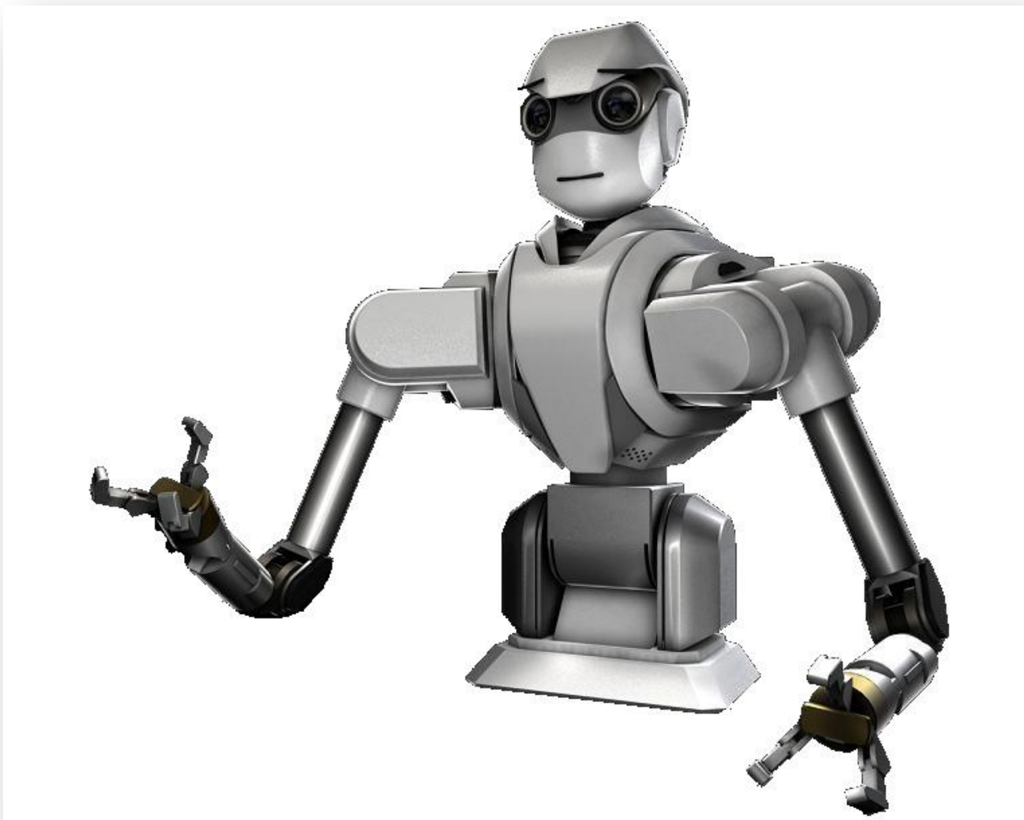
Design Report

Senior Design May 10-26

Artificial Fingernails for a Humanoid Robot



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1. Executive Summary

The ability to scratch objects and surfaces plays an important role in human development and learning. Scratching is facilitated by the sense of touch (which includes receptors for touch, vibration, pain, heat) and the presence of nails. While most animals have some form of nails (or hoofs) this concept does not even exists in robotics.

The solution is designing artificial fingernails for a humanoid robot that are suitable for identifying surfaces and material properties of objects simply by scratching them. The nails will have to be equipped with sensors for touch, vibrations, and accelerations. Aesthetics are important in this project, so miniaturization will be key. The nails will have to be designed so that they fit the three-finger Barrett hands of the Upper-torso humanoid robot in the Developmental Robotics Lab. A printed circuit board will have to be designed to control and read the input of up to three finger nails per hand at the same time. Finally, control software must be written for the finished product and demonstrate a working hardware and software prototype.

The end product will be a new upper-segment finger frame with attached nail along with the electronics necessary to log nail vibrations via USB to the computer connected to the robot. The electronics will consist of one accelerometer per finger, along with at least one microcontroller per hand and any other sensors that fit the finger and the budget. The microcontrollers will transmit the accelerometer data along with data from any other sensor that was included via a USB cable that is run along the robot's arm to the computer.

Additionally, software to log the data from the microcontroller via USB will be delivered. The software will facilitate correlating the data from the scratching with movement data logged from the separate movement controlling software. The software will parse incoming data and log it in a delimited format.

Both deliverables will be completed and delivered by the end of March 2010.

The major issue to be resolved is the task of optimizing sensor and electronics selection breadth, compactness of the electronics design, the power consumed by the system as a whole, and the effective transmission of the vibrations through the nail to the accelerometer.

2. Acknowledgement

The following individuals should be acknowledged for their contributions to this project.

- Dr. Alexander Stoytchev
- Vlad Sukhoy
- Steven Lischer
- Iowa State University ECpE Department
- Manimaran Govindarasu
- Developmental Robotics Laboratory

Dr. Stoytchev has helped tremendously by providing continuing guidance to the team as well as establishing the original research need. Dr. Stoytchev also provides financial support for the project.

Vlad Sukhoy has helped the project through his coding efforts and software interfacing with the other robotic systems.

Steven Lischer has made contributions to the project by helping with the mechanical design of the fingernail in SolidWorks.

The ECpE department at Iowa State University continues to provide the facilities, equipment, and faculty expertise needed to bring about this and many other engineering projects. The ECpE department has also provided financial support to the project.

Manimaran Govindarasu has provided organizational direction and project management support through his classroom instruction for the EE 491 class this project is a part of.

Finally, the Developmental Robotics Laboratory has provided developmental computers, workspace, and the robot itself for use with this project. Access to this lab has been critical in furthering this project.

3. Problem Statement

The problem statement gives an overview of the problem this project is solving, as well as the approach taken to solve it. Two sub-sections are included:

1. General problem statement
2. General solution approach

The general problem statement emphasizes how the ability to scratch objects and surfaces plays an important role in human development and learning. Scratching is facilitated by the sense of touch (which includes receptors for touch, vibration, pain, heat) and the presence of nails. While most animals have some form of nails (or hoofs) this concept does not even exists in robotics.

The general solution approach is about designing artificial finger nails for a humanoid robot that are suitable for identifying surfaces and material properties of objects simply by scratching them. The nails will have to be equipped with sensors for touch, vibrations, and accelerations. Aesthetics are important in this project, so miniaturization would be a key. The nails will have to be designed so that they fit the three-finger Barrett hands of the Upper-torso humanoid robot in the Developmental Robotics Lab. A printed circuit board will have to be designed to control and read the input of up to three finger nails per hand at the same time. Finally, control software must be written for the finished product and demonstrate a working hardware and software prototype.

4. Operating Environment

The end product will be attached to the humanoid robot of the Developmental Robotics Laboratory at Iowa State University. This lab is climate controlled and is restricted access only. The product will be integrated into the robotic hand and finger. As such, it will be subjected to 3D movement on a regular basis. As the purpose of the product is to gather sample surface data through scratching, the product will be subjected to thousands of scratching tests. Each test will induce physical strain on the "nail" and vibrations to all the product components.

5. Intended User(s) and Intended Use(s)

This section will detail the intended users and intended uses of the product. The intended users description will explain the characteristics of any possible user of the end product. The intended uses description will detail any expected use of the end product.

There are three levels of intended users for this product. They are:

1. Undergraduate engineering students
2. Graduate engineering students
3. Engineering faculty

As such, each user is expected to be deeply familiar with computer use and safe-handling of electrical components. Additionally, because the lab where the robot is situated is always locked, any user must either be pre-authorized to access the lab (and therefore the robot), or get temporary access. This ensures that there is always a limited number of persons with access to the robot. The restricted access therefore ensures that only approved users with the appropriate working knowledge of how to run the robot will have access.

All users with access to the lab should be aware of safety procedures when the robot is in use. During experiments, no user should be within reach of any of the moving parts of the robot. Also, users must be capable of using a keyboard and mouse to interface with the nail software. At least one end user must be capable of changing out the nail when it has been worn out.

The intended uses of the product are fairly straightforward. The nail and all associated hardware will be used to scratch a wide variety of surfaces. The surfaces can range from very soft to very hard. All surfaces are assumed to be dry. The data will be logged to the computer connected to the robot. After many repetitive experiments, the data will be analyzed in an attempt to identify materials based on their scratching data profile.

6. Assumptions and Limitations

This section contains the list of assumptions and limitations to this project. First the assumptions list will be presented, followed by the limitations list.

The assumptions for this product are listed in this paragraph. The product will only be used on the Barrett hand of the robot of the Developmental Robotics Lab at Iowa State University. All tested surfaces will be dry. The product will be used to identify one material type at a time. The initial number of nails installed will be three per hand, six total. Data from arm, hand, and finger movement will be available for correlation with scratching data. The computer attached to the robot will be running Linux, Windows XP, Windows Vista, or Windows 7.

The limitations for this product are listed in this paragraph. The product will be capable of sampling at least 1000 Hertz to identify hard surfaces. The product must be capable of running on USB power of 5 Volts at a maximum of 500 milli-Amperes. The product must not be used by anyone without the proper training on using the robot, or anyone that is not on the intended user list. The product will not be used underwater. The robot must be stationary during the scratching tests. The end product will fit on the hand and in the upper-segment of each finger so as to not hinder object manipulation the hand is currently able to perform.

7. Expected End Product and Other Deliverables

The end product will be a new upper-segment finger frame with attached nail along with the electronics necessary to log nail vibrations via USB to the computer connected to the robot. The finger frame is expected to be molded from the 3D plastic printer, printed at Iowa State University's output center in the Design College. The electronics will consist of one accelerometer per finger, along with at least one microcontroller per hand and any other sensors that fit the finger and the budget. The microcontrollers will transmit the accelerometer data along with data from any other sensor that was included via a USB cable that is run along the robot's arm to the computer.

Additionally, software to log the data from the microcontroller via USB will be delivered. The software will facilitate correlating the data from the scratching with movement data logged from the separate movement controlling software. The software will parse incoming data and log it in a delimited format.

Both deliverables will be completed and delivered by the end of March 2010.

8. Approach and Product Design Results

This section will detail the proposed approach as well as the statement of work in two separate subsections.

8.1. Proposed Approach

This subsection includes the items shown in the list below. Each of these elements is key to the project's success.

1. Functional requirements
2. Constraints considerations
3. Technology considerations
4. Technical approach considerations
5. Testing requirements considerations
6. Security considerations
7. Safety considerations
8. Intellectual property considerations
9. Commercialization considerations
10. Possible risks and risk management
11. Project proposed milestones and evaluation criteria
12. Project tracking procedures

8.1.1 Functional Requirements

The first element of the proposed approach is the list of functional requirements. The functional requirements shown will define what the end product should and should not do. Each functional requirement will appear as an item in a list and be accompanied by a brief description.

FR#001 - The nail shall be capable of transmitting vibration to the associated accelerometer for that finger.

FR#002 - The nail shall be able to perform at least 10,000 scratching tests before needing to be replaced.

FR#003 - The electronics shall be able to sample vibrations at at least 1000 Hertz.

FR#004 - The electronics shall be able receive accelerometer data from 3 accelerometers simultaneously.

FR#005 - The electronics shall be able to transmit all sensor data to the attached computer via the USB port.

FR#006 - The electronics and nail unit shall be removable from the robot hand.

FR#007 - The software shall log the sensor data delimited by sensor and finger.

FR#008 - The software shall associate time-stamps with each data set.

FR#009 - Vibrations shall be sensed using an accelerometer.

FR#010 - Nail unit shall look similar to a human nail.

FR#011 - The electronics shall be integrated into the robot hand such to not limit existing robotic capabilities.

FR#012 - The product shall log data individually from each finger.

FR#013 - The software shall be capable of starting new log files for each new material tested.

FR#014 - The product shall integrate as many other sensors of the following list as space and budget permit: Heat, Pressure, Ambient Light, Moisture, Sound, and Visual.

FR#015 - The electronics shall be covered to prevent ESD discharge and/or human shock.

8.1.2. Constraints Considerations

The following section lists the design constraint considerations for this product.

C#001 - The product will only be used on the Barrett hand of the robot of the Developmental Robotics Lab at Iowa State University.

C#002 - All tested surfaces will be dry.

C#003 - The product will be used to identify one material type at a time.

C#004 - Data from arm, hand, and finger movement will be available for correlation with scratching data.

C#005 - The computer attached to the robot will be running Linux, Windows XP, Windows Vista, or Windows 7.

C#006 - The product must be capable of running on USB power of 5 Volts at a maximum of 500 milli-Amperes.

C#007 - The product must not be used by anyone without the proper training on using the robot, or anyone that is not on the intended user list.

C#008 - The product will not be used underwater.

C#009 - The robot must be stationary during the scratching tests.

8.1.3. Technology Considerations

This section details the technology that will be considered when developing this product. Four main technology areas will be developed. They are shown below.

1. **Sensors** - Which accelerometers, microphones, pressure sensors, etc. are chosen here depends primarily on the interface to the microcontroller, the data acquisition rate, power consumption, and the size of the sensor.

2. **Microcontrollers** - Which microcontrollers are chosen depends on number of ports available, different communication standards available in that controller, speed, memory, power consumption, and size.

3. **Logging Software** - The choice of logging software is based on group familiarity with the language, language responsiveness to high data-rates, stability, platform compatibility, and USB protocol support.

4. **Nail Material** - The nail material selection is based on vibrational transmission effectiveness, strength, and durability.

8.1.4. Technical Approach Considerations

The technical approach to be taken for this project will be rapid prototyping. The goal will be to make baseline decisions on all four technology considerations listed above early on. Then develop prototypes using that technology to optimize the selection and uncover problems quickly. This method was chosen because the sensors and microcontrollers are low-cost and easily obtained, but the development in time-consuming and very complicated.

The prototyping phase will hammer out the details of the interfaces and hardware selection. From there the hardware will be optimized for size by designing our own printed circuit boards. All interfacing issues should have been discovered before the PCB design phase. Eagle will be used for PCB design.

Throughout the development process, many milestone tests will be performed to establish a baseline for sensor performance and research capabilities. Ultimately, the selection criteria will be a combination of the most sensors that can be packed into a small space, which accelerometers being the only mandatory sensor. The optimization of size constraints will be done using Solidworks to model the plastic frame and component integration and simulate the layout before actually assembling it.

8.1.5. Testing Considerations

In light of rapid prototyping being used for development, testing will be continuous throughout the project and smaller than typical from heavy up-front design projects. The testing philosophy is to modularize and test individual prototypes as much as possible. The planned prototyping test order with the associated prototype milestone is shown below.

1. Prototype and test USB to microcontroller interface
2. Prototype and test accelerometer to microcontroller interface
3. Prototype and test any additional sensor to microcontroller interfaces on an individual basis
4. Prototype and test software to log "hello world" data from microcontroller via USB port
5. Prototype and test nail design using accelerometer prototype
6. Prototype and test in Eagle and PSpice the PCB layout
7. Prototype and test in Solidworks complete layout

Acceptance of each prototype will be tied directly to the functional requirements.

8.1.6. Security Considerations

No security concerns have been directly listed by the client for this project. The client did want to research if this research had been done already, indicating an indirect concern about originality. Because of the timeline of this project, the risk of research driven competition from information provided online is low because information detailing the working design will only be provided after being completed. Much of the security of the concept alone then comes from a lack of known channels from this project's website to competing researchers.

Security related to the operation of the product is taken care of through the restricted access policy implemented in the Developmental Robotics Lab.

8.1.7. Safety Considerations

The end product will be using standard USB electrical specifications. The final design will have covered electronics to prevent accidental shock.

Any identifiable safety issues that are likely to occur during the manufacture, use, maintenance or disposal of the end product should be identified and addressed up front. This is extremely important because changes in the end product, its manufacture, its maintenance, or its disposal may be required.

8.1.8. Intellectual Property Considerations

Because the project is being hosted by a lab within the ECpE department, the intellectual property considerations fall under the policy of Iowa State University.

8.1.9. Commercial Considerations

There are no indicated commercial plans associated with this project at the present.

8.1.10. Possible Risks and Risk Management

The risks associated with this project are listed below along with the mitigation plan.

- Loss of a team member - To mitigate this risk, the key is documentation and continuous communication. Prototyping efforts will be documented and shared after each success. This will create an evolving knowledge-base of development up to that point.

- Lack of expertise - The mitigation of this risk is done through early prototyping and reaching out to known experts. By identifying this risk early on and resolving lack of expertise through education efforts or associate assistance, the risk of not having enough time or not having the associates available during "crunch-time" is diminished.

- Part ordering delays - To mitigate this risk, multiple manufacturers have been identified selling the critical system components. Also, the manufacturers chosen are reliable distributors. To further diminish this risk, early prototyping provides a clear channel to obtain the hardware early on.

8.1.11. Project Proposed Milestones and Evaluation Criteria

The project milestones are directly related to the prototyping and testing efforts. They are shown below along with additional items related to beginning and finishing the project, that are not considered part of the rapid-prototyping.

1. Define problem
2. Research, decide on, and order Microcontroller
3. Research, decide on, and order accelerometer
4. Research, decide on, and order other sensors
5. Prototype and test USB to microcontroller interface
6. Prototype and test accelerometer to microcontroller interface
7. Prototype and test any additional sensor to microcontroller interfaces on an individual basis
8. Prototype and test software to log "hello world" data from microcontroller via USB port
9. Prototype and test nail design using accelerometer prototype
10. Prototype and test in Eagle and PSpice the PCB layout
11. Prototype and test in Solidworks complete layout
12. Order PCB and nail unit (from the complete layout)
13. Assemble and test fully integrated and optimized unit
14. Finish product documentation
15. Demonstrate working project
16. Report on project success

Evaluation criteria will be directly tied to the functional requirements. Items 1, 2, 4, and 5 are all or nothing. They must be working for the project to succeed at all. Also, for those items there isn't much room to go beyond the task. Items 3 and 6 will be successful depending on how many sensors end up being in the final product. This ties to items 9 and 10 which report on how well the space optimization was done. Finally, the overall success of the project depends on how well the other items come together. Success is mainly dictated by items 1, 2, 4, and 5, with excellent size layout and extra sensors just being bonus.

8.1.12. Project Tracking Procedures

The project tracking procedure is as follows. Each week the team's activities will be compared against the milestone list, with each individual having an assignment directly tied to a given milestone. Then, the results of that meeting will be posted to the course professor via e-mail and to rest of the team and advisor through the project website. Course corrections will happen throughout the project depending on the prototyping progress.

Additionally, the overall time of the project will be tracked according to the course time-line for deliverables, to ensure that report items are prepared when needed. Finally, as part of the meetings, estimated time for completion of the broken down prototyping tasks will be given to facilitate even task distribution and bottleneck detection.

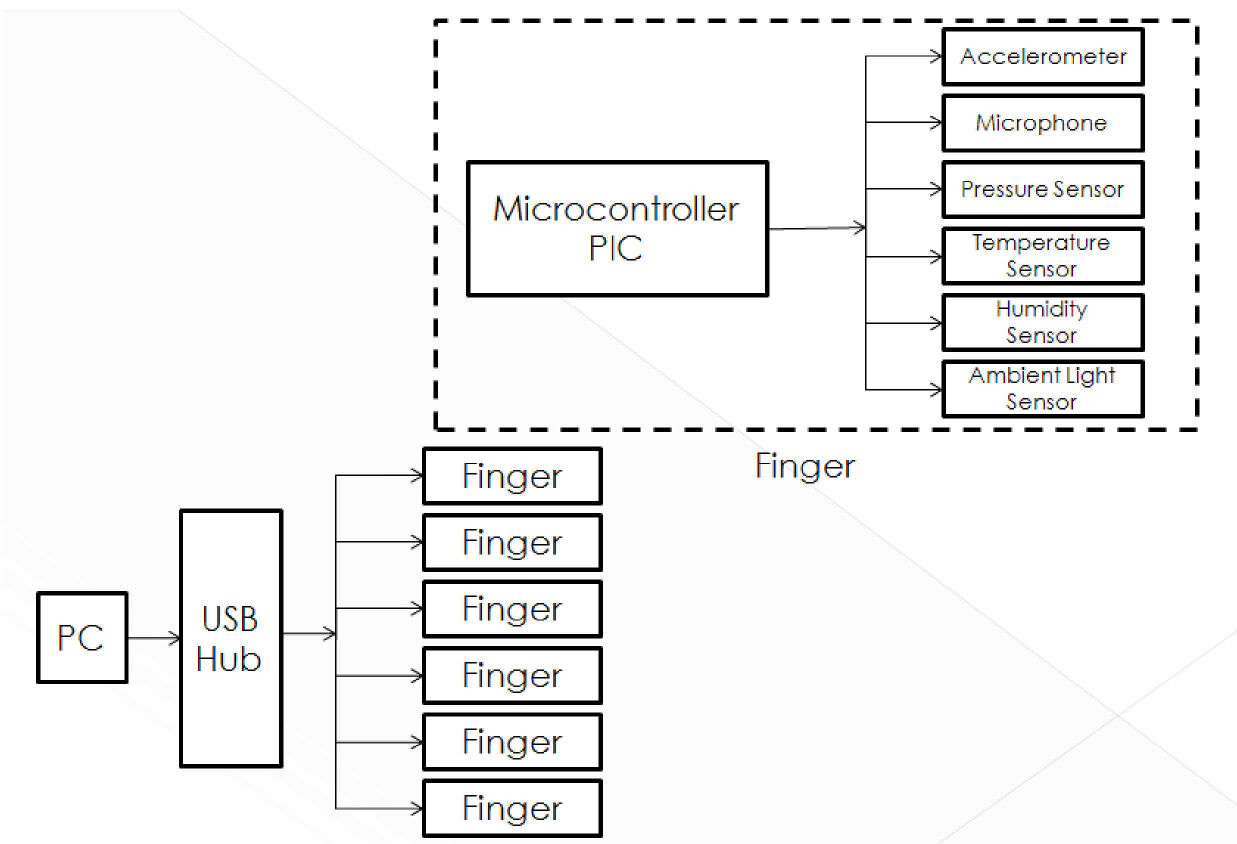
Financially, the project will be tracking using a spreadsheet that will be shared between the team members and the advisor. This spreadsheet will track all expenditures related to the project. All other documents related to the project that are critically shared information will be posted to the team's website.

9. Market and Literature Survey

Kuchenbecker at UPenn proposed using accelerometers, strain gauges and other types of contact sensors to record tactile sensations with the idea of reproducing them later so that similar sensations can be experienced again. Howe and Cutkosky (Stanford) suggested detecting slip from the readings of a 3-axial accelerometer. They also reported that the accelerometer's output is affected mostly by the sliding velocity, a bit less by the surface roughness and only slightly by the normal force applied. Hosoda et al. (Osaka University, Japan) used a robotic finger to apply two exploratory behaviors (pushing and rubbing) to objects made of five different materials. The finger contained polyvinylidene fluoride (PVDF) films and strain gauges sensors. de Boissieu et al. (MINATEC, France) used three-axial force sensors embedded in an artificial finger that was mounted on a plotter to discriminate between 10 different types of paper. Iwamoto et al. (University of Tokyo, Japan) proposed embedding an accelerometer inside a ring that a human can wear. The device was used to implement a "virtual mouse."

10. Detailed Design

Each of the Barrett hand contains three fingers each (shown in the figure on the right). For each of the fingers, there will be a microcontroller and the set of sensors. This hardware will be connected to a computer which will be running Linux using a USB Hub.

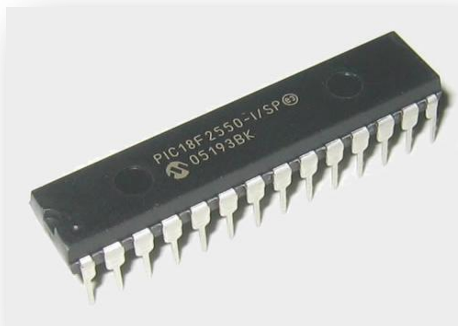


10.1 Electrical Components

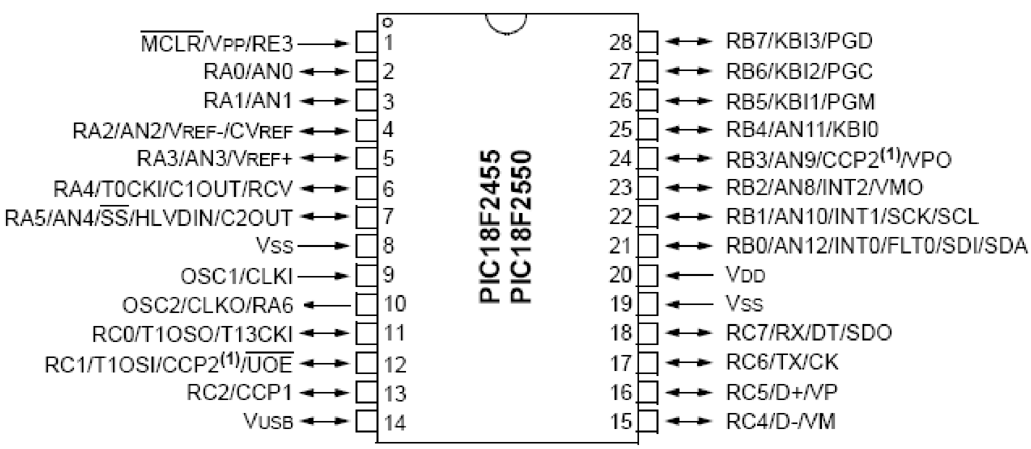
This section includes a complete list of parts, the source of each part, qualification criteria and the estimated cost.

10.1.1 Microcontroller

The microcontroller must be fast, accurate, and have at least 28 pins, enhanced flash, high performance, and be controllable over USB. So, PIC18F2550 manufactured by Microchip was chosen.



The pin diagram looks like this:



The main reason for this decision was that this device is incorporated with a fully featured Universal Serial Bus (USB) communications module.

10.1.2 Accelerometer

The accelerometer, one of the main requirements for the project, must be small, low-power, digital 3-axis with high resolution and high output data rate. It should be accessible through a I^2C digital interface.

The chosen accelerometer is manufactured by Analog Devices, part number ADXL345. It has a bandwidth of upto 3200 Hz, i.e., each reading takes about 0.31 milli-seconds. The functional block

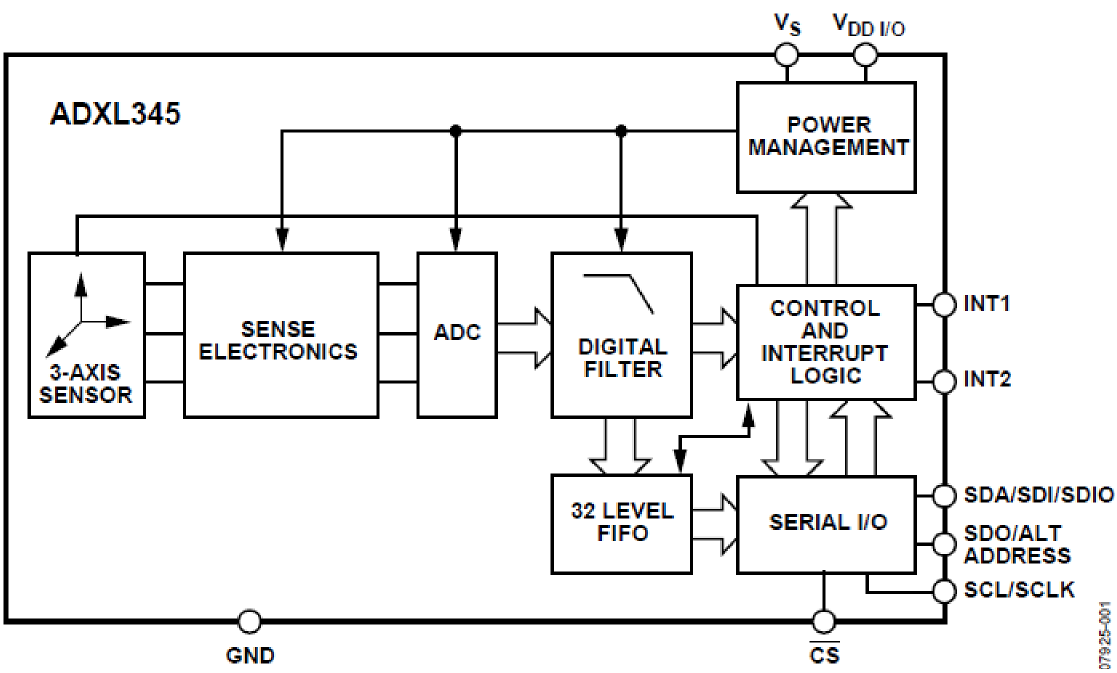
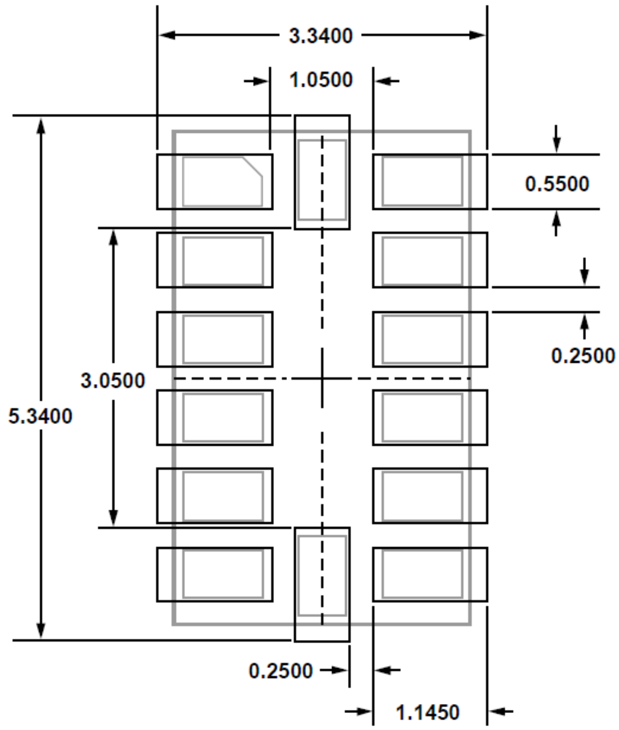


diagram is shown below.

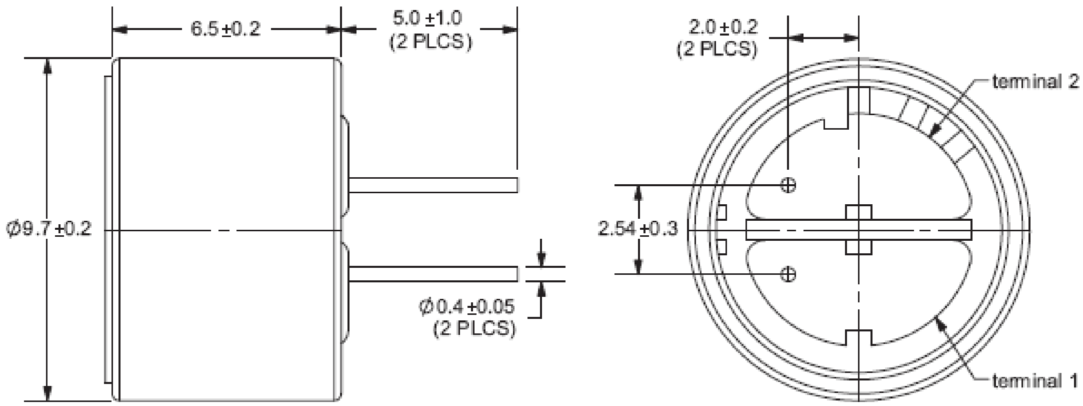
The outline dimensions of the part are shown in the figure below.



10.1.3 Microphone

The microphone is an integral part of our design. A high quality microphone must be used so that the end-user can perform digital signal processing using the input from the microphone. Since noise reduction is an overarching premise, the size of the microphone must be kept in check so that it can fit in the upper segment of the hand.

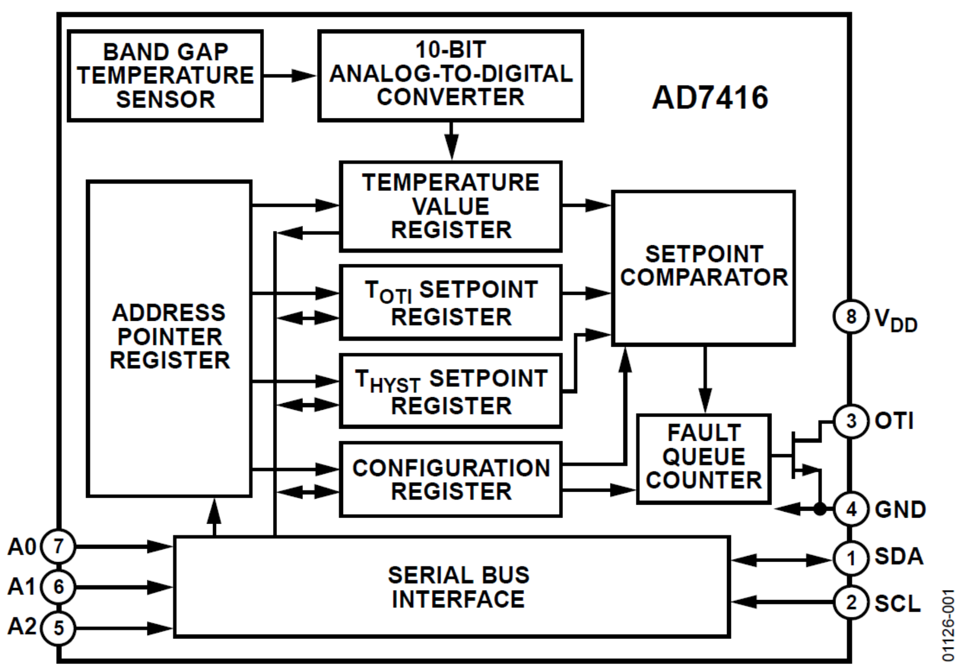
So, a microphone made by CUI Inc, part number CMA-6542PF was chosen. It has high sensitivity and small in size. The appearance drawing is shown below:



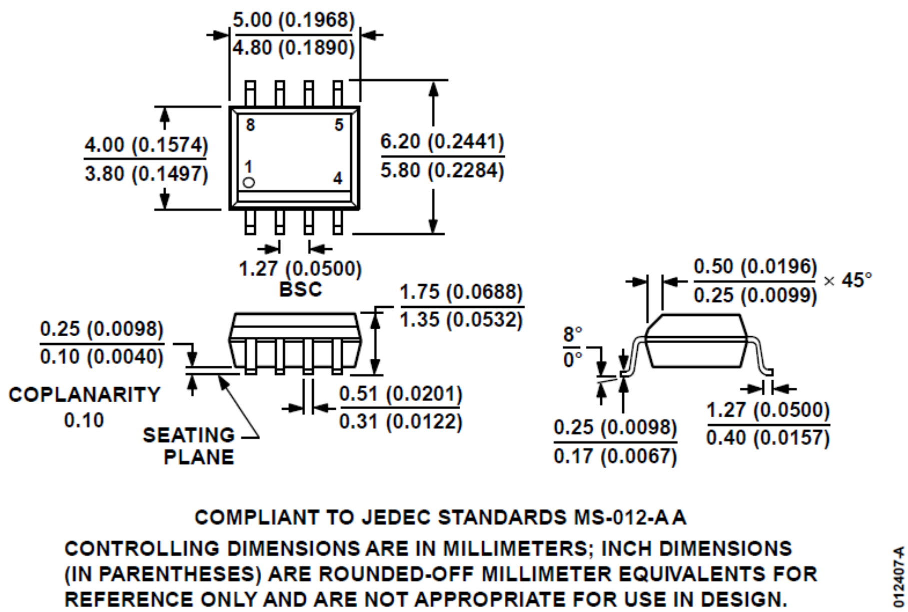
10.1.4 Temperature Sensor

This sensor must be small, I^2C serial interface compatible and should have a fast output rate. The chosen sensor is manufactured by Analog Devices, part number AD7416 and has a conversion rate of 27 μs.

The block diagram is shown below.



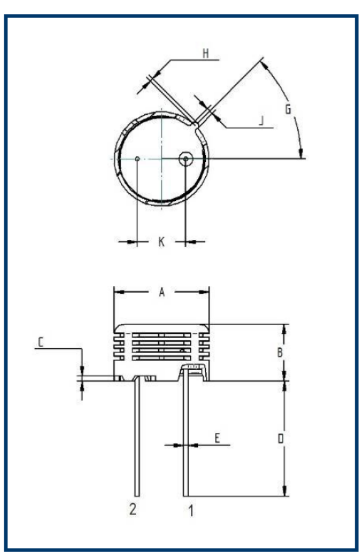
The outline dimensions of the sensor are shown in the figure below.



10.1.5 Humidity Sensor

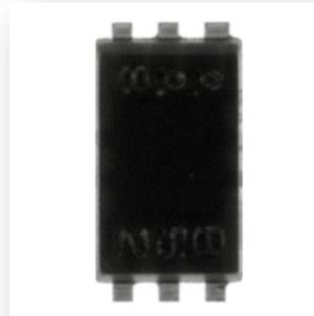
This sensor must be small and reliable with fast response time and low temperature coefficient. So, HS1101LF manufactured by Measurement Specialties was chosen. It has a time constant of about 5 seconds and measures from 1 to 99%RH.

The outline dimensions are shown below.



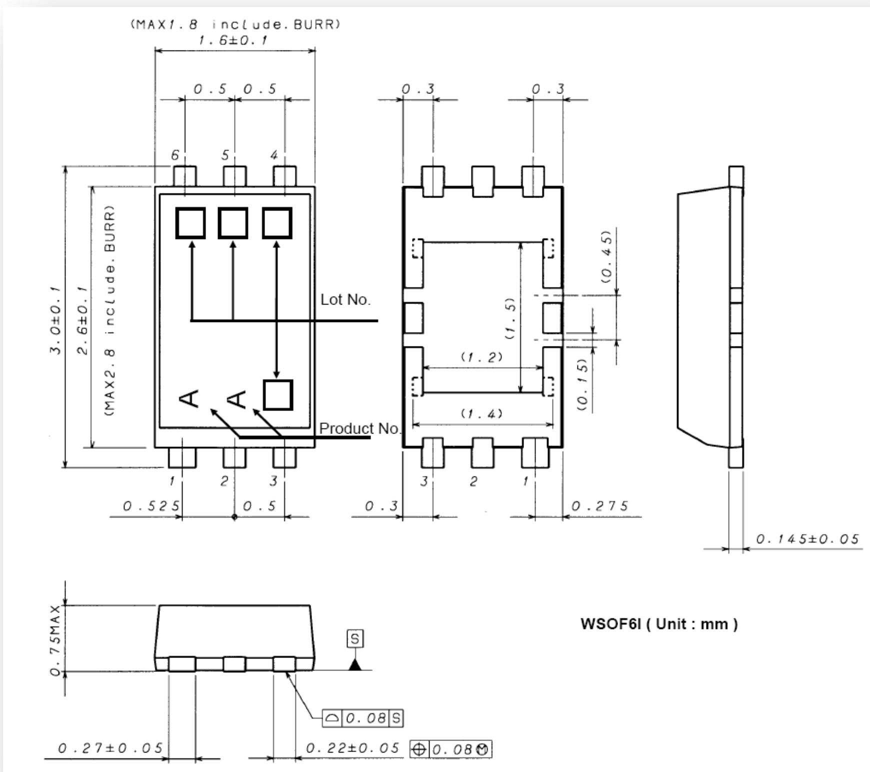
Dim	Min (mm)	Max (mm)
A	9.70	10.20
B	5.70	6.20
C	0.40	0.60
D	12.00	14.00
E	0.40	0.50
G	45° BCS	
H	0.70	1.10
J	0.70	0.90
K	4.83	5.33

10.1.6 Ambient Light Sensor



This sensor, like the others, must be small in order to fit in the upper segment of the finger. It should also be accurate, fast and approximately have the same sensitivity as that of a human eye.

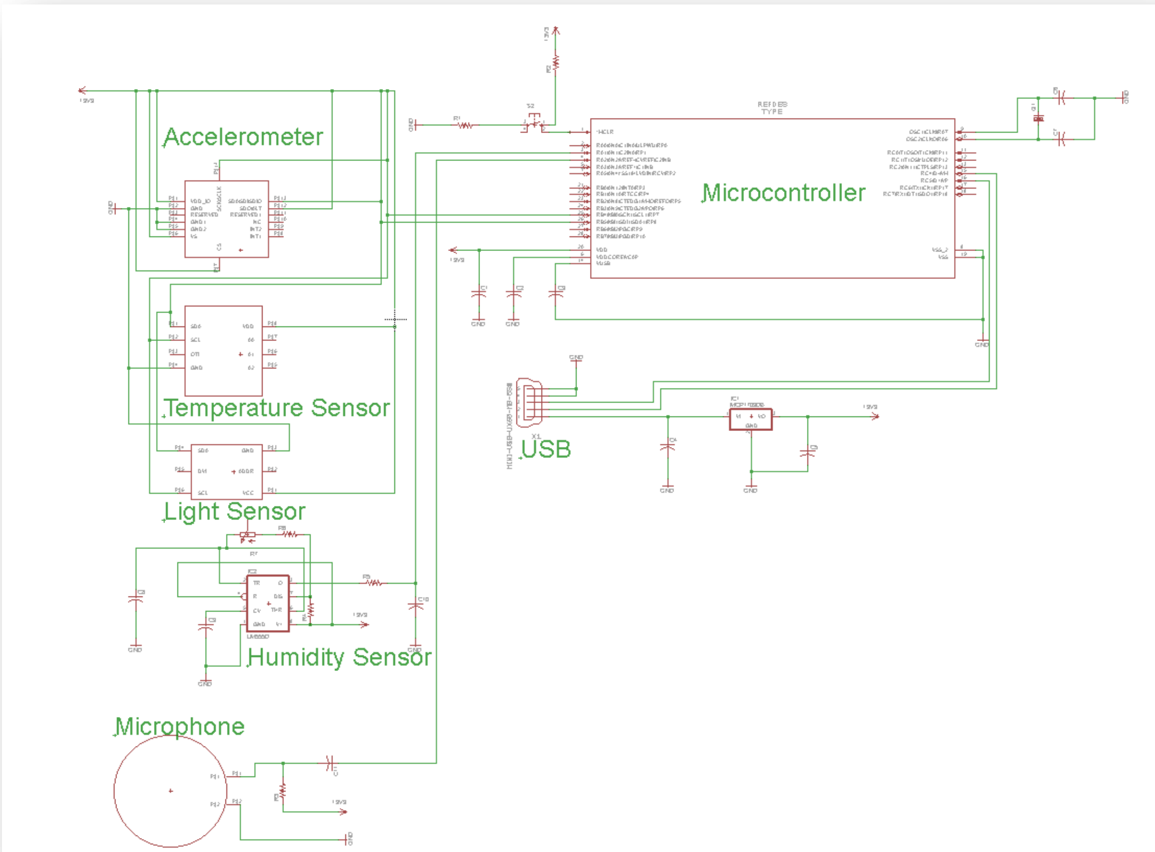
So, BH1750FVI, made by ROHM Co. Ltd, is a digital, accurate, fast light sensor IC. Its measurement time is approximately 120 ms for high resolution mode. The package dimensions are shown below.



NOTE: All datasheets are available online at our website
http://seniord.ece.iastate.edu/may1026/documents.html

10.2 Electronic Circuit Design

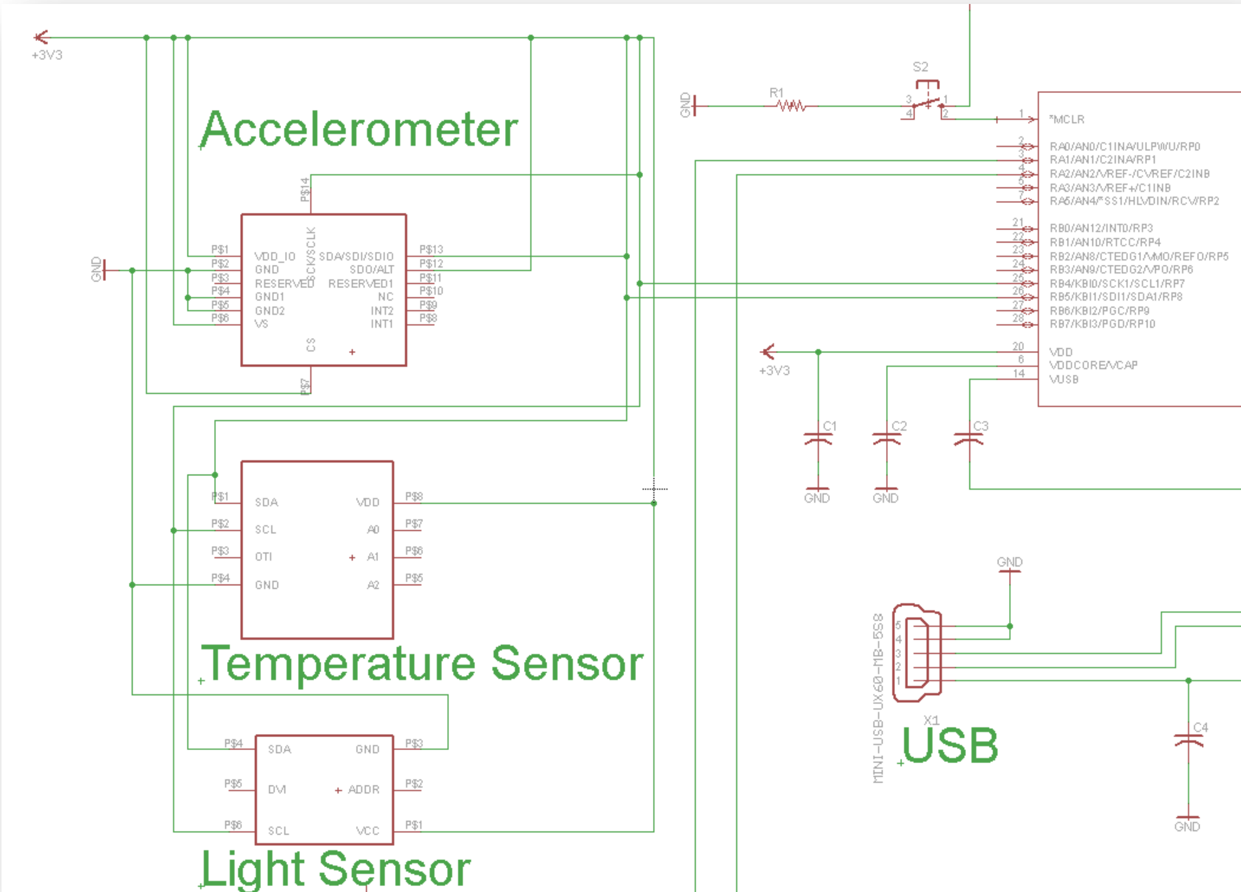
The printed circuit board which will control the various sensors was laid out using Cadsoft Eagle. Here is the entire schematic of the board, with appropriate sensors and their respective circuits:



In the schematic above, the accelerometer, temperature sensor, and light sensor are digital devices, whereas the humidity sensor and microphone output analog signals and must be interpreted by the microcontroller.

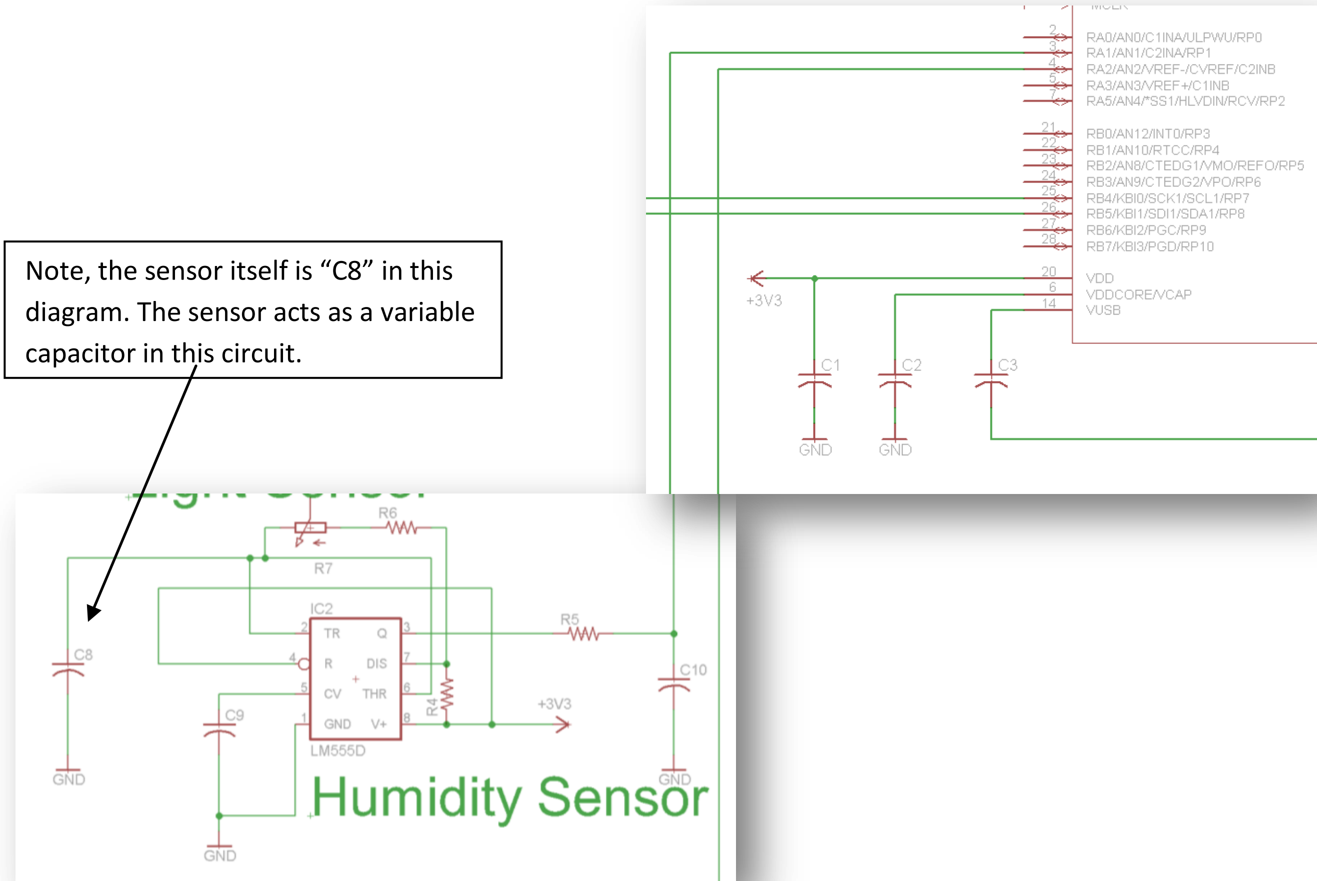
This section is now subdivided to take a closer look at each of the sensors and then finally the peripheral circuitry that will be used to support the microcontroller and sensors is explained.

The digital circuits are all I^2C ready, and are thusly all connected in the same manner:



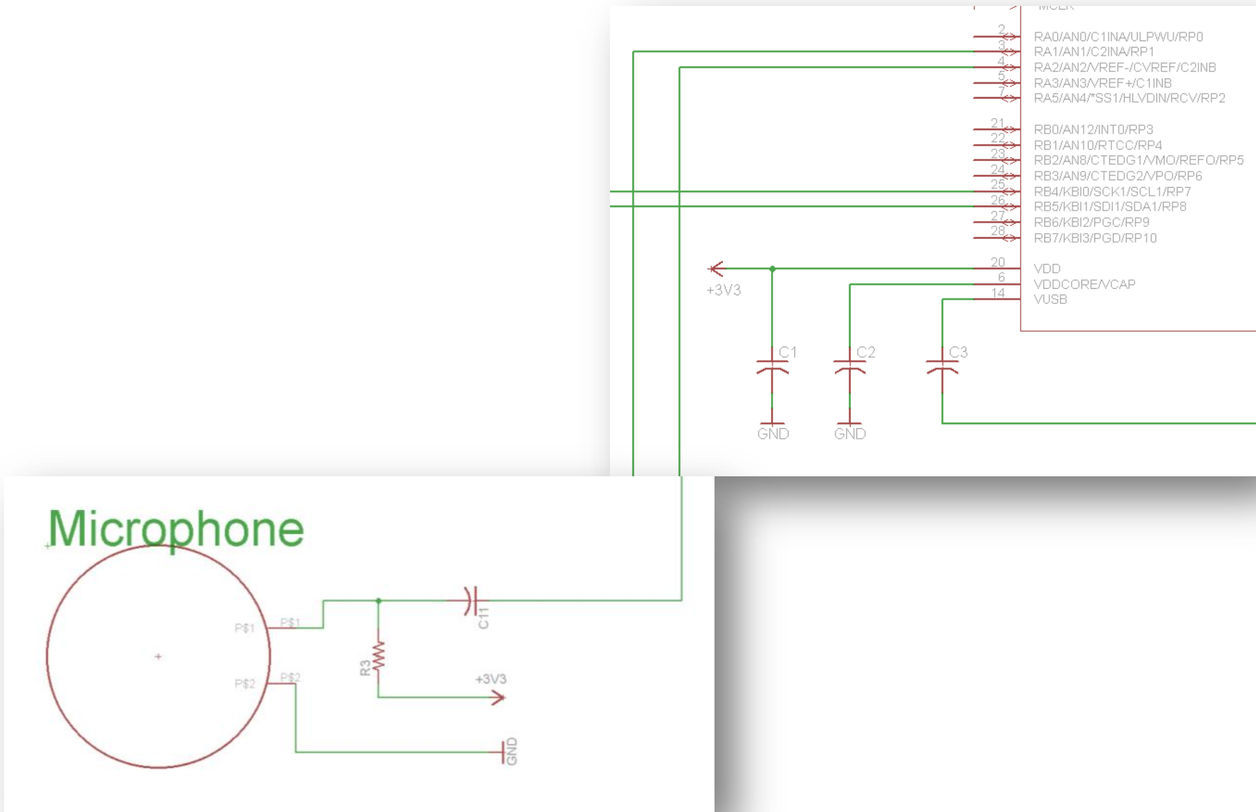
Each of these three sensors has a VCC port for power, a GND port for ground, and an SDA & SCL port for data. The SDA & SCL ports are each connected to a respective bus, which is biased by the 3.3V power supply. They are connected to the microcontroller for data output. The GND ports are connected to the GND bus of the system, and the VCC ports are biased with the 3.3V power supply.

The humidity sensor, being an analog device, has a circuit to convert the data into a usable signal, and is then connected to one of the analog data inputs of the microcontroller:

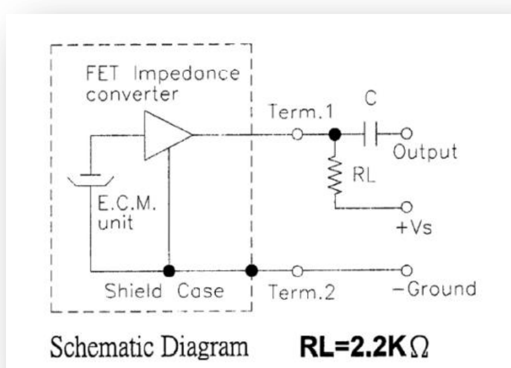


This circuit forces the 555 into an unstable mode of operation. The sensor charges through R6 and R4, then discharges through R6. The microcontroller will read the duty cycle of the output, determined by the capacitance of the humidity sensor (determined by ambient humidity), which will allow us to read the ambient humidity through the microcontroller.

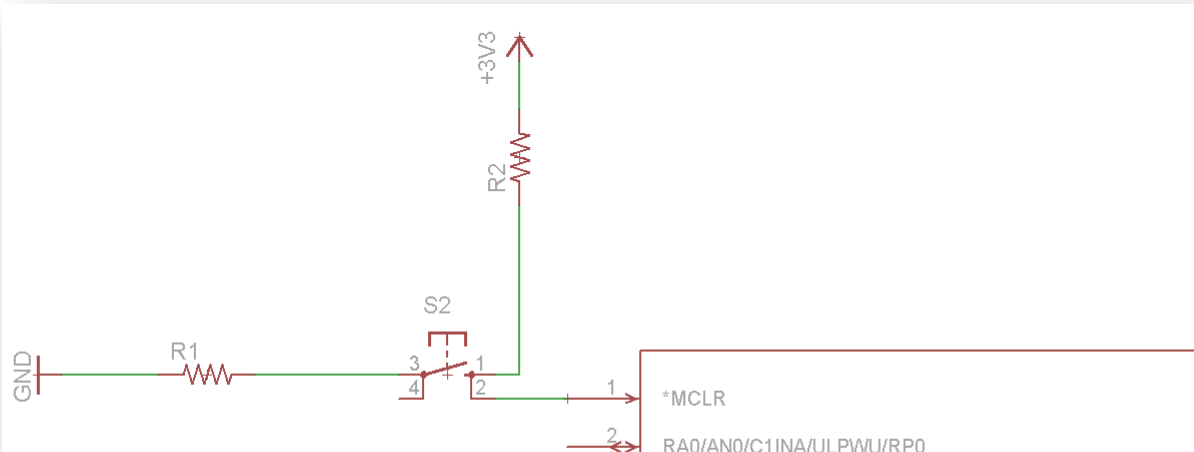
The microphone runs on a much simpler concept, but also connects to an analog port of the microcontroller:



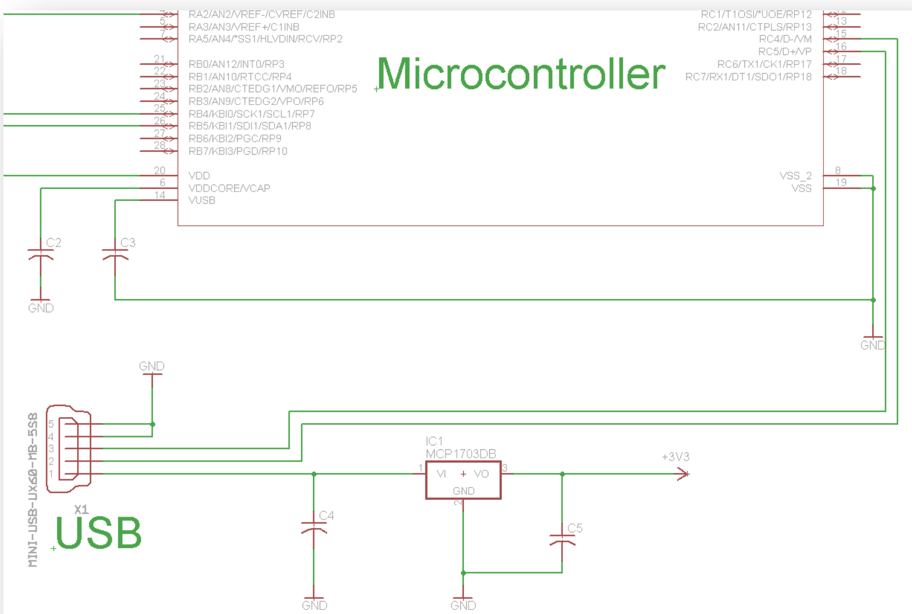
In the following figure, the microphone is acting as a preamp circuit. “C11”, above, is a DC blocking capacitor, and the microphone is biased with the power supply. The other port goes to ground:



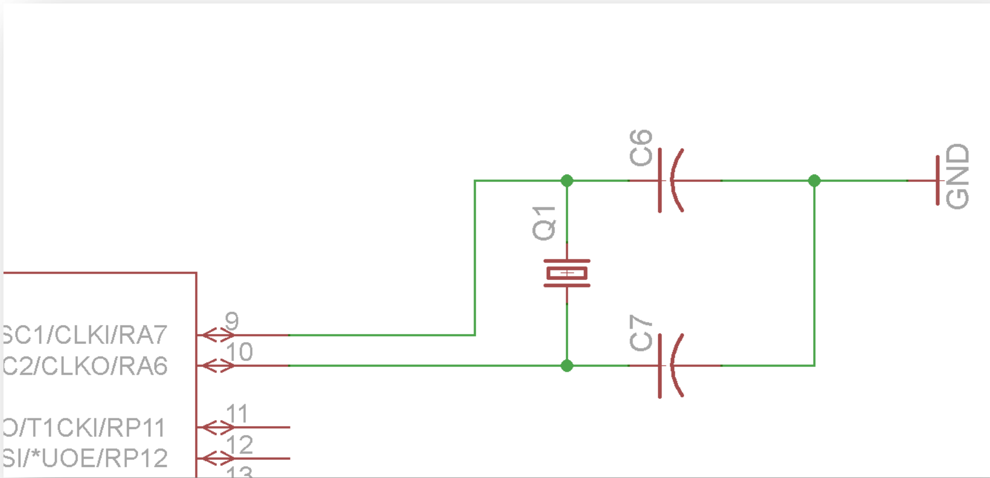
To finalize the circuitry, some necessary peripheral devices were added. There's a push-button switch tied to the hard reset (MCLR):



Also, there is a USB jack, which the primary power supply for the microcontroller and all sensors will be used, as well as for data output. An MCP1703 voltage regulator will be used to convert the regular 5V output to a more usable 3.3V output for the sensors:

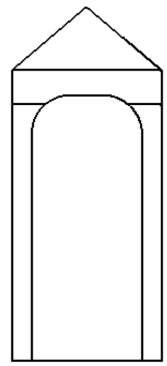
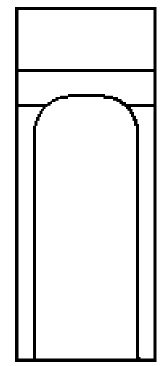
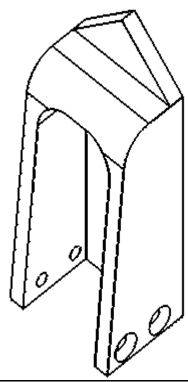
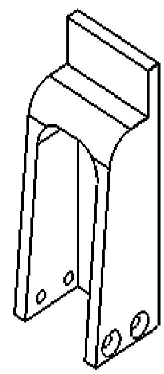
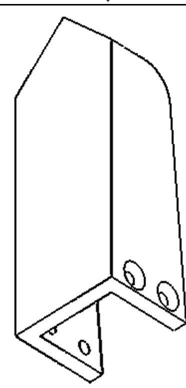
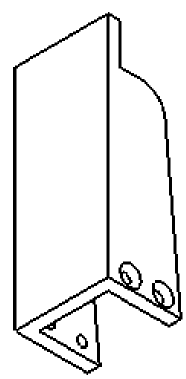
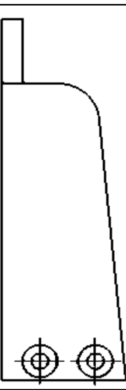
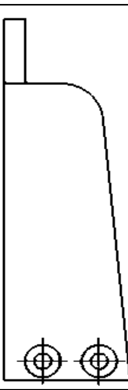


Finally, we're using a crystal oscillator circuit to generate the microcontroller CLK:



10.3 Mechanical Design of the Nail

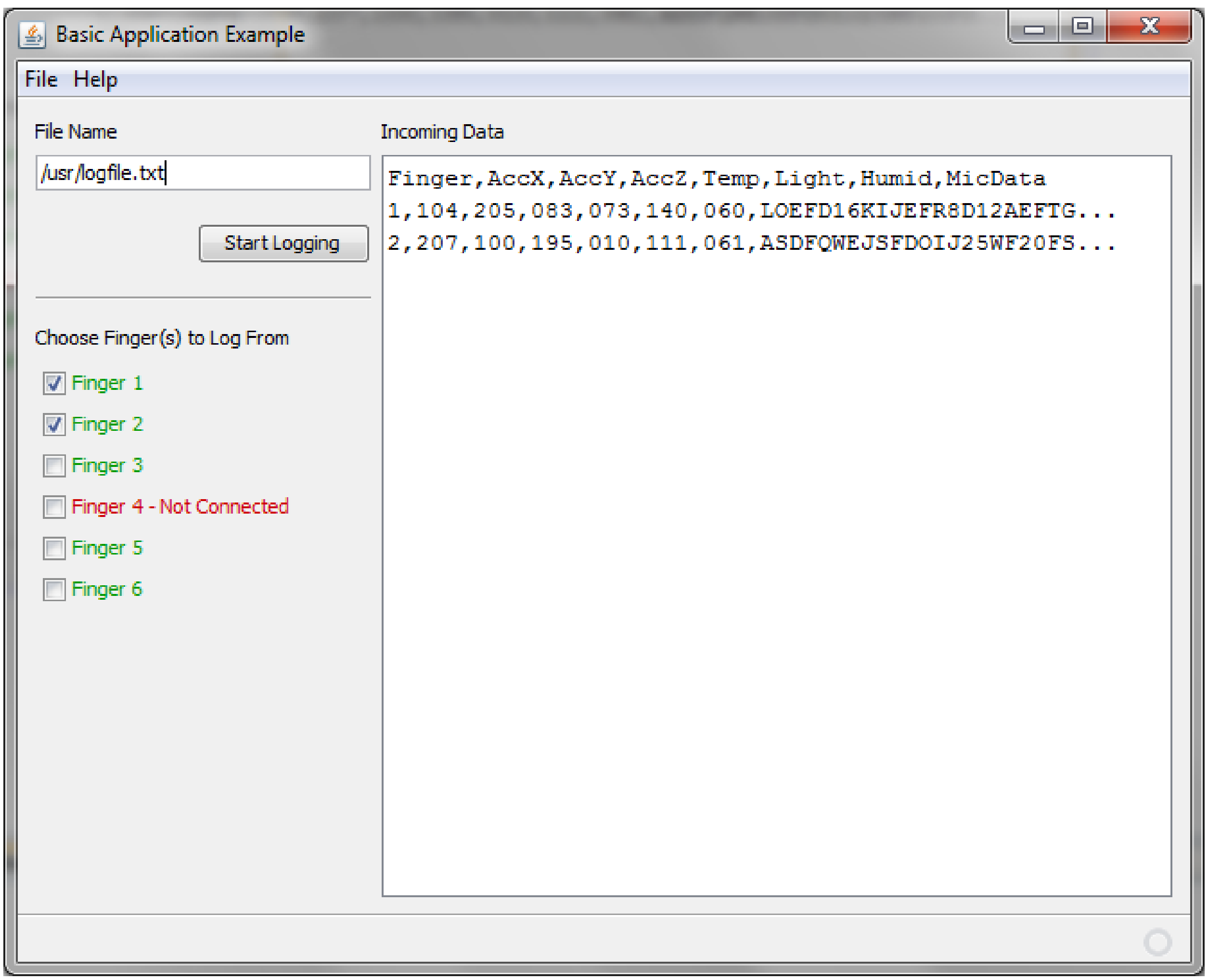
The fingernail was prototyped using a Rapid Prototyping Machine. The design was made in SolidWorks for two different types of fingertips, namely flat tip and sharp tip. The design is shown below.

Tip	Sharp Tip	Flat Tip
Back view		
Isometric back view		
Isometric front view		
Side view		

10.4 User Interface Specification

The user interface will be a simple graphics user interface (GUI) that shows incoming information from the connected microcontroller. There will be a text area of the GUI that will display incoming data regardless of if the data is being logged or not. On the GUI there will be checkboxes allowing the selection of which fingers/microcontrollers to log data from. Also, the color and text of the labels for these checkboxes will change to indicate the connection state of that device. There will be a text field allowing the user to specify the destination file name where the logged data is to be placed. Finally, there will be a button that starts logging to the file. The default behavior will be to append all data to a log file if one already exists of the same name.

A sample of the described GUI is shown below.



10.5 Input/Output Specification

Input for this system is to come in the following two forms.

1. User Input
2. Sensor Input

The user input will be from a mouse and keyboard connected to the controlling computer. The user input will specify what fingers to log from and the name of the file where the data is to be logged.

The sensor input from the sensor will be collected in mixed form. The accelerometer, temperature, and light sensors will all transmit their data digitally to the microcontroller via the I^2C bus. The microphone and humidity sensors are analog sensors and will be sampled voltages read from two separate analog pins of the microcontroller.

The microcontroller will package the data into an ASCII string that will be transmitted to the controlling computer via Full-Speed USB interrupt-mode transfers. Each microcontroller will identify itself as a unique USB device on the system. The ASCII string will contain a non-delimited ASCII string of a fixed length. The length is not specified here, but will be determined based on the final sampling intervals of the various devices. According to the USB specification for interrupt transfers, the maximum packet transmit frequency is 1000Hz, with a packet size of 64 bytes. Each device that is sampled at greater than 1000Hz will be packaged as a discrete sample string. Once received by the controller computer, the string will be delimited based on its length and the fixed length specification decided upon.

Output for this system will be the text area of the GUI, and the logfile that the GUI creates. Both the text area of the GUI and the logfile will contain data that is formatted exactly the same. The only difference would be the contents as the text area of the GUI is not synchronized with the logfile, but instead merely displays any incoming data seen by the program.

11. Testing and Evaluation Plan

Rapid prototyping causes testing to be small and continuous throughout. The testing philosophy is to modularize and test individual prototypes as much as possible. The order of testing is listed below:

1- USB to microcontroller interface -
Test Plan: Create basic packet program on the microcontroller and reception software on the controlling computer; Subsequently create testing program to tax the USB bus to determine the maximum throughput.

Evaluation Criteria: Successful "Hello World" packet sent from microcontroller to controlling computer via USB; USB throughput allows for a minimum of 64 KB/s.
Preliminary Results: Connecting the microcontroller to the USB bus through a serial-to-USB converter does not yield acceptable throughput.

2- Accelerometer to microcontroller interface -
Test Plan: Use framework from test 1 to send data from the accelerometer to the logging program via USB.
Evaluation Criteria: Correctly formatted data is received at an frequency of at least 1000Hz.
Preliminary Results: I2C communication established with the accelerometer using the prototype microcontroller.

3- Any additional sensor to microcontroller interfaces on an individual basis
Test Plan: Use framework from test 1 to send individual data for each sensor to the logging program via USB.
Evaluation Criteria: Correctly formatted data is received at the appropriate sensor sampling interval.
Preliminary Results: None

4- Software to log data from microcontroller via USB port
Test Plan: Extend framework from tests 1-3 to send and receive a fixed length ASCII string and comma delimit the information.
Evaluation Criteria: Data string is formatted correctly by the microcontroller and parsed correctly into a comma delimited list.
Preliminary Results: None

5- Nail design using accelerometer prototype
Test Plan: Use fingernail prototype along with the framework of tests 1,2 and 4 to test the acceptability of the nail design.
Evaluation Criteria: Nail design is able to generate sufficient accelerometer data to identify the surfaces being scratched.
Preliminary Results: Initial tests indicate 80% accuracy with the current nail design.

6- System Integration Testing
Test Plan: Combine prototypes from tests 1-5 to test all parts simultaneously.
Evaluation Criteria: Data from all sensors is formed into a 64 byte packet and transmitted at 1000 Hz to the controlling computer. The data is then parsed correctly and logged by the logging program.
Preliminary Results: None.

12. Resources and Schedules

This section is divided into two sections.

1. Resources requirements
2. Schedules

12.1 Resources requirements

Given below is an overview of the project breakout, showing individual tasks necessary to undergo project completion:

Task 1-	**Design Planning**	
	Subtask 1a	Sensor Research/Nail Material Selection
	Subtask 1b	CAD Tutorials
	Subtask 1c	PCB Design Software Tutorials
Task 2-	**Project Design**	
	Subtask 2a	CAD Design
	Subtask 2b	Prototype Coding
	Subtask 2c	Prototype Hardware Design
	Subtask 2d	Evaluation of Prototype
Task 3-	**Implementation**	
	Subtask 3a	Finalize Design
	Subtask 3b	Build Final Design
	Subtask 3c	Evaluate Final Design
	Subtask 3d	Final Report
	Subtask 3e	Project Poster

To estimate project resource requirements, we need to estimate labor and costs associated with each task and subtask, and aggregate these estimates into total project estimates. For each section, we've examined the necessary tasks and, based on team member skills, made appropriate labor estimates. This is shown in the following table:

Team Member	Task 1	Task 2	Task 3	Total
Akerson, Bob	60	70	65	195
Coleman, Joe	65	80	55	200
Sahai, Ritika	65	75	65	205
Total	190	225	185	600

These values represent our best estimates, and may not represent actual effort requirements at project completion.

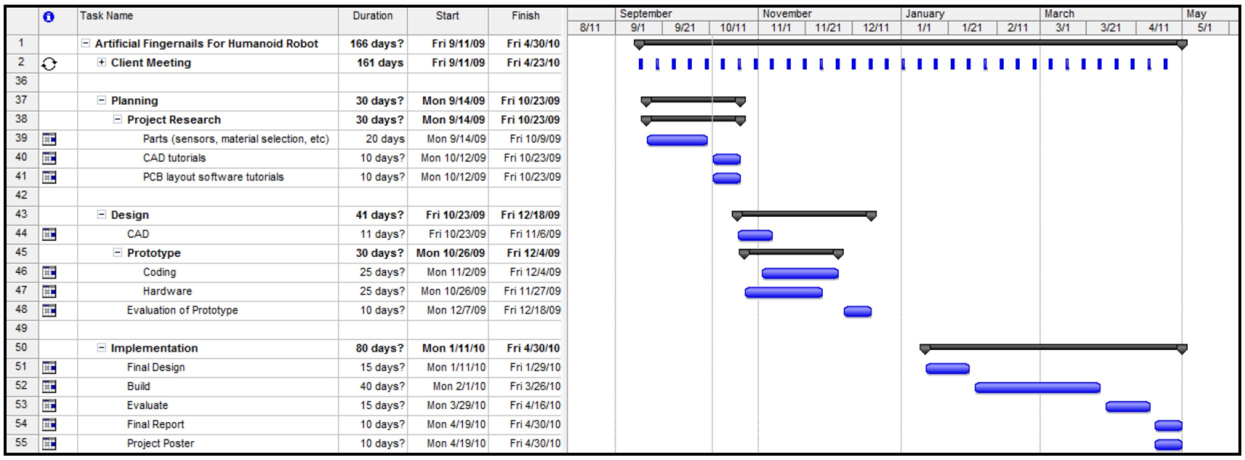
To finalize estimated resource requirements, we estimate the total cost of the project. Material costs are approximate based on industry research, fabrication costs are based on estimates from previous team member experience, and labor costs are based on a $20/hour rate. It should be noted here that labor costs will not actually exist for the project, but are a basis for simulating a real-life project estimate.

The project budget includes $250 from the college of engineering, as well as an undefined budget provided by the client. The following table contains our original estimated cost and updated cost estimates for the project:

Item	**Original Cost**	**Updated Cost**	**Reason for change**
Electrical Parts			
Accelerometers	$30	$25	The change in price is because at this point we know the exact price of the parts we need.
Temperature Sensor	$10	$15	
Light Sensor	$10	$18	
Humidity Sensor	$10	$90	
Microphones	$10	$5	
Microcontroller	$10	$26	
Fabrication			
Nail Fabrication	$30	$30	
PCB Fabrication	$120	$180	Exact price known
Subtotal (Non-labor)	**$240**	**$389**	
Labor	(Based on $20/hr)		
Akerson, Bob	$3,900	$3,900	
Coleman, Joseph	$4,000	$4,000	
Sahai, Ritika	$4,100	$4,100	
Total	**$12,240**	**$12,389**	

12.2 Schedules

Based on our project breakout and our effort estimates, we created a Gantt chart to show a tentative project completion schedule. Due to the size of the team and the nature of the project, many tasks will be completed in parallel or worked on by two to three engineers. This is particularly easy to see in the "design" section of the project. Here tasks are either interrelated (and therefore must be done simultaneously), or are unrelated (requiring only one or two team members), and therefore must be done concurrently with other tasks.



	Task Name	Duration	Start	Finish
1	**Artificial Fingernails For Humanoid Robot**	**166 days?**	**Fri 9/11/09**	**Fri 4/30/10**
2	**Client Meeting**	**161 days**	**Fri 9/11/09**	**Fri 4/23/10**
36				
37	**Planning**	**30 days?**	**Mon 9/14/09**	**Fri 10/23/09**
38	**Project Research**	**30 days?**	**Mon 9/14/09**	**Fri 10/23/09**
39	Parts (sensors, material selection, etc)	20 days	Mon 9/14/09	Fri 10/9/09
40	CAD tutorials	10 days?	Mon 10/12/09	Fri 10/23/09
41	PCB layout software tutorials	10 days?	Mon 10/12/09	Fri 10/23/09
42				
43	**Design**	**41 days?**	**Fri 10/23/09**	**Fri 12/18/09**
44	CAD	11 days?	Fri 10/23/09	Fri 11/6/09
45	**Prototype**	**30 days?**	**Mon 10/26/09**	**Fri 12/4/09**
46	Coding	25 days?	Mon 11/2/09	Fri 12/4/09
47	Hardware	25 days?	Mon 10/26/09	Fri 11/27/09
48	Evaluation of Prototype	10 days?	Mon 12/7/09	Fri 12/18/09
49				
50	**Implementation**	**80 days?**	**Mon 1/11/10**	**Fri 4/30/10**
51	Final Design	15 days?	Mon 1/11/10	Fri 1/29/10
52	Build	40 days?	Mon 2/1/10	Fri 3/26/10
53	Evaluate	15 days?	Mon 3/29/10	Fri 4/16/10
54	Final Report	10 days?	Mon 4/19/10	Fri 4/30/10
55	Project Poster	10 days?	Mon 4/19/10	Fri 4/30/10

There is not an updated schedule since the team is on schedule.

13. Project Team Information

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14. Summary Statement

By expanding the ability of the humanoid robot to process sensory information, we will allow the robot to more closely emulate the experiences of an infant human. Through our design, the robot will be able to, at minimum, add scratching to its repertoire of abilities which allow it to discover the outside world. Depending on project constraints, our design will add a few more sensory inputs to allow the robot to receive additional sensory information from the outside world. These new abilities will be dominant in allowing the robot to emulate the learning processes of an infant human. In being able to emulate more human sensations, the robot will become closer to being able to learn like a human infant.