Meat Fat Analyzer with Smartphone Integration

ECE4012-L2A Senior Design Project

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Executive Summary

Today's user is very limited in their ability to have accurate and quick body fat measurements without having to spend extra money for professional grade testing. This experience can be enhanced by adjusting the model that many current on the market devices use and presenting that information in a way that is intuitive and easy to understand for the user. In order to test this concept, Team Quadcopter has designed the FatAnalyzer, a meat fat analyzer that is able to achieve accuracy of within 15% and present the data to the user on their smartphone in a timely manner. The FatAnalyzer is comprised of an Arduino based Ohm meter that applies a test voltage to a circuit comprised of a known resistance and probes to insert into the meat, where the resistance of the meat is measured. A Bluetooth modem is used to then transmit this data to an Android or iOS based smartphone where the data acquired for resistance and weight are used to estimate meat fat percentage. Team Quadcopter's goal was to develop a prototype for $107.

Personal Body Fat Analyzer with Smartphone Integration

1. Introduction

In the interest of personal health and fitness, Team Quadcopter wanted to design a system to calculate an individual's body fat percentage in a swift and accurate manner. It was not possible to receive approval for human testing in time, so the concept was tested using pork. The final prototype cost less than the requested $107. This was mostly due to the request for a body fat scanner was no longer needed.

1.1 Objective

The team designed and implemented a system based on bioelectrical impedance analysis to determine the fat content of a cut of meat. This serves as proof of concept for how a similar system could be implemented to test body fat content on a consumer in a noninvasive way. By applying a voltage across the body of a subject, and in conjunction with a small known input resistance, a small current will be generated that will be detected by the device hardware. Based on the detected current, the impedance of the meat in question will be determined. This impedance is used in conjunction with a regression equation and other characteristics of the meat to determine the fat free mass (FFM) of the individual. The regression model was built around pork to allow for a more accurate result.

1.2 Motivation

Current body composition technology can be split into 2 categories: those that are accurate but take considerable time or effort, and those that give results quickly but are highly inaccurate [1].

The most easily accessible option for body composition testing is bioelectrical impedance analysis. This technique allows users to quickly determine their body composition alone and in the comfort of their own homes. However, despite the advantages this method allows, the results are often skewed by as much as 12% from the true value [2]. These inaccuracies can be caused by a number of factors including the subjects level of hydration, how recently they have eaten, and the distribution of fat across their body. Additionally, often bioelectrical impedance devices are designed to use a single body composition regression equation that makes assumptions about the subject's body. While it is always necessary to make some assumptions about the subject for generation of a usable equation, these assumptions proving to be unfounded can lead to a considerable error. Compared to the gold standards of hydrostatic weighing or Dual-Energy X-Ray Absorptiometry which both offer results nearly within 3% accuracy [3], bioelectrical impedance analysis devices have a great deal of room for improvement. Current on market body composition analyzer models can cost anywhere from $20 to $200 [4]. Our product goal was to design a device that was inexpensive, fast, and easy to use. Our efforts resulted in a device that was able to make fewer assumptions in estimating fat content and as a result yielded an inexpensive device with greater accuracy than current products. of many inexpensive solutions.

1.3 Background

While there are many different methods of determining body fat percentage in an individual, some of the most common are skin caliper testing, hydrostatic weighing, Dual-Energy X-Ray Absorptiometry (DEXA), and bioelectrical impedance [1].

Skin caliper testing requires that the subject use a set of calipers to take measurements of the amount of foldable skin on the body at different points including the arms, back, abdominals, and thighs. The measurements taken can then be read into a formula and an estimation of body fat percentage can be calculated. This method is viewed as very low cost, but prone to errors due to the limited amount of testing points.

Hydrostatic weighing requires that the subject be completely submerged in water and weighed. Based on the submerged readings, a calculation can be made for body fat percentage. This is viewed as one of the most accurate methods of obtaining body fat percentage and is viewed as "the gold standard", but it requires specialized equipment. It is difficult to perform often and at low cost. Additionally, because during the process the person is asked to breathe out as much air as possible, it is often described as uncomfortable.

DEXA testing employs X-ray beams of different strengths. The subject is exposed to the different beams and the absorption of the X-rays by the body is used to determine its composition. DEXA is considered to be at least as accurate as hydrostatic weighing, but is less accessible due to the need for high energy X-ray equipment and a subsequent higher cost.

Bioelectrical impedance analysis (BIA) is conducted using a small electrical current on the order of 500 µA at a high frequency. A voltage is placed across the body and current is conducted from hand-to-foot, foot-to-foot, or hand-to-hand. The signal relies on conductive material to make its way through the body, most notably water. Because the water in the body is laced with conductive components such as sodium and potassium ions, its ability to conduct an electrical charge is further increased. In general, lean tissue is well hydrated, both inside and outside the cell in order to allow for normal operation. This hydration allows signals to be conducted very easily through these regions. However, fat stores are inherently hydrophobic, causing considerably lower levels of water to be found where fat is stored. Because of this lack of conductive material, signals travel more slowly because of the increased resistance of the region. By noting the net resistance that the signal experiences to travel from the source to the receiver, a general proportion of how much lean and fatty mass a subject has can be made [5] [6].

Many of the devices on the market today allow for considerable margins of error when testing body fat, with errors as high as 20%. This inaccuracy is in part due to considerable variations in body composition when considering a large target demographic. To compensate, the devices are limited to specific demographics of people. This allows for an increased accuracy within those groups. The FatAnalyzer has an accuracy within 15%. Also, we make the population base for our device as large as possible, but limit our target demographic in ways that allow us to reach our goal in accuracy. Allowing the user to input various information about his-or-her body will allow for a dramatic increase in accuracy. Based on the information provided, the equation can be customized for the individual, and accuracy can be maximized. This idea can be used similarly with meat.

The FatAnalyzer is comprised of an Arduino microcontroller for resistance measurements, probes to attach to the test points on the body, and a Bluetooth modem to communicate with a smartphone running the FatAnalyzer application. This design calls for the use of Android as the operating system of choice due to the fact that the permissions necessary for application development, in this case Bluetooth permissions, are easily accessible and can be pulled off of the internet [7]. In the end, we decided to pursue a universal app development that resulted in an application that worked on both iOS and Android.

2. Project Description and Goals

The goal of the FatAnalyzer was to allow the user to take accurate meat fat measurements on pork chops in a way that is intuitive, accurate, and can be operated with a smartphone. This system is comprised of an Arduino microcontroller, a RedBearLab BLE (Bluetooth Low Energy) shield, a simple circuit comprised of a known resistance, and an Android smartphone running the FatTracker application. The Goals of this system are as follows:

Overall

- Body fat measurement results presented to user within 10 seconds of test execution
- The results have an accuracy of within 15%

FatAnalyzer Hardware

- Bluetooth connectivity between the FatTracker and a smartphone via RedBearLab's BLE shield
- Simple circuit comprised of known resistance of ~14 kOhm.

Smartphone Application

- Simple and intuitive navigation for the user
- Initiate the test using the application
- Easy to access the results of the test

3. Technical Specifications

Specification	**Objective**	**Final Implementation**
Target Subject	Cuts of Meat	Pork Chops
Meat Fat % Accuracy	10-20%	14%
Test Duration	<10 Seconds	<10 Seconds
Device Weight	<3 lbs	0.60 lbs
Signal Voltage	3.3 - 5 V	5 V
Number of Probes	2 - 4	2

Table 1. Technical Specification

4. Design Approach and Details

4.1 Design Approach

4.1.1 Overall System

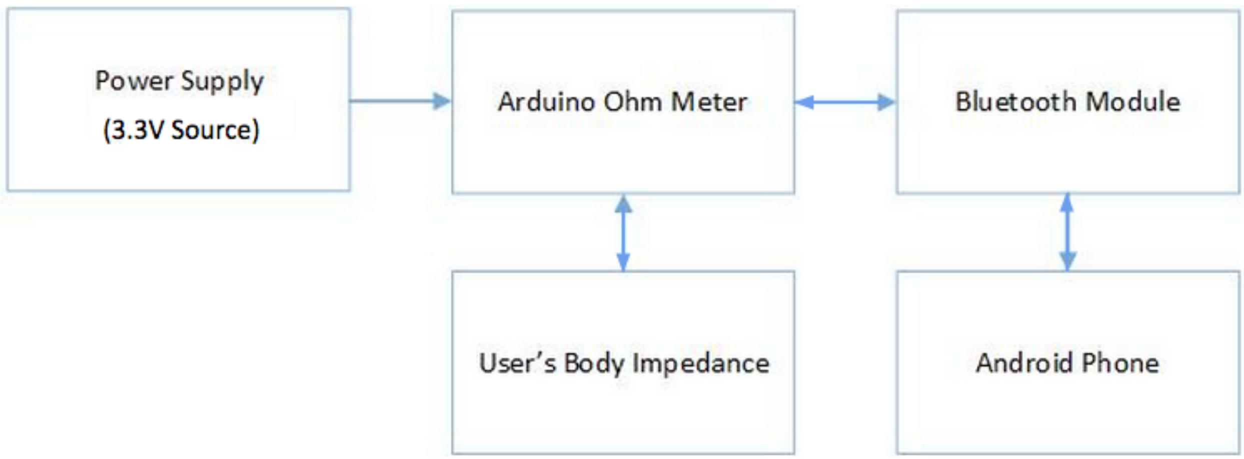

Figure 4.1 - Block Diagram of FatAnalyzer Device

The FatAnalyzer requires three main hardware components to facilitate body fat computation as shown in Figure 4.1:

- Arduino ohm meter
- Bluetooth module
- Android phone
    - Arduino ohm meter
    - Bluetooth module
    - Smartphone

The role of the Arduino will be to apply the test voltage to an analog output pin from one part of the subject (such as a wrist in the case of human testing) and to another (such as an ankle). During transmission, the Arduino will utilize an internal analog-to-digital module (ADC) to measure the voltage drop developed across the meat, which will be then be used to compute the corresponding impedance of the meat. Finally, the Arduino will interface with an external bluetooth module to send the resulting impedance measurement to the user's Android phone. Upon receipt of the impedance measurement, the smartphone will plug the measured value of the subjects impedance into a regression equation. The result of the regression equation calculation will yield an estimated fat percentage, which will then be displayed to the user on the smartphone screen.

4.1.2 Arduino Ohm Meter Subsystem

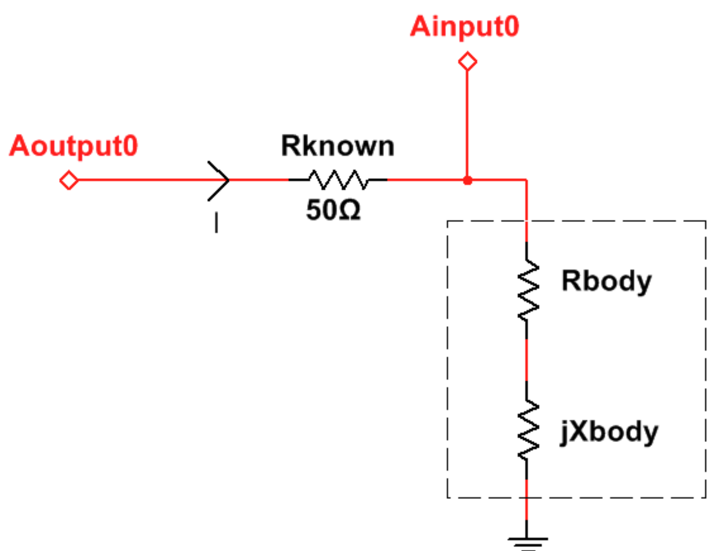

Figure 4.2 - Ohm Meter Schematic ($A_{output0}$ and A_{input0} correspond to pins on the Arduino)

The Arduino ohm meter subsystem is illustrated in Figure 4.2 and will be comprised of a 14.84 kOhm resistor (R_{known}) in series with the pork (represented by the dashed box). The meat impedance is modeled as the series interconnection of two components: the real resistance (R_{body}) and the imaginary reactance (X_{body}). The arduino will drive a high frequency AC sinusoid (to overcome the high-pass filtering effect induced by the cell membranes of the cells under test) through node $A_{output0}$ and will measure the resulting magnitude and phase of the voltage at node A_{input0}. The purpose of R_{known} is to enable the calculation of the current (I) flowing through the body via Ohm's law:

$$I = (Vin - Vbody)Rknown$$

where

V_{in}: voltage supplied by the arduino at node $A_{output0}$

V_{body}: measured voltage at node A_{input0}

Once the current flowing through the meat is known, the meat's impedance can be calculated via Ohm's law by combining the computed current (I) with the voltage measured at node A_{input0}, which is equivalent to the voltage drop across the meat (V_{body}):

$$Z_{body} = R_{body} + jX_{body} = V_{body}/I$$

If our device were to be implemented for human testing, the FatAnalyzer would include four ohmic contacts (one to be placed on each wrist, and one to be placed on each ankle) to enable the impedance measurement of three unique body cross-sections:

- Upper-body (from right wrist to left wrist)
- Lower-body (from right ankle to left ankle)
- Full-body (from right wrist to left ankle)

By measuring multiple cross-sections, the design team hypothesizes that a more accurate body fat percentage measurement can be obtained than what is achievable from the measurement of only one cross-section. The locations of the ohmic contacts and the current paths through the three cross-sections to be measured are shown in Figure 4.3 below:

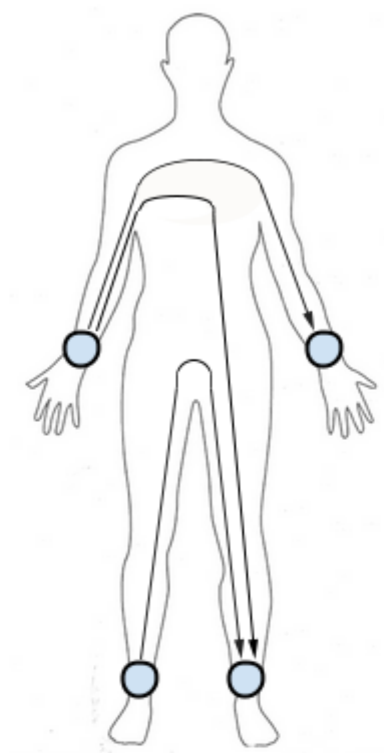

Figure 4.3 - Ohm Meter Contact Point Locations and Current Paths to Be Measured (Diagram created by Team Quadcopter)

4.1.3 Android Application

The android application serves as the user interface for the FatAnalyzer. Upon placing each probe into the opposite ends of the meat, the user initiates the body fat measurement by tapping a button on the android phone, which sends a signal to the Arduino via bluetooth to begin resistance measurements. As soon as the Arduino completes resistance measurements, the arduino transmits the measured impedance values to the android application via bluetooth. The application then plugs the impedance values into the generated regression model that is discussed in section 4.1.4. If the same approach were taken to generate a model for humans, it could hold the same form as the following:

$$FFM\ (kg) = 0.7 * (\mathbf{Ht^2/R_{body}}) + .18 * \mathbf{BW} - .18 * \mathbf{Age} + .12 * \mathbf{X_{body}} - 2.5 \text{ [8]}$$

Where: FFM is the fat-free mass, Ht^2 is height in cm, R_{body} is the body resistance in ohms, BW is body weight in kg, age is in years, and X_{body} is the body reactance in ohms. The βparameters are regression coefficients to be computed from experimental data once the first prototype has been built.

Once the fat-free mass has been approximated according to the equation above, the corresponding body fat percentage is computed according to (BW - FFM)/BW. The body fat percentage is then displayed on the smartphone screen and stored in non-volatile memory for long-term tracking.

Figure 4.4 below illustrates the three main screens with which the user will interact. The first displays the fat percentage that has been most recently measured and contains a button to initiate a new measurement. The second is the screen where the user can input the weight in grams of the pork. The third depicts what is shown to the user as a measurement is taking place and gives the user the option to cancel the measurement. After the measurement completes, the user is again shown the screen on the left with the fat percentage now updated to show the result of the latest measurement.

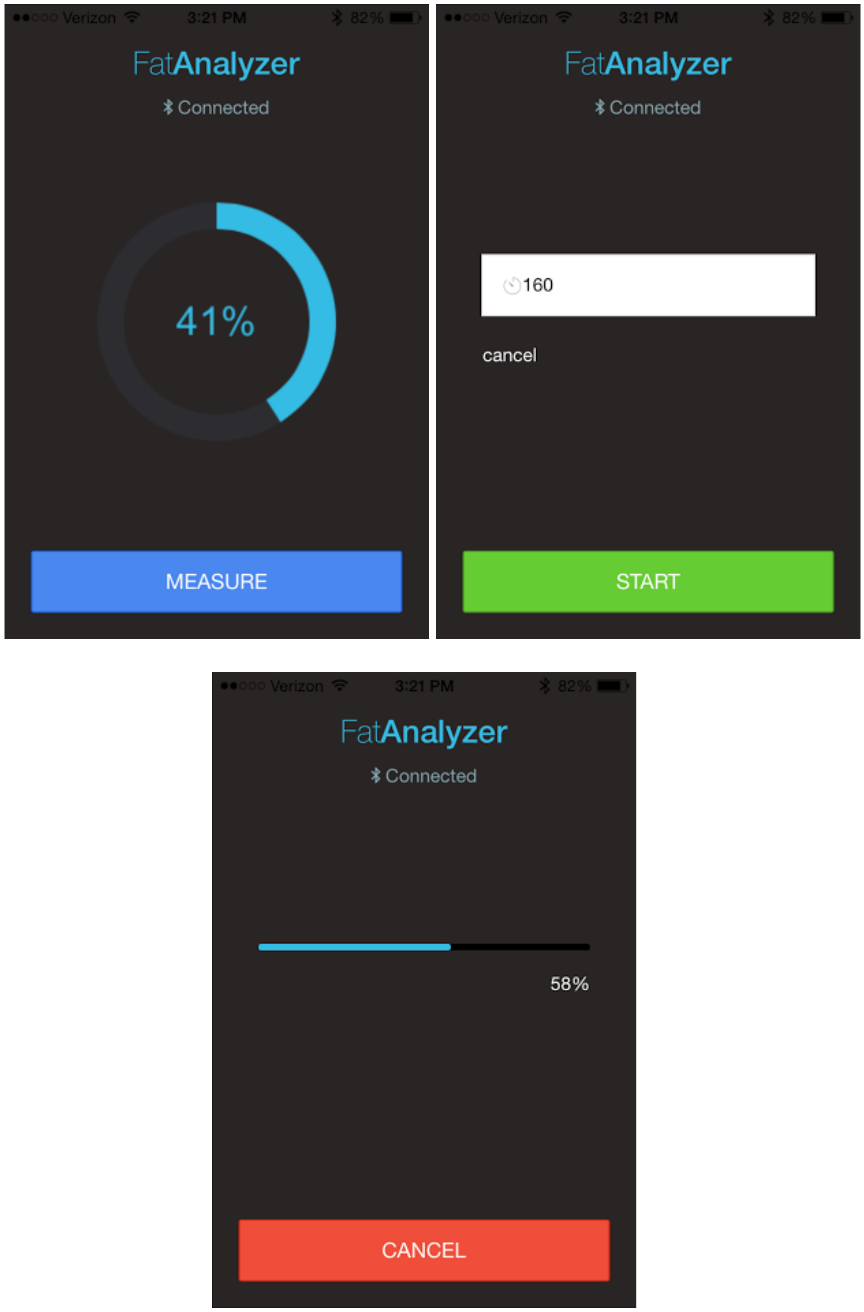

Figure 4.4 - Android App User Interface

4.1.4 Regression Model Development

In order to calculate fat percentage, a regression model was developed from scratch through rigorous testing. Each piece was tested with to determine resistance and weight. The meat was individually boiled for 1-2 hours causing the lean meat to seperate from the water within the pork and the fat. This allowed for the measuring of lean weight, and fat weight. All of these values were used to generate a statistical model in STATA for the estimation of fat weight of total non water weight. The generated regression model can be seen in Figure 4.5.

```
Linear regression                                      Number of obs =      53
                                                       F(  2,     50) =   67.27
                                                       Prob > F      =  0.0000
                                                       R-squared     =  0.8619
                                                       Root MSE      =  5.2629

--------------------------------------------------------------------------------
               |               Robust
    leanweight |      Coef.   Std. Err.      t    P>|t|     [95% Conf. Interval]
---------------+----------------------------------------------------------------
resistanceohms |  -.0047503    .002185    -2.17   0.034     -.009139   -.0003616
       weightg |   .5542703   .0496811    11.16   0.000     .4544829    .6540577
         _cons |   1.207298   5.077608     0.24   0.813    -8.991377    11.40597
--------------------------------------------------------------------------------
```

Figure 4.5 Generated Regression Model

4.1.5 *Issues Encountered*

The design process was not issue free. Several changes were made to the design plan. These are as follows:

- The original design called for the measurement of complex impedance in hopes that the added capacitance would allow for a more accurate model. It was found once capacitance was measured and plotted that it was statistically insignificant.
- When capacitance was still being measured, it was discovered that the Arduino could not

sample fast enough to make the measurement. After much time spent programming other microcontrollers, it was found that capacitance was statistically insignificant, and design with the Arduino was resumed.

- When the resistance of the pork was being measured, it was found that the value of the resistance would rise over time. To address this, the measurements were taken in short pulses to not allow the pork to charge. The results of measurements over time can be seen in Figure 4.6. The resistance that was used was the average of these resistance measurements.

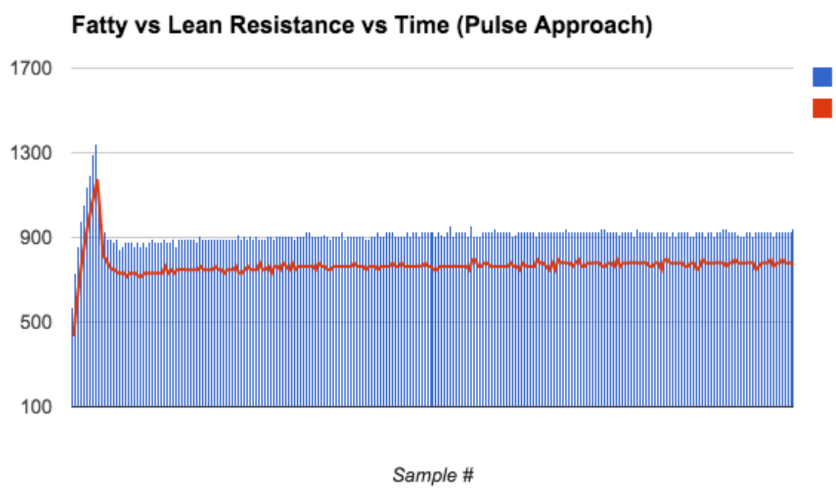

Figure 4.6 Resistance Measurements over time.

4.2 Codes and Standards

- *Bluetooth (IEEE 802.15.1)*

  This is the code and standard for the 2.4GHz range of data communication. It is required for the communication between the processor and any Bluetooth rated device [9]. The standard must be followed to ensure that there is proper communication between devices.

The FatTracker will address this standard by interfacing the Arduino with a commercially available Bluetooth module to transmit the user's body impedance measurements to the smartphone.

- *IEC 60601*

  This is the medical standard for electrical devices that are used commercially. It defines safety and efficiency standards for approval for commercial distribution. Its requirements must be met for a product to be sold as a medical device. To meet this standard, the FatTracker must deliver no more than 500uA of current to the body during an impedance measurement [10]. If the FatAnalyzer were implemented for human testing, this would be a needed code to follow.

4.3 Constraints, Alternatives, and Tradeoffs

From the user's perspective, the FatAnalyzer needs to be intuitive to use and easy to operate. The user interface of the FatTracker was laid out in a way that will allow the user to easily navigate and initiate testing.

The largest tradeoff for the FatTracker is the accuracy of the model that will be used. One large issue with meat testing is that there are many variables that cannot be measured, such as age of the cut, dryness, storing conditions, etc. In order to improve the accuracy of the model, it was decided to limit testing to pork chops of a similar cut. Each piece was about 0.75 inches thick. If we had been able to test with humans, we suspected that the inclusion of measurable variables such as height, age, weight, arm/leg length, etc. could have resulted in a accurate model for humans.

5. Schedule, Tasks, and Milestones

The FatAnalyzer prototype and application development was completed between the time period of August to December of this year. Appendix A contains a table, breaking down each task involved, the associated team members leading those tasks, and the expected risk level at the beginning of the semester. Appendix B contains a Gantt chart associated with the major tasks of this project. Appendix C contains a comprehensive Gantt chart for the entire project, including individual tasks. Team Quadcopter was able to stay on schedule most of the semester, and as a result, the Gantt Charts stayed very accurate. The only differences were the omission of the need to design straps for the human user.

6. Project Demonstration

In order to validate the proposed design, 2 areas of testing were required:

1. Accuracy
2. Speed

The easier metric to prove was speed. Over the course of several trials, the device was timed for total performance time. Overall, the device was found to have an average operating time well within our 10 second target window. On average, the device was found to take approximately 8 second to complete testing.

Accuracy is by far the harder metric to prove, as demonstrating the validity of our result requires boiling the subject down for several hours. While this is feasible for generating test data, it does not lend itself well to a live demonstration. As such, we were forced to rely on a more visual confirmation during actual demonstration. However, by selecting subjects that clearly had different levels of fat content, we were able to demonstrate that our prototype does generate results that are consistent with a visual observations.

In order to validate our final human system, two rounds of testing would be conducted. The first round would involve a small group being tested via one of the "gold standards" for body composition testing. Here, the most likely option will be hydrostatic weighing. These results will be compared to the results obtained from the FatTracker via statistical analysis. The second phase will involve a larger group being tested via skin calipers. Again, these measures will be compared to the results of the FatTracker. Ideally the first group will be as large as possible since hydrostatic testing will give us the most accurate measure with which to compare findings. However, skin calipers are still considered fairly accurate, and so they will be used as a means of minimizing prototyping costs.

Because the accuracy of this system will be based on a living person and will need to be compared to another method of testing, it will be impractical to truly demonstrate the accuracy to an audience, as that would involve hydrostatic testing. However, it will be practical to allow individuals to be measured by the FatTracker, a Omron Body Fat Analyzer [11], and possibly skin calipers. While this will not demonstrate the true accuracy of the system, it will demonstrate how the designed system compares with previously established, non-invasive measures. This, combined with well reported statistical analysis should serve to establish confidence in system accuracy.

A comparative demonstration as described above will necessitate the use of the FatTracker on individuals in the test. Because it will be in constant use for this demonstration, there will be ample opportunity to demonstrate the time taken for the system to operate. Again, when the speed of the FatTracker is compared to current on market devices, claims made about the speed of the device will be validated.

7. Marketing and Cost Analysis

7.1 Marketing Analysis

While there are several human body composition devices on the market, there are very few devices that provide a quantitative analysis of the composition of consumer meat products. Because of this, the market appears very open for the development of that sort of product. There are two distinct approaches for potentially marketing the FatAnalyzer: seller use and personal use.

The easiest place for this system to be implemented would be when the meat is being packaged by the seller. Once the device is integrated with a scale, this product could be marketed as a replacement for current packaging scales. When the FatAnalyzer is used to weigh the meat for packaging, the label that would print would not only include the price and weight, but would also include the lean to fat ratio as calculated by the device. This would give the consumer an actual measure of what they are purchasing, allowing them to have another metric for use in their selection.

The alternative market would be for personal home use. In this case, the user would be concerned with finding what they are actually consuming, whether to ensure a balance between fats and protein, or through simple interest. This would be a far more specialized market, as not everyone would be concerned enough with the composition of their meat products to justify purchasing the FatAnalyzer. However, by marketing the device specifically to that group, a considerable niche market could be formed. In order to accomplish this, market testing would need to be conducted to find correlations between the people that would be interested in this product for home use and the activities in which they engage.

The purpose of the FatTracker is to improve on existing models while keeping the price relatively close to current market prices. Most electronic body fat analyzers currently being used have error percentages that range from 10-20% on an average person. The problems with these analyzers are that they are not useful for those under 18, older than 60, those pregnant or suffering from dehydration, etc [11]. There is a long list of qualifications that are needed for someone to use one, which makes the user base much smaller than it could be. This is coupled with the fact that although there are more accurate ways of calculating body fat such as calipers, BodPods, hydrostatic weighing, the digital fat analyzers have still remained popular over the past decade. The market potential of a faster, more accurate body fat analyzer with a price range within a marginal budget is one that would be in high demand.

7.2 Cost Analysis

It was expected that the cost of the FatAnalyzer prototype would be approximately $107. Below, Table 2 displays the expected costs for each component both in individual costs, as well as what the total cost will be. The Omron body fat analyzer [11] and the skin calipers were ultimately not purchased, due to the switch to meat testing. It was also discovered that the LNA was not needed.

Product Description	Quantity	Unit Price ($)	Total Price ($)
Omron Body Fat Analyzer	1	35	35
Skin Calipers	1	12	12
Arduino	1	25	25
Bluetooth Modem	1	11	11
Low-Noise Amplifier	1	4	4
Probe Patches	4	2.5	10
Cables	4	2.5	10
Total			107

Table 2 - Prototype Costs

A though cost analysis of this project was performed. There was not much difference in cost when meat became the test subject. The costs of development labor shown in Table 3 are assuming that each engineer will be paid an average starting salary of $60,000 per year, which equates to roughly $29 per hour. Team Quadcopter will be splitting task leads into two primary portions, hardware development and software development. The most time consuming task will be Algorithm Development at an expected 90 hours per person for two engineers. The Improvements task will tie heavily into Algorithm enhancement, therefore increasing the cost of this portion of development even further.

Project Task	Marty Labor (hrs)	Brandon Labor (hrs)	John Labor (hrs)	Philip Labor (hrs)
Group Meeting	40	40	40	40
Algorithm Development		75		75
Hardware Development		45		45
Software Development	60		60	
Application Development	60		60	
Improvements	40	40	40	40
Total	200	200	200	200
Overall Total (hrs)	800			
Hourly Wage ($)	29			
Total Labor Cost ($)	23200			

Table 3 - Labor Cost Analysis

Under the assumption of marketing the analyzer for five years and also assuming that sales of the unit are favorable, an estimate for the number of units sold will be 50,000 a year for a total of 250,000 units over five years. This means that the prices for each of the units will need to be the bulk-pricing format. The prices in Table 4 assume that the items were purchased in bulk and assembled by a contracted factory.

Component	Individual Costs ($)	Bulk Costs ($)
Arduino Pro Mini	10	6
Bluetooth Module	11	4
SmallSignal Amplifer	4	1
Cables	10	1.5
Plastic Case	0.5	0.5
Velcro Bracelets	0.5	0.5
Total	36	13.5

Table 4 - Bulk Component costs

For determining a marketable price, fringe benefits of 30% of labor costs will be included as well as a total overhead of 120% of the overall cost.

Parts	107
Labor	23200
Fringe Benefits (30% of Labor)	6960
Subtotal	30267
Overhead (120%)	30268.2
Total Cost ($)	60535.2

Table 5 - Total Costs of Development

The expected time for assembly is four units per hour per assembler. The expected time for unit testing is eight units per hour per technician. With an hourly wage of $10 per assembler and technician, the tabulated costs are in Table 6. All of the parts for assembly can be purchased at discount rates in bulk and have been totaled in the table below. After calculating fringe benefits, overhead and assuming that advertisements and salesmen will cost 10% of the total input costs, the final selling price will be set at $60.00 per unit. The expected revenue over the total five year production life of the analyzer from 250,000 units is $3,820,000.

Parts Cost	13.5
Assembly Labor	2.5
Testing Labor	1.25
Total Labor	3.75
Fringe Benefits, (30% of Labor)	1.13
Subtotal	18.38
Overhead, (120% of Matl, Labor & Fringe)	22.06
Subtotal, Input Costs	40.44
Sales Expense (10% Total Input)	4.04
Amortized Development Costs	0.24
Subtotal, All Costs	44.72
Profit	15.28
Selling Price	60

Table 6 - Per Unit Price Calculation

8. Conclusion

Team Quadcopter has successfully developed a working prototype for our Arduino based Ohm meter. This system utilizes the regression equation derived from the statistical analysis done on our final data set of pork chops. While this system will work on pork chops, it has not been designed for use with other meat products. This severely limits the marketability of this product.

Future work should include development of other statistical models for use in other types of meat, including chicken, beef, and fish. Looking forward to a beta prototype, the current system should be incorporated onto a digital scale, eliminating the need for external input from the user.

A PCB should be designed to implement our testing circuit, minimizing the hardware footprint. In order to minimize cost at this stage, different microcontrollers could be investigated to determine the minimal needs of our circuit, allowing for the cheapest implementation possible. Finally, an actual casing should be designed using CAD tools for either 3D printing or CAM techniques.

This accuracy of the FatAnalyzer suffers from many unquantifiable variables with meat, such as age, hydration, etc. If this product were developed to work on the human body, it is possible that the increase in quantifiable variabls (age, height, weight, etc.) could result in a very useful model.

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Appendix A: Website

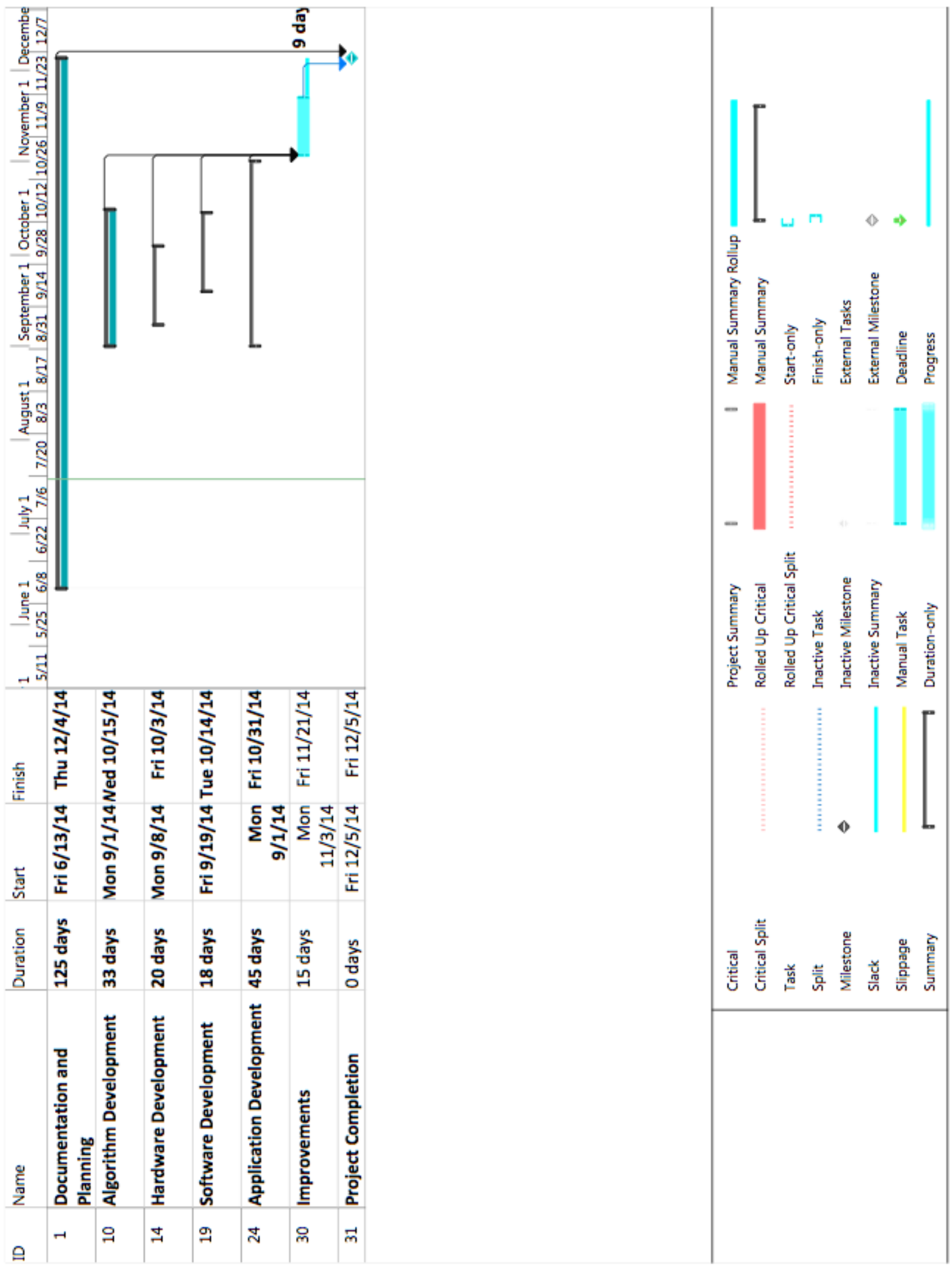
Detailed information about the work of Team Quadcopter and their reports, presentations, and final code can be found here:

http://www.ece.gatech.edu/academic/courses/ece4012/14fall/ECE4012L2A/pb2/

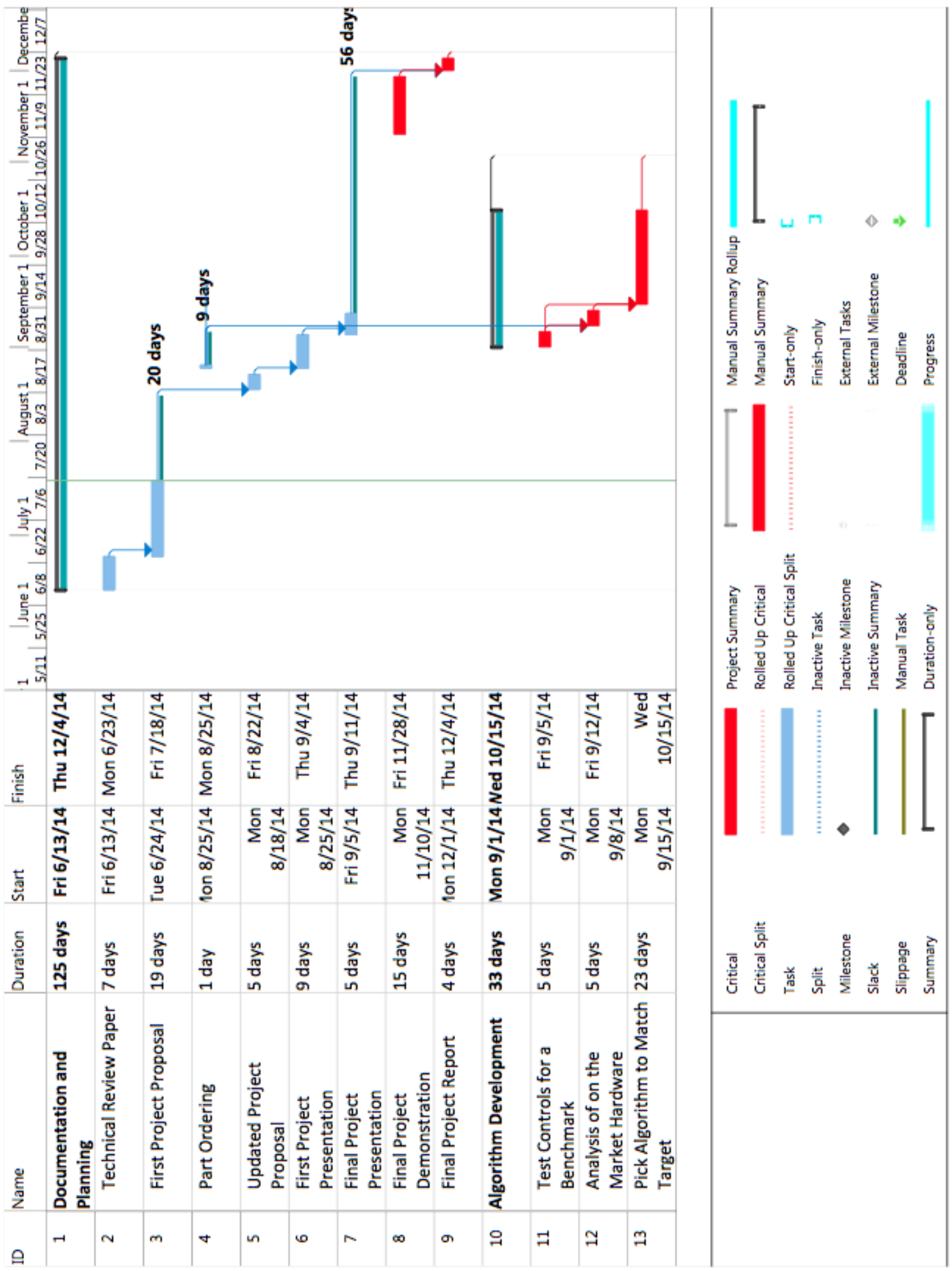
Appendix B: Task List

Task Name	Task Lead	Risk Level
Documentation and Planning	All	Low
Technical Review Paper	All	Low
First Project Proposal	All	Low
Part Ordering	All	Low
Updated Project Proposal	All	Low
First Presentation	All	Low
Final Project Presentation	All	Low
Final Project Demonstration	All	Medium
Final Project Report	All	Low
Algorithm Development	Brandon, Philip	Medium
Test Controls for a Benchmark	Brandon, Philip	Low
Analysis of on the Market Hardware	Brandon, Philip	Low
Pick Algorithm to Match Target	Brandon, Philip	High
Hardware Development	Brandon, Philip	Low
Probe Modification	Brandon, Philip	Low
Strap Design	Brandon, Philip	Medium
Design LNA Circuit	Brandon, Philip	Medium
Assembly and Testing	Brandon, Philip	Low
Software Development	Marty, John	Medium
Generate Signal in Arduino	Marty, John	Medium
Transmit Signal to Probe A	Marty, John	Medium
Receive Signal at Probe B	Marty, John	High
Uses Algorithm to Calculate Body Fat	Marty, John	Low
Application Development	Marty, John	Medium
Bluetooth Configured Properly	Marty, John	Low
Connect with Arduino	Marty, John	Medium
Initiate Test from Application	Marty, John	High
Receive Information from Arduino	Marty, John	High
U/I Completed	Marty, John	Medium
Improvements	All	Medium

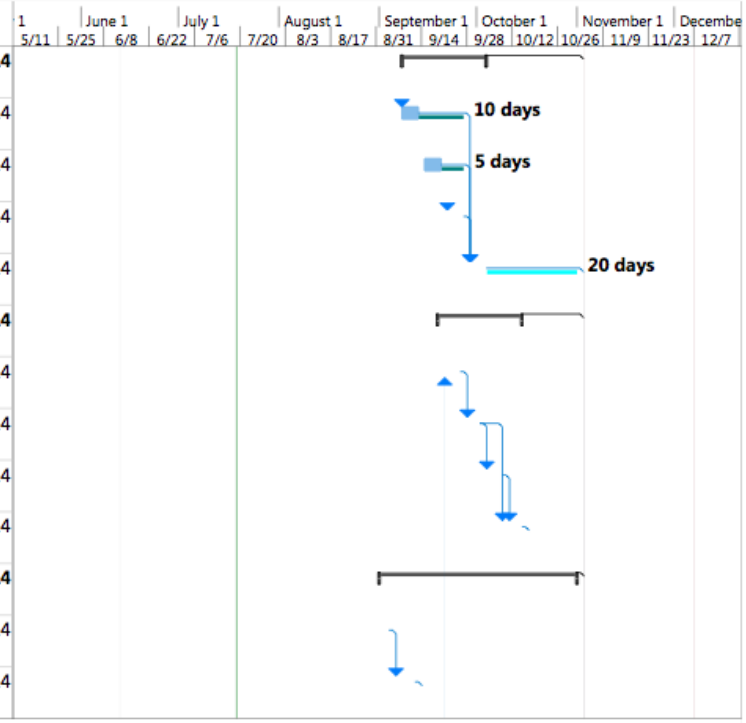
Appendix C: Project Gantt Chart

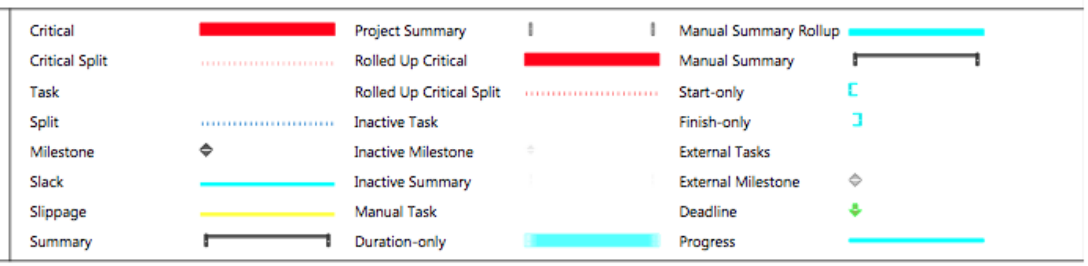


Appendix D: Comprehensive Gantt Chart



ID	Name	Duration	Start	Finish
14	**Hardware Development**	**20 days**	**Mon 9/8/14**	**Fri 10/3/14**
15	Probe Modification	5 days	Mon 9/8/14	Fri 9/12/14
16	Design LNA circuit (if needed)	5 days	Mon 9/15/14	Fri 9/19/14
17	Strap Design	5 days	Mon 9/22/14	Fri 9/26/14
18	Assembly and Testing	5 days	Mon 9/29/14	Fri 10/3/14
19	**Software Development**	**18 days**	**Fri 9/19/14**	**Tue 10/14/14**
20	Generate Signal in Arduino	5 days	Fri 9/19/14	Thu 9/25/14
21	Transmit Signal Through Probe A	4 days	Fri 9/26/14	Wed 10/1/14
22	Receive Signal at Probe B	5 days	Thu 10/2/14	Wed 10/8/14
23	Use Algorithm to Calculate Body Fat	4 days	Thu 10/9/14	Tue 10/14/14
24	**Application Development**	**45 days**	**Mon 9/1/14**	**Fri 10/31/14**
25	Bluetooth Configured	3 days	Mon 9/1/14	Wed 9/3/14
26	Connect with Arduino	6 days	Thu 9/4/14	Thu 9/11/14





ID	Name	Duration	Start	Finish
27	Initiate Test from Application	5 days	Fri 9/12/14	Thu 9/18/14
28	Receive information from Arduino	4 days	Wed 10/15/14	Mon 10/20/14
29	U/I Completed	9 days	Tue 10/21/14	Fri 10/31/14
30	**Improvements**	15 days	Mon 11/3/14	Fri 11/21/14
31	**Project Completion**	0 days	Fri 12/5/14	Fri 12/5/14