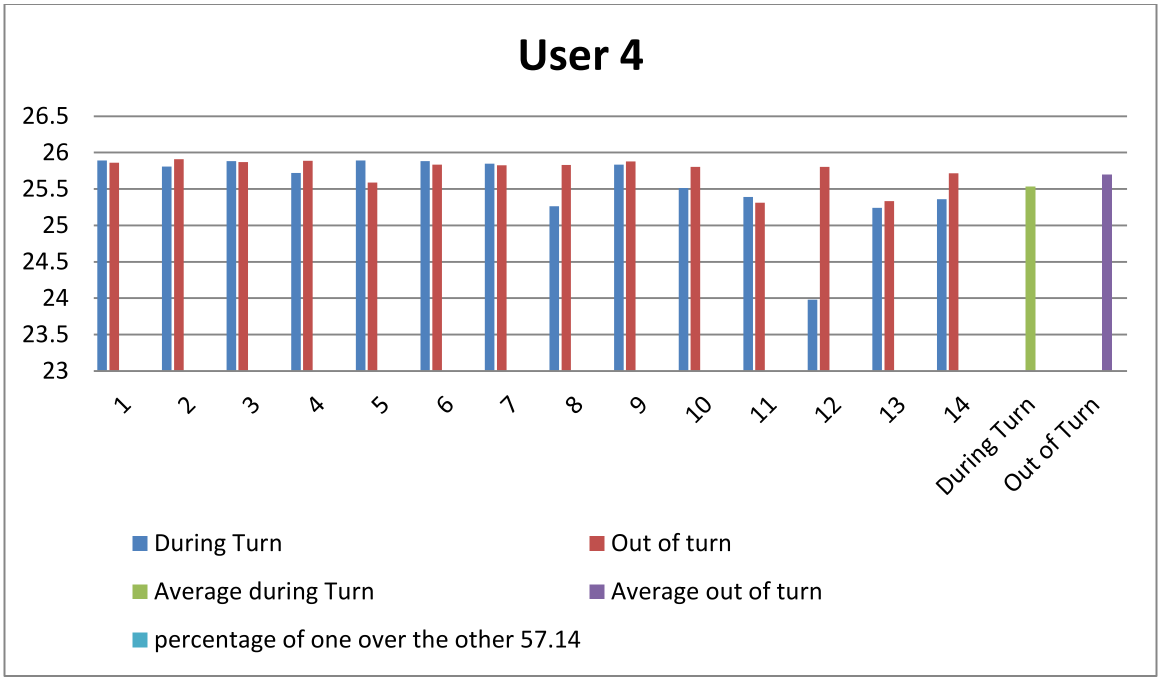
This user study proved to be harder and I initially thought. The first thing I looked for in the collected data was for a difference in the average temperature when in turn against when out of turn. The differences where too small to be meaningful and there was no pattern to if it would increase or decrease when the subject was in turn.

This means that either my sensor was not adequate. Either not sensible enough or the FOV was too broad and it detected too much of the ambient temperature that would wash over the small changes I was looking for. The other possibility is that for this temperature and emotion correlation to be detectable, the activity has to be really stressful as is the case in no-limit poker when the subjects use their own money. It might be that the game of Liar's Dice, as exciting as it may be, was not stressful enough to generate a noticeable difference in the subject's temperature.




User 2
31.2
31
30.8
30.6
30.4
30.2
30
29.8
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
During Turn
Out of Turn
During Turn
Out of turn
Average during Turn
Average out of turn
percentage of one over the other 57.89%


User 3
24.85
24.8
24.75
24.7
24.65
24.6
24.55
24.5
24.45
24.4
1
2
3
4
5
6
During Turn
Out of Turn
During Turn
Out of turn
Average during Turn
Average out of turn
percentage of one over the other 100%


User 4
26.5
26
25.5
25
24.5
24
23.5
23
1
2
3
4
5
6
7
8
9
10
11
12
13
14
During Turn
Out of Turn
During Turn
Out of turn
Average during Turn
Average out of turn
percentage of one over the other 57.14

Location to temperature

This user study was designed to test a subject in the identification of an unknown signal. It is also the only study I made using a peltier device as the feedback mechanism, essentially using temperature as an output.

Preparation

Hardware

The hardware configuration for this study was very similar to the ones discussed before. Incoming data was received by a IOIO OTG board and sent via PWM through a MOSFET to the Peltier Device. The data that the IOIO received was collected from the DoppelLab project at the MIT Media Lab.

The subject would wear a lanyard around their neck where the IOIO and power source would be hanging at their chest, while the peltier device would be in the back of the neck, against the skin. Since peltier devices can be used either on the warm or cold side, for this study only the cold side was used.

Software

The DoppelLab project uses a sensor network that reports a variety of real-time information to the web. An app was written to take the data from DoppelLab and use it as the input for the Digital Synesthesia system. For this study I used only the RFID Tag reader to give me location information. The system can recognize the user through the RFID Tag and the system knows where the reader is located in the building, essentially giving out location information.

The app creates a listener in the DoppelLab stream that is constantly looking for a specific ID. Once the ID is found, the signal would be sent to the IOIO to control the PWM to set the temperature of the peltier according to the distance between the subject's current position and the location of their final objective.

Procedure

Ahead of time, a specific sensor in the lab was selected. The subject's task was to find this specific sensor by interpreting the signal in the back of their neck. The peltier would cold when passing in front of a sensor that was far away from the objective and would feel warmer as they got closer.

Results

This experiment was not completed because it became clear early on that the temperature feedback was not clear enough for the users to be successful. But some important lessons where found from this experience.

Evaluation

An interesting finding is that the subjects were much quicker at detecting the change in temperature when it became colder than when it became hotter, this might prove useful when the users need to be aware of something urgent that is detected through the artificial sense.

Another finding and the one that proved to be the hardest to overcome in the study was that even though the users were quick to notice a change, these changes were quickly assimilated to by the brain and so the concept of war to warmer or cold to colder was not successful. There was no sense of increment or decrease, only the feel of neutral to new temperature. In order to create the sense for gradual change, I would either have to start and stop the signal or use temperature values that would be outside of the comfortable area for most users.

The third finding was that once the brain had assimilated a constant temperature, stopping the signal would feel like a signal in itself. So if the first signal was cold, and it was kept at a constant temperature, the brain would ignore it after a while, if then I turned the peltier off, the brain would interpret that a big jump in temperature towards heat, even giving the illusion of close to burning. Even though I knew that the peltier was simply going from cold to room temperature. Again, there might be a future use for this effect where the user would feel a big change while not really needing to use any extreme temperatures that could be dangerous.

User Studies Summary

User Studies	**Results and Conclusions**
Proximity to Vibration	• Users are able to quickly learn to use the sense and identify the objects with high accuracy rate. • The ability to confirm their guess greatly increases the learning curve. • Changing the sensitivity does affect the outcome and the users report an understanding of how it works. • Objects may have peculiar signatures that would be difficult to predict but are easy to identify and learn experientially.
Temperature to Sound	• Users are able to quickly learn the sense but have a hard time since they can't see where the sensor is precisely. • Offering feedback to tell the user if they were correct or not, not only helped the learning process but also their performance, making the experience more enjoyable. • The results show how the time per turn goes down while the accuracy tends to remain constant, showing that the users are becoming more comfortable and efficient with the experience.
Cellphone Sensors to Sound	• With no contextual information, the users felt the need to guess at their artificial sense; this guess was for the most part accurate. • When the guess was wrong, it was very interesting to see how the users would use their context to venture a guess. This is important because it begins to show how the brain tries to make sense of the signal.
Smell Notification	• Great for more than one user with a single signal. • The slow dissipation of the smell can be an indicator of passed time since the signal.
Smell Creation	• The creation of different smells with a single machine starts to become a possibility.
Stress to Sound	• The distance between the sensor and the target was too far; this affects the accuracy of the sensor and of the user aiming at that target. • The changes in temperature that I was interested in were too small, I either needed a better sensor or an activity that created more dramatic changes in the target's emotions.
Glass Infrastructure to Temperature	• Temperature is a great feedback for binary signals, not so much for analog. • Using temperature will allow for a long term wearable that will not be annoying to the user and noticeable enough when the change happens.