Long-Range RFID Sensing UAV System

ECE4012 Senior Design Project

Team: Raising The Steaks
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Submitted December 15, 2016

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Executive Summary

The purpose of this project was to design, build, and test a Radio-Frequency Identification (RFID) system for use in the cattle industry which records inventory of cattle in various herds across several pastures. The project was focused on improving the read range and reading capabilities of the RFID technology through a system level optimized design. A system of this caliber reduces the day to day labor of counting cattle in various herds from a multi-hour procedure down to less than one hour. In order to meet these specifications, the transmitter/receiver components of a typical RFID system was researched, redesigned, and optimized. Higher frequencies are used because they are known to increase the read range of the system and allow multiple tags to be read at once. RFID systems with longer read ranges also require more sophisticated power management solution, so a secondary effort went into designing the platform on which this system is built upon. The solution sought to investigate the design of a mobile reader mounted on an unmanned aerial vehicle (UAV) for inventory and field rotation of cattle with possible location capabilities. The development of readers with these capabilities depends on (1) frequency of operation, (2) antenna structure and size, and (3) power management. The outcome of the design is a fully functional prototype consisting of hardware that costs around $2,200.

Long Range RFID Sensing UAV System

1 Introduction

The “Raising the Steaks” team designed a long-range RFID sensing system for taking inventory of cattle on a pasture. The team is requested approximately $3,000 to develop a fully functioning prototype.

1.1 Objective

The objective was to design a stand-alone system for use on cattle ranches which takes inventory of herds of cattle. In the past, this procedure had been done manually—by a rancher physically counting and recording cattle. It is not unusual for cattle to go unnoticed during these pasture rotations because they are sleeping, injured, or have wandered off. Our team’s solution allows quick and easy cattle inventory management, and allows the rancher to determine which cows are out of place. The entire system is mounted on a drone or unmanned aerial vehicle (UAV) and consists of an RFID reader and antenna, an external battery pack, a RaspberryPi, a GPS module, and a USB thumb drive that contains a file that is populated with a list of cattle ID’s.

1.2 Motivation

The motivation for this project is to revolutionize the cattle industry technology in the United States and allow ranchers to quickly and reliably count and track their cattle. This is a new product to be used by CattleTime on its ranches. Currently, there exists no solution to take quick inventory of cattle because RFID technology has a limited range of a few feet. This requires a rancher to physically get close to each animal to identify it. Raising the Steaks offers a system with a more efficient way of taking inventory by optimizing the RFID tag read range through design and offering of a full inventory system.

1.3 Background

In 2004, the US Government asked cattle farmers to tag their animals with RFID for the purposes of tracking the lifetime and health of cattle [1]. This effort would help control various diseases and serve as an authentication to any animal in question after the discovery of mad cow disease. However, due to the extreme limited range of RFID technology, this effort was unsuccessful and only 30% of cattle producers adopted this technology. The current market is moving towards Ultra High Frequency (UHF) RFID tags to try to increase readability distance.

Raising the Steaks' industry partner, CattleTime, is using UHF RFID tags along with mobile readers which achieve a distance of a few feet. Workers walk up to each animal and brandish a reader which is in the shape of a large wand and either receive information from the tag or program the chip in the tag using the mobile reader's interface. The mobile reader was designed and manufactured by Motorola, while the physical tag itself (not the RFID chip) was designed and tested by a Mechanical Engineering Senior Design group from Georgia Tech. The RFID chip itself was designed and manufactured by a third party prior to the team beginning this project. The RFID tag uses ultra-high frequencies (around 900 MHz) and is a passive tag, meaning that is uses incident electromagnetic radiation to reflect out a signal to the reader. The key building blocks are the RFID tag and chip, which are fixed in the scope of our project unless the sponsors desire changes with the testing in the following weeks.

2 Project Description and Goals

The team designed a UAV mounted system which takes inventory of cattle with RFID tags from a range of several meters and populate a list of cattle in a file on a USB thumb drive. The UAV can be flown by a rancher over each herd or autonomously using waypoints. Once the UAV passes within the read range of each animal, the ID for each animal is added to a comma separated value (*.csv) file stored in a USB drive on the RaspberryPi. The rancher can check the file to see the cattle IDs and location and determine if any cattle are missing. The UAV can then be flown around the pasture again to find a desired animal.

The target user is ranchers on large-scale cattle farms around the continental United States. The target price is roughly $3,000 which, despite increasing up-front costs, will save our sponsor money in the long run due to reduced labor time. The features of the UAV system include:

- Maximized read range of the UHF RFID reader and tags.
- Reader mounted to the UAV to fly around and energize the RFID tags
- Ability to read multiple tags quickly and populate a list in a CSV file
- Ability to gather GPS data
- Ability to export the list on a USB stick

3 Technical Specifications

The tags are energized by an incoming electromagnetic signal of ~900MHz and reflect a fraction of the received power. Once the signal is reflected the receiver reads each tag and populates a list of cattle IDs.

Specification	Target	Actual
Tag Operating Frequency	~ 915 MHz	~ 915 MHz
Output Power to activate passive tag	≤ 30 dBm	30 dBm
Read-Range for various antennae	≤ 4 m	~ 2 m (circular polarized) ~ 8 m (linear polarized)
Size of System	All aboard a UAV	0.8 x 0.8 x 0.8 ft
Weight (hardware)	< 5 kg	~ 1.5 kg
Power Source for UAV system	Rechargeable battery pack	4000 mAh rechargeable battery pack with 2 USB outputs
Communication with Database on CPU	USB/WiFi/Bluetooth	USB
Flight time of UAV	Up to 28 min	~ 25 min

Table 1. Target and Actual System Specifications

4 Design Approach and Details

4.1 Design Approach

The entire system consists of a 1) UAV (DJI Phantom 4), 2a) an RFID reader (ThingMagic USB Pro), 2b/2c) an external antenna (circular and linear polarized, respectively), 3) a central processor (RaspberryPi), 4) a GPS module (Adafruit), and 5) an external battery pack (Shinngo). A visual of the system design is shown in figure 1.

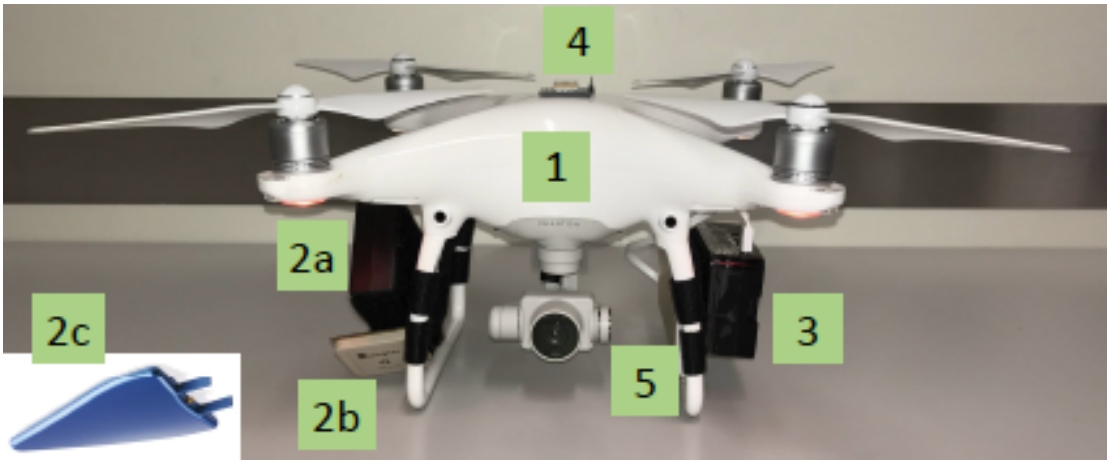

Figure 1. Marked picture of UAV system.

We were aiming to have an LCD display that allowed the instantaneous viewing of tag readings, but were not able to achieve that design specification. With more research and optimization of weight, an LCD screen could be easily incorporated into our system thanks to the presence of the RaspberryPi. The external antenna of the mobile reader is mounted on one side of the UAV and angled down towards the cattle. This is done in an effort to reduce the amount of interference between the interrogator and the RFID tag. For example, a cow may have its head down behind another cow while it is pasturing, the interrogator signal would have to travel through the first cow to get to the desired tag. We decided on using the ThingMagic USB Pro RFID reader because it is lightweight, has an adjustable power output, is compatible with a Linux system, and has a port for an external antenna.

Once the interrogator's signal arrives at the tag, a reflection occurs and the tag sends out a signal with information pertaining to the cow. The RFID reader receives the tags' signals and populates a list of all received tags. The list is stored in a *.csv file on a USB drive that can easily be removed and imported into an Excel file to be viewed. All communication between the different hardware within our system is via USB connection.

If this plan had not worked, our contingency project was to post fixed readers at exits of different pastures. Since all cattle have to pass through the same gate to get from pasture A to pasture B, this bottleneck would provide a great opportunity for the team to set up closer range readers and take inventory there.

4.2 Codes and Standards

ISO 11784: (The international standard defining frequencies, baud rate, bit coding and data structures of transponders used for animal identification) will be used for bit patterns to identify animals, bit pattern country code, manufacturer code [2].

Class 2/Class 3 RFID tag standards (for semi-passive tags) will be used in research for semi-passive tags [3]. As of now the team must work with the provided passive tags.

Data content codes for 64-bit identification code (15 digit numeric) will be used to identify birth, herd, range, and other ranch variables [4].

Air interface protocol [5] defines the physical and logical requirements for an RFID system of interrogators and passive tags, operating in the 860 MHz - 960 MHz UHF range.

FCC Rule Section15.247 defines the maximum output RF energy for RFID systems to be 1 Watt. [6]

4.3 Alternatives, Constraints, and Tradeoffs

4.3.1 Alternatives

The team explored using a separate high powered interrogator on an ATV to increase read range. The high powered interrogator can draw much more power from a car battery. However, read range is largely limited by the use of passive tags and the angle of incidence, regardless of what reader is used.

The team also explored the idea of using semi-passive tags instead of the provided passive tags. Semi-passive tags gather electromagnetic radiation from the environment to charge up small capacitors and help boost the output signal. In contrast, passive tags rely entirely on the strength of the interrogators signal to power outputting its RFID information. The additional cost and weight of semi-passive tags makes them unlikely to be implemented by our sponsor.

4.3.2 Constraints

This system has several constraints. The first is the amount of output power delivered to the antenna by the RFID reader. While 40 Watts of power would greatly improve the read range, anyone caught in the path of the reader would be physically damaged. Cost and weight of the tags is also a large constraint: active tags have a battery source and do not require an interrogator signal to be fully energized. However, they cost anywhere from $50 to $100 in contrast to the $0.05 passive tags cost. Since this will be applied to large herds of 200 or more cattle, the high cost tag is not an option. The orientation of the tag is also of concern. Tags are ideally read at a normal incidence from the RFID reader antenna.

4.3.3 Tradeoffs

If the system is to be mobile, then a part of the system must be battery powered. This means less power available to interrogate the tags, which translates into a smaller read range. If the system was fixed at the gate exit of each pasture as our contingency plan details, then the team could run a power line from a 120 V outlet to power the system. The tradeoff here is that the ranchers would only be able to take inventory while doing pasture rotation. The type of tag depends on the amount of money the team and sponsor company are willing to spend. There are some tags which are designed differently to allow farther innate read ranges. To switch to different tag technology would require great manufacturing costs and may not leave enough time to complete other parts of the project.

Antenna polarization is also a significant tradeoff. Circular and linear polarized antennas were tested during the development of our prototype. Linear polarized antennas offer a longer read range by concentrating RF locus but limit the degree of freedom in tag orientation. On the other hand, circular polarized antennas provide larger degree of freedom in tag orientation, but have a relatively shorter read range.

5 Schedule, Tasks, and Milestones

Raising the Steaks designed and implemented this RFID reader prototype from April 2016 to December 2016. Appendix A contains a GANTT chart that outlines the timeline of major tasks and milestones. Appendix B contains a PERT chart that shows the progression of the tasks and how they are interconnected. Appendix C contains a spreadsheet that reveals the probabilities associated with each task with a final calculation of the completion of the prototype at least one week earlier than the Capstone event in December 2016.

6 Final Project Demonstration (Field Test)

The demonstration of this prototype took place on a ranch in Rydal, GA where multiple hundred cattle have previously been tagged with RFID cattle tags. The UAV was provided by Dr. Tentzeris' lab. A standard ATV was provided by Nathan, who was in charge of the ranch at that time, to drive around the pasture and test the RFID UAV system.

6.1 Integration with UAV

The first part of the demonstration was to mount the developed RFID reader prototype on a UAV. The RFID system was able to work off a mounted battery and was secure enough to withstand reasonable flight maneuvers. Before proceeding to the next part of the demonstration, the team ensured that tags were being read consistently by the system. Table 2 shows the read range results of the system operating in a lab environment with no cattle. "System without Drone" indicates that the RFID reader and antenna are being operated separately from the drone platform and thus not in flight. "System with Drone" indicates that the "Isolated tag" indicates that the tag was in free space, whereas "tag on human" indicates that the tag was flush against a human body. Note that the tag contact with a human body drastically reduces read range.

Lab Test

	Linear pol.	Circular pol.
Isolated tag	25 ft	6.5 ft
Tag on human	< 1 ft	< 1 ft
Isolated tag	5 ft	2 ft
Tag on human	none	none

Legend	
System without Drone	System with Drone

Table 2. Results from lab testing RFID UAV system in lab environment.

6.2 Counting Cattle

The next part of the demonstration involved driving up to a herd of cattle. The operator flew the UAV RFID system with a linear polarized antenna over the pasture to appropriately scan the herd. Only the linear polarized antenna was tested due to time constraints. In this field test, there were no tag reads recorded during flight, as seen in Table 3. Additionally, read ranges seen in the field test were less than the read ranges seen during lab tests. A possible contributor to these results is moisture from precipitation and dew. It is known that moisture has an adverse effect on RFID systems. “Retro-fitted” tags on the ears of the cattle could have also affected results. Cattle tags read during these tests were standard cattle tags with a passive RFID antenna taped/glued to the back of the tag (i.e. retro-fitted), making these tags different from the ones used in lab tests. Lastly, undesirable orientation of the cattle tags with respect to the linear polarized antenna mounted on the drone affected the readability of the tags. The antenna was mounted to avoid the flight-enabling sensors on the drone, resulting in the antenna polarization and tag orientation being perpendicular.

Field Test

	Linear pol.	Circular pol.
Isolated tag	6 ft	N/A
Tag on Cow	10 ft	N/A
Isolated tag	5 ft	N/A
Tag on Cow	none	N/A

Legend	
System without Drone	System with Drone

Table 3. Results from field testing RFID UAV system in a cow pasture.

This field test was captured on video and shown at the Senior Design Expo on December 6, 2016.

7 Marketing and Cost Analysis

7.1 Marketing Analysis

Tracking and maintaining cattle using UHF RFID systems is not a new concept. However, most of these concepts exist in other countries outside the United States. These existing concepts also have a very limited range and capability compared to the prototype proposed in this project. Table 4 shows the cost and read range of the RFID reader used in this system (highlighted) as compared to alternative RFID readers.

Item	**Allflex Cost**	**Agrident Cost**	**ThingMagic USB Pro Cost**
Mobile Stick Reader	$1,100.00 [7]	$790.00 [8]	$495.00
Read Range	50 cm [7]	35 cm [8]	Up to 20 ft with external antenna

Table 4. Allflex, Agrident, and ThingMagic mobile reader costs. Highlighted is the RFID reader used in this system.

7.2 Cost Analysis

7.2.1 Opportunity Cost Savings

Assuming that the average rancher salary is $60,000 per year in the state of Georgia [9], this equates to about $30 per hour. From talking to people in this field, on average, the rancher will spend about 15 hours per week counting cattle and looking for lost cattle. This comes up to $23,400 per year per rancher of money spent finding and counting cattle. Using the proposed prototype, it will severely cut this opportunity cost down to the retail price of the reader system and a small fraction of time spent driving around and counting cattle.

7.2.2 Parts/Materials

Raising the Steaks developed a working RFID reader system prototype that is mounted on a UAV. To accomplish this, multiple RFID antenna were acquired, characterized, and modified to accomplish this effort. RFID cattle tags were provided by our sponsor, CattleTime. The bill of materials for each piece of hardware used in our prototype is listed in Table 5.

Item	**Cost**
DJI Phantom 4	$1,200
RaspberryPi 2B	$40
Velcro for mounting	$50
ThingMagic Pro RFID Reader	$495
External Linearly Polarized Antenna [10]	$210
External Circularly Polarized Antenna [11]	$21
Rechargeable battery pack	$11

Table 5. Costs to prototype.

7.2.3 Costs of Labor and Profits

There are 5 engineers on Raising the Steaks. The labor hours spent per engineer is predicted in Table 6 for a whole semester.

TASK	**HOURS**
Weekly Meetings	22
Paper Reports and Summaries	30
Presentation	1
Testing	25
Transportation	15
TOTAL	**93**

Table 6. Hours of labor.

The total labor costs are calculated using the hours per engineer for a semester and an annual average salary of an entry level Electrical Engineering graduate from Georgia Tech which is currently around $68,000. At 93 hours of labor, the cost per engineer is $3,162. Assuming 30% fringe benefits of labor and 120% overhead for unexpected costs, the total development cost for the RFID reader system is shown in Table 7. The total development cost is estimated to be around $47,545.50.

DEVELOPMENT	**COST**
Parts	$2,149.50
Labor	$15,810
Fringe Benefits	$4,743
Overhead	$24,843
TOTAL	**$47,545.50**

Table 7. Total development costs.

If the assumed selling price of the reading system was $3,000, then only 16 readers need to be sold to break even from all the development costs. With the expected impact of such a reader in the cattle industry, the chances of selling more than 16 is highly likely since there are numerous ranches around the United States. Maintenance costs are currently undefined because the design is still in its initial phase and sources of failure in physical parts have not been identified nor tested.

8 Summary, Conclusions, and Future Work

8.1 Summary

All the ECE 4011 and ECE4012 requirements are now complete. This includes initial project scheduling, project cost analysis, final project summary, final project proposal, final project demonstration, and website. Raising The Steaks also was awarded best ECE project at the Senior Design Expo on December 6, 2016.

8.2 Conclusions

Although no tag reads were registered during the in-flight portion of the field test, there are several significant conclusions that can be made. Firstly, it was noticed that when cows are startled and move around, their ears move around also. Movement of a cow's ears can cause the RFID cattle tag to come in contact with the cow's body, thus nullifying RFID transmission.

The movement of the drone and the movement of the cattle contribute to the misalignment of antenna polarization and tag orientation when a linear polarized antenna is used. As a result, a tradeoff may have to be made in which a circular polarized antenna with a shorter read range is used. These conclusions can be built upon for further improvement of the prototype.

8.3 Future Work

8.3.1 Possible solutions to existing problems

To combat the case when the cattle tag contacts the body of the cow, a small, lightweight spacer could be introduced to the back of the tag. This allows more efficient RFID reflections as the cow moves its ears.

More testing needs to be done regarding various polarized antennas and their mounting orientations. Testing several circular and linear polarized antennas with different gains in multiple orientations on the drone will provide more data to characterize and optimize this system. This data will determine if the tradeoff of polarization versus read range is necessary.

Since our system is modular, different drone platforms can be substituted and tested. Some drones are more suitable for having additional hardware attached to them.

8.3.2 Expansion into alternative markets

Raising the Steaks is confident in the current prototype of the UAV RFID system we have built, but we are even more confident in how it could be expanded and improved upon—especially in terms of reaching alternative markets. We believe that with the expansion of RFID technology to incorporate various sensors, our model could be adapted to more than just taking inventory on a farm. RFID temperature and humidity sensors could be used to monitor crops and agriculture. The incorporation of UAV and RFID could be used in warehouses and airports to help with inventory and baggage. We believe that the UAV RFID technology that our prototype demonstrates will be a major factor in different markets in the coming years, as it introduces more flexibility and increases efficiency.

9 References & Works Consulted

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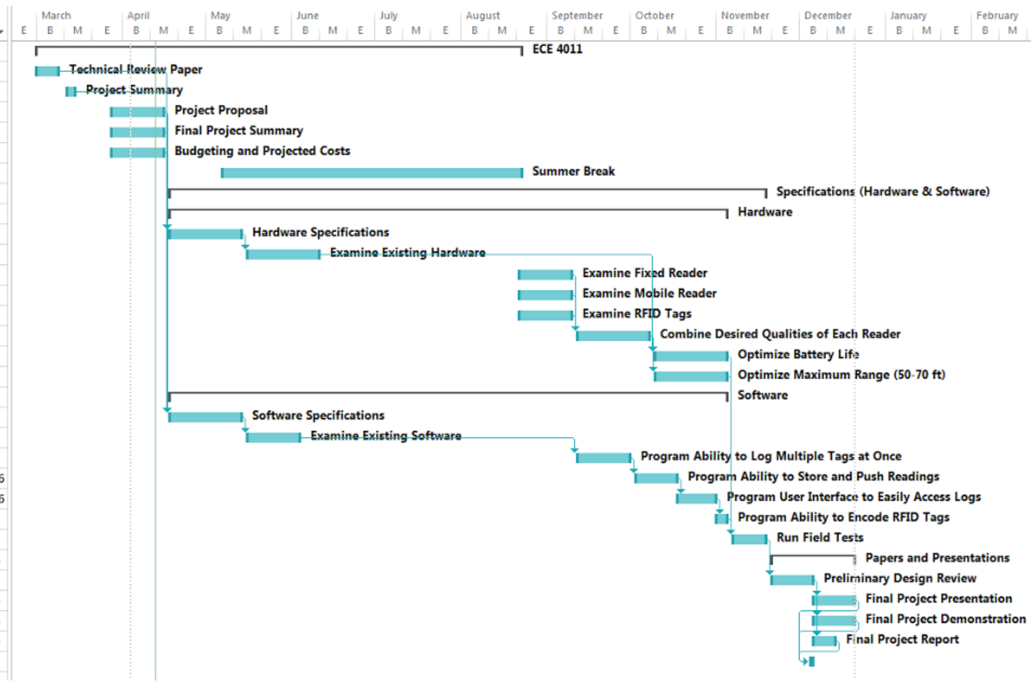
Appendix A: Project GANTT Chart

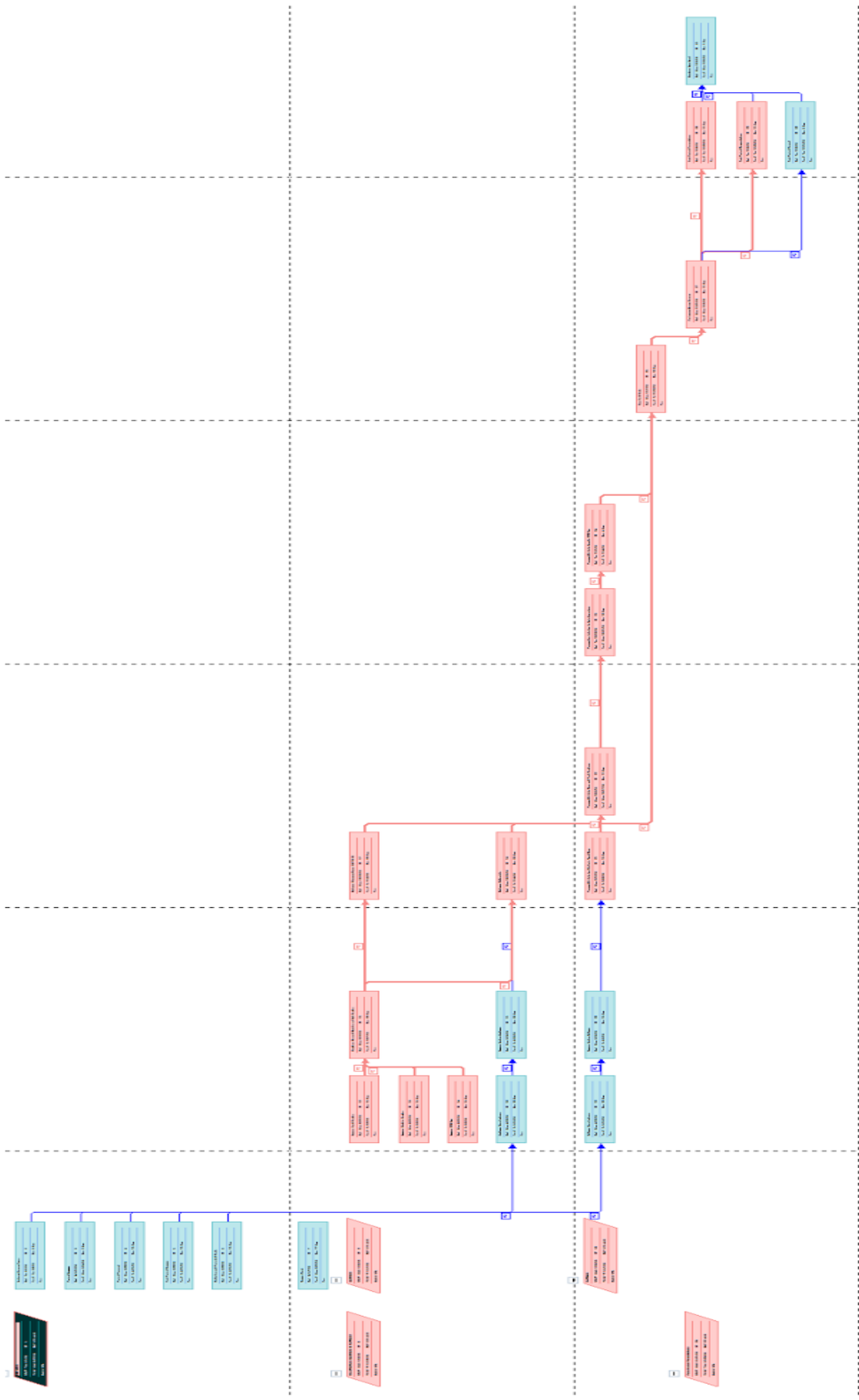
See next page for project GANTT chart.

	Task Mode	Task Name	Duration	Start	Finish
1		1 ECE 4011	**125 days**	**Tue 3/1/16**	**Mon 8/22/16**
2		1.1 Technical Review Paper	6 days	Tue 3/1/16	Tue 3/8/16
3		1.2 Project Summary	2 days	Sat 3/12/16	Mon 3/14/16
4		1.3 Project Proposal	15 days	Mon 3/28/16	Fri 4/15/16
5		1.4 Final Project Summary	15 days	Mon 3/28/16	Fri 4/15/16
6		1.5 Budgeting and Projected Costs	15 days	Mon 3/28/16	Fri 4/15/16
7		1.6 Summer Break	77 days	Sat 5/7/16	Mon 8/22/16
8		**2 Specifications (Hardware & Software)**	**155 days**	**Mon 4/18/16**	**Fri 11/18/16**
9		**2.1 Hardware**	**145 days**	**Mon 4/18/16**	**Fri 11/4/16**
10		2.1.1 Hardware Specifications	20 days	Mon 4/18/16	Fri 5/13/16
11		2.1.2 Examine Existing Hardware	20 days	Mon 5/16/16	Fri 6/10/16
12		2.1.3 Examine Fixed Reader	15 days	Mon 8/22/16	Fri 9/9/16
13		2.1.4 Examine Mobile Reader	15 days	Mon 8/22/16	Fri 9/9/16
14		2.1.5 Examine RFID Tags	15 days	Mon 8/22/16	Fri 9/9/16
15		2.1.6 Combine Desired Qualities of Each Reader	20 days	Mon 9/12/16	Fri 10/7/16
16		2.1.7 Optimize Battery Life	20 days	Mon 10/10/16	Fri 11/4/16
17		2.1.8 Optimize Maximum Range (50-70 ft)	20 days	Mon 10/10/16	Fri 11/4/16
18		**2.2 Software**	**145 days**	**Mon 4/18/16**	**Fri 11/4/16**
19		2.2.1 Software Specifications	20 days	Mon 4/18/16	Fri 5/13/16
20		2.2.2 Examine Existing Software	15 days	Mon 5/16/16	Fri 6/3/16
21		2.2.3 Program Ability to Log Multiple Tags at Once	15 days	Mon 9/12/16	Fri 9/30/16
22		2.2.4 Program Ability to Store and Push Readings	11 days	Mon 10/3/16	Mon 10/17/16
23		2.2.5 Program User Interface to Easily Access Logs	10 days	Tue 10/18/16	Mon 10/31/16
24		2.2.6 Program Ability to Encode RFID Tags	4 days	Tue 11/1/16	Fri 11/4/16
25		2.3 Run Field Tests	10 days	Mon 11/7/16	Fri 11/18/16
26		**3 Papers and Presentations**	**22 days**	**Mon 11/21/16**	**Tue 12/20/16**
27		3.1 Preliminary Design Review	11 days	Mon 11/21/16	Mon 12/5/16
28		3.2 Final Project Presentation	11 days	Tue 12/6/16	Tue 12/20/16
29		3.3 Final Project Demonstration	11 days	Tue 12/6/16	Tue 12/20/16
30		3.4 Final Project Report	6 days	Tue 12/6/16	Tue 12/13/16
31		3.5 Capstone Expo Event	1 day	Mon 12/5/16	Mon 12/5/16



Appendix B: Project PERT Chart

See next page for project PERT chart.


NETWORK DIAGRAM

Appendix C: Project PERT Analysis

See next page for project PERT analysis.

	A	B	C	D	E	F	G	H	I	J
1	**Tasks**	**Dur_Optimistic (days)**	**Dur_Expected (days)**	**Dur_Pessimistic (days)**	**Std_Dev**	**Var**	**Crit_Path_Mean**	**Crit_Path_Std_Dev**	**Z_transform**	**Prob_Finish_Week_Early (Percentage)**
2	**ECE 4011**		**125**							
3	Technical Review Paper	x	x	x						
4	Project Summary	x	x	x						
5	Project Proposal	14	15	15	0.17	0.03				
6	Final Project Summary	14	15	15	0.17	0.03				
7	Budgeting and Projected Costs	13	15	18	0.83	0.69				
8	Summer Break	77	77	77	0.00	0.00				
9	**Specifications (Hardware & Software)**		**155**							
10	**Hardware**		**145**							
11	Hardware Specifications	17	20	21	0.67	0.44				
12	Examine Existing Hardware	17	20	25	1.33	1.78				
13	Examine Fixed Reader	13	15	16	0.50	0.25				
14	Examine Mobile Reader	13	15	18	0.83	0.69				
15	Examine RFID Tags	12	**15**	16	0.67	0.44				
16	Combine Desired Qualities of Each Reader	18	20	24	1.00	1.00				
17	Optimize Battery Life	17	20	22	0.83	0.69				
18	Optimize Maximum Range (50-70 ft)	18	20	23	0.83	0.69				
19	**Software**		**145**							
20	Software Specifications	17	20	21	0.67	0.44				
21	Examine Existing Software	17	15	23	1.00	1.00				
22	Program Ability to Log Multiple Tags at Once	13	15	16	0.50	0.25				
23	Program Ability to Store and Push Readings	13	11	16	0.50	0.25				
24	Program User Interface to Easily Access Logs	8	10	13	0.83	0.69				
25	Program Ability to Encode RFID Tags	3	4	5	0.33	0.11				
26	Run Field Tests	9	10	13	0.67	0.44				
27	**Papers and Presentations**		**22**							
28	Preliminary Design Review	10	11	12	0.33	0.11				
29	Final Project Presentation	9	11	13	0.67	0.44				
30	Final Project Demonstration	11	11	11	0	0				
31	Final Project Report	6	6	6	0	0				
32	Capstone Expo Event	1	**1**	1	0	0				
33							135	2.15	1.39	91.77
34		**Key**								
35		x = already completed								
36		**BOLD** = simply for organization								
37		(not included)								
38										