April 30, 2010
Andrew Rawicz
School of Engineering Science
Simon Fraser University
Burnaby, BC
V5A 1S6

Re: ENSC 440 Post-Mortem for the Robotic Item Retrieval System

Dear Dr. Rawicz,

Attached is the Post-Mortem from Freedom Innovation Research. The Robotic Item Retrieval System is an automated system that can help disabled people to retrieve item at home.

The Post-Mortem describes the current state of the project and the plan for future development. The proposed and the actual budget and time constraints are also included. Finally, we outlined some technical and non-technical hardship encountered by the team and what we have learned by working on this project.

Freedom Innovation Research (FIR) consists of five motivated and innovative people: Steven Choi, John Ogawa, Jason Tsai, Kenta Yuan, and Richard Zhang. We are all fifth-year engineering students with at least one year of industrial work experience.

If you have any question or comment about our project, please feel free to contact us at ensc-440-2010sp-fir@sfu.ca.

Sincerely,

John Ogawa
Chief Executive Officer
Freedom Innovation Research

Enclosure: *Post-Mortem for the Robotic Item Retrieval System*

Abstract

The post mortem outlines the current development state of the Automated Item Retrieval System and lists the deviations from the original plan. It also describes the team dynamics and the individual reflections of each team members. In terms of the current state of the project, we have met most of the functional specifications. Some technical modifications have been made to make certain features work. The actual timeline differs from the original one because of a more realistic time. The actually budget spending is within the proposed budget. The team dynamic is still healthy. By doing this project we have learned a lot of valuable skills that can be found in any textbook.

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Glossary

A	Ampere
ADC	Analog-to-Digital Converter
AWG	American wire gauge
DB	Decibels
DHCP	Dynamic Host Configuration Protocol
FCC	Federal Communications Commission
FIR	Freedom Innovation Research
Fps	Frame per Second
G	Gravity = 9.8m/s^2
GB	Gigabyte
GPIO	General Purpose Input/Output
GUI	Graphical User Interface
I2C	Inter-Integrated Circuit, a multi-master serial computer BUS that is used to attach low-speed peripherals to a motherboard, embedded system, or cellphone
IEEE	Institute of Electrical and Electronics Engineers
Lux	the SI unit of illuminance and luminous emittance
MB	Megabyte
MTBF	Mean time between failures
PWM	Pulse-width modulation
QVGA	Quarter Video Graphics Array
RFID	Radio-frequency identification
TCP	Transmission Control Protocol
UDP	User Datagram Protocol

1 Introduction

During the past 16 weeks, the Freedom Innovation Research Inc. has been working on the prototype of Robotic Item Retrieval System, which is a device that can assist disabled people to retrieve item at home. This post mortem outlines the current state of the project, deviation from the original design specification, the financial details, development timeline and the plan for the future development. Lastly, the document concludes with each team member's reflection on the project.

2 Current State of the Project

All the necessary functions have been implemented and meet most of the prototype function requirement as we list in the functional specification. The following figure shows the system flow of our product.

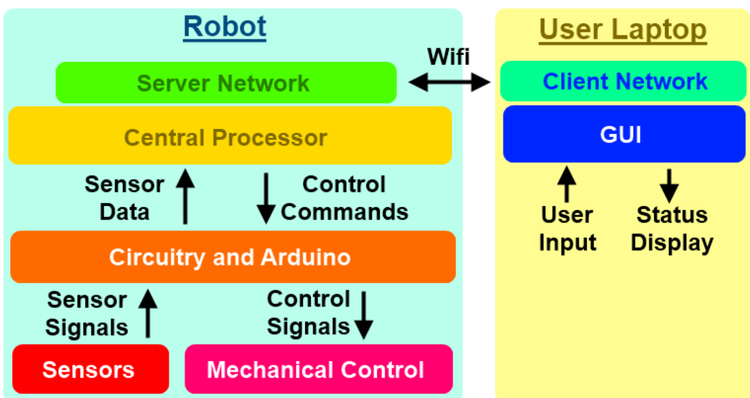

Figure 1. Overall System Flow

1. Sensors, such as ultrasonic distance sensors, light sensors
2. Circuitry picks up the signal and Arduino translates it into digital data
3. Central processor analyzes the data and sends it to client
4. Client receives data and displays it on GUI
5. Client analyzes data and sends command to central processor
6. User inputs command and client sends it to central processor
7. Mechanical components, such as robotic arms, move based on control signal

The major components as well as the deviations from the original scope of the project will be discussed below.

2.1 Robotic Base (Drive Train)

While the DC motors is running, the servo is able to steer based on the reflection from the light sensors and hence the robot is following the line taped on ground. There are four ultrasonic distance sensors in the front and back sides for the collision detection. The heart of the Robot consists with a Roboard development and an Ardruino board that has to be operating without power interference from any other electrical components. Since the high torque DC motors require quite large current for operation, in order to maintain the stability of the system, we decided to use two batteries to separate the two critical modules as mentioned. One battery is used to power the drive train and the other battery is used to power the sensors and the control units. We also built charging circuit for the rechargeable batteries. The following figure shows the Drive Train of the final product.

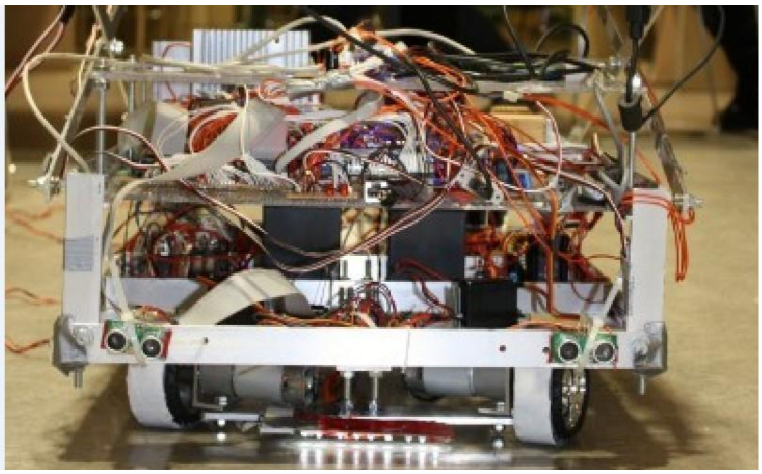

Figure 2. Drive Train

2.2 Robotic Platform and Arms

Once the robot gets to the destination, the platform can rise up or down. When the platform gets to the item's height, its arms can extend out to reach the item. The arms, controlled by servos, will grip the item. There are four buttons for the platform and arms to stop them before they go beyond limit. Also, there are two micro switches installed on the edge of the arms to sense if the item was held successfully or not. All of these motions are controlled by user wirelessly.

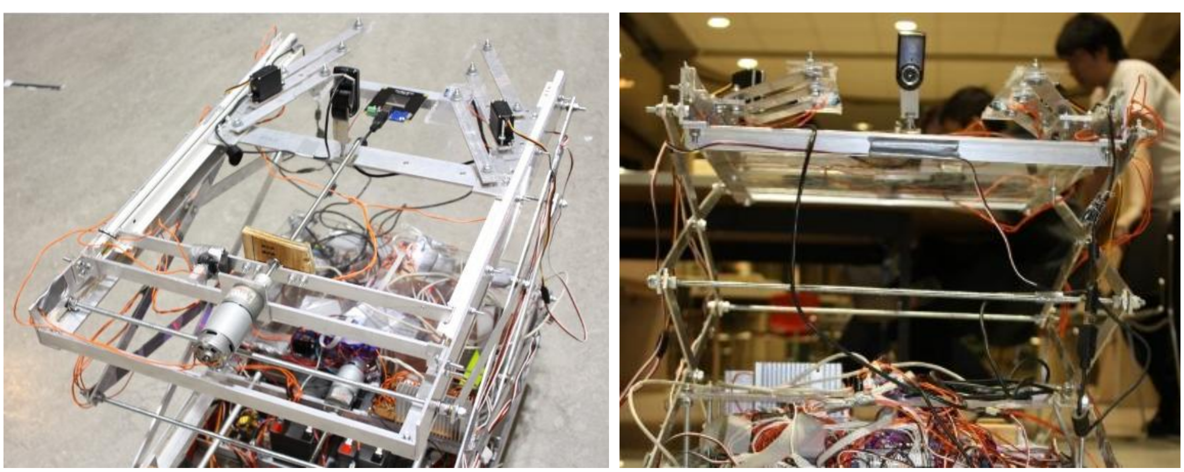

Figure 3. Robotic Arm Platform

2.3 Software

2.3.1 Operating System

The control unit, Roboard, is using Ubuntu operating system because we could remove unnecessary features from the kernel to optimize the maximum performance and use minimum resources. We also added service code that will automatically setup wireless connection.

2.3.2 Driver and Communication Protocol

Roboard provided libraries of I/O controls. We developed drivers for I/O's, wireless communication, and data process. Data pass in and out of GPIO, ADC ports, serial ports, and PWM. The software receives the sensor data, and the data is processed according to the control protocol. Then the software gives instructions to the corresponding components, such as motors and servos. Serial port communicates with Arduino, which retrieves data from ultrasonic sensors and monitors the power consumption.

2.3.3 Server and Client Communication

The server and client communicate with the protocol specified by the team. The server sends two data structures to the client. Once the data structure is identified, the data is decoded and is used to show the status of the robot to the user.

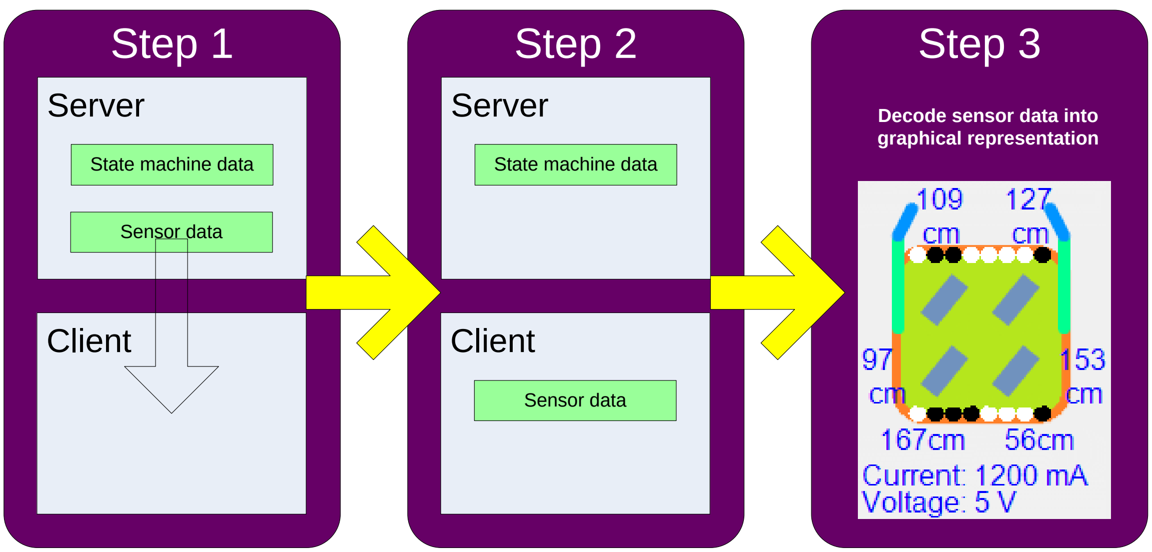

Figure 4. The flow of the server and client communication

The sensor data contains all the information about the robot status for the user to see. The data is processed within the server program, not the client program. The client program will only display the data to the user.

The state machine data contains the information that the client must process. A lot of computation must be carried out to process the data. The server is designed only to process the low-level logic, not the large computation. Therefore, the server sends the data for the client to process, and then the server expects computed answers from the client. For example, the state machine data contains the next direction variable. The server sets the next direction variable to be undefined if the server does not know which direction to go on the next intersection. When the client reads the undefined value of the next direction variable, the client computes the path algorithm and sends the instruction to turn the robot left or right on the next intersection.

When user clicks on a direction control button, the client program recognizes the command and sends the command to the server. The server receives the command and the robot executes the command.

3 Deviation from the Original Plan

3.1 Robotic Arm Platform

Building the robotic arm platform is a major difficulty that we faced when working on the project. In the early development phase, the base of the scissor lift is neither stables enough nor slides forward and backward smoothly. Therefore, during testing, the entire scissor lifts tilts and wobbles as the platform moves either upward or downward. In the worst situation, the lifting base is stuck and the lift won't move at all. We had to redesign the lift base by adding smooth metal sticks to support and constrain the slider bar on the robotic base. Moreover, we installed sliding wheels to smooth the base movement.

3.2 Map Navigation

We developed a program that can navigate through any path in a map, given the travelled distance data and the compass data are available. The program had complicated logic because it searches through each path point and records the correct path and directed the robot to turn left or right at each intersection. In the end, we couldn't use this program because we didn't have enough time to integrate and test it. Instead, we used single path without any intersection for the demo.

3.3 Inter-Processor Communication

In our original design, the communication between the Roboard and the Ardunio relies on the I^2C bus interface. Unfortunately, in the middle of the development phase, the I^2C bus interface failed unexpectedly. After thorough investigation we found out the I^2C interface on the roboard is fried and we are forced to switch to serial port for inter processor communication.

3.4 Ultrasonic Distance Sensors

In the integration phase we found that the ultrasonic sensors start to fail one after the other. We checked the connections and reviewed the circuit design; they are all within the specs of the ultrasonic sensor modules we used. We conclude that this batch of ultrasonic sensors is faulty and they have a unreasonably short MTBF (mean time between failure). Because the demo was already at hand when we found this, we had to go to the demo with only three functioning ultrasonic sensors installed. We purchased these units initially because of their great price and performance. However, we didn’t spend enough time to analysis their reliability. This taught us a lesson that for engineering the reliability of a product is much more important than shear performance.

4 Project Management

4.1 Actual and Estimated Budgets

Freedom Innovation System has minimized the cost for the project by purchasing separate electronic components from selected store and assembles them together according to the design of the project. For example, rather than purchasing finished modules which cost more, we have purchased aluminum metals, screws, and plastic glasses from local stores and assemble them as our robot base and the robot arm to reduce the cost. The most critical decision made that contributed to the budget saving is that we have ordered most of the sensors, servo motors from China.

Table 1 and Table 2 contain the estimated and actual costs of the project respectively.

Table 1. Estimated Project Cost

Component	Estimated Cost
Drive Motor w/ Optical Encoder	$115.45
H Bridge Motor Driving Circuits	$131.20
SRV-1 Blackfin Camera + WiFi (Robot Controller)	$367.50
Ultrasonic Range Sensor	$62.95
Reflectance Sensor Array	$16.25
Customize robotic arm and elevation platform	$300
Robotic base and drivetrain	$200
Power system(12V lead-acid battery and charging station)	$200
Phidgets RFID Quick Start Kit	$100
Other building materials and electronic components	$200
Total Cost (Before tax)	**$1693.35**

Table 2. Actual Project Cost

Motors(Servo and geared)	294.78
Microntrollers (Roboard, Arduino)	380.42
Ultrasonic Sensors	76.44
Line tracking sensors	30
Accelerometers	20.67
Compass	70.13
RFID sensor	89.99
IR sensors	21.61
Power Relays	27.42
Fuses	8.54
Battery	21
Capacitors	20.32
Current Sensors	20.01
Voltage Regulators	1
Power Diodes	13.78
Transformer	27.08
Connectors and wires	45.81
Almunium Materials	94.81
Wheels	31.47
Motor hubs and couplers	42.22
Screws	47.7
Other building materials	131.47
Prototype PCB	19.38
Electronic components(Reistors, switches..etc)	19.26
IC chips	11.4

Storage Devices	19.96
Shipping	62.18
Tax	136.1
Total	1784.95

Actual and Estimated Timeline

The actual timeline is longer than we originally anticipated. We are not able to meet the original deadline for the following reasons: first, the Robotic Item Retrieval System is a comprehensive project which by its nature requires more time and resource. Moreover, we have been modifying the design for the robot base and arm during the development phase. Second, the scheduled project demo date for our group is April 30th, so it's only wise to use the extra one month to improve the quality of our project. We have used the extra month to further refine the robotic arm design and to create a more user friendly GUI. The following two figures show the comparison between the actual and estimated timeline.

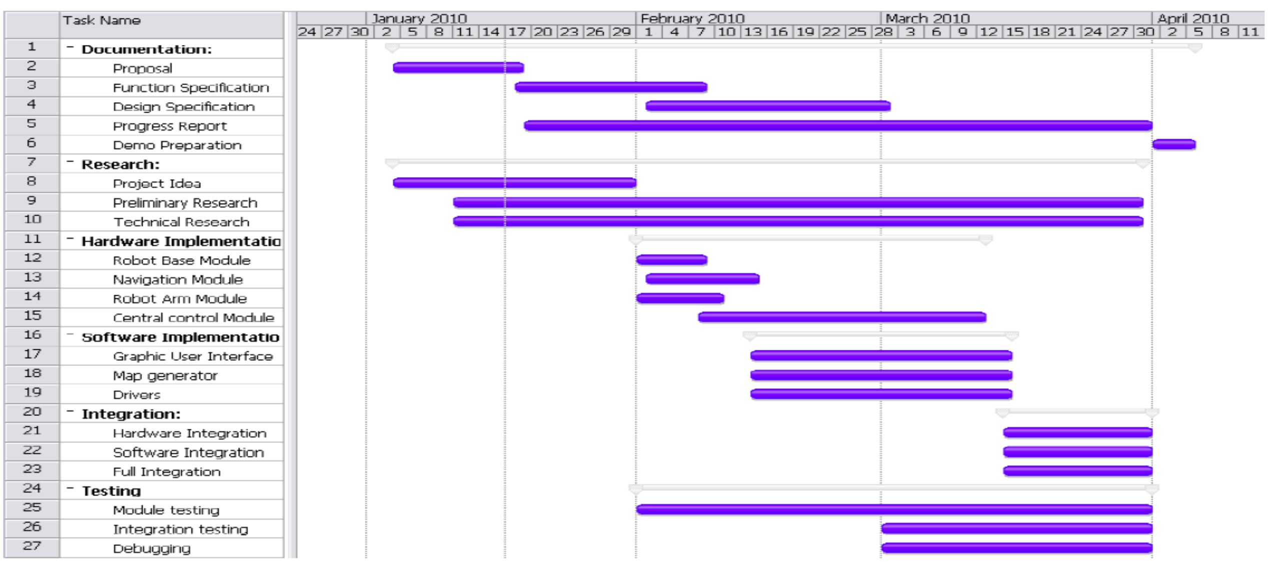

Figure 5 Gantt chart of the Estimated Timeline

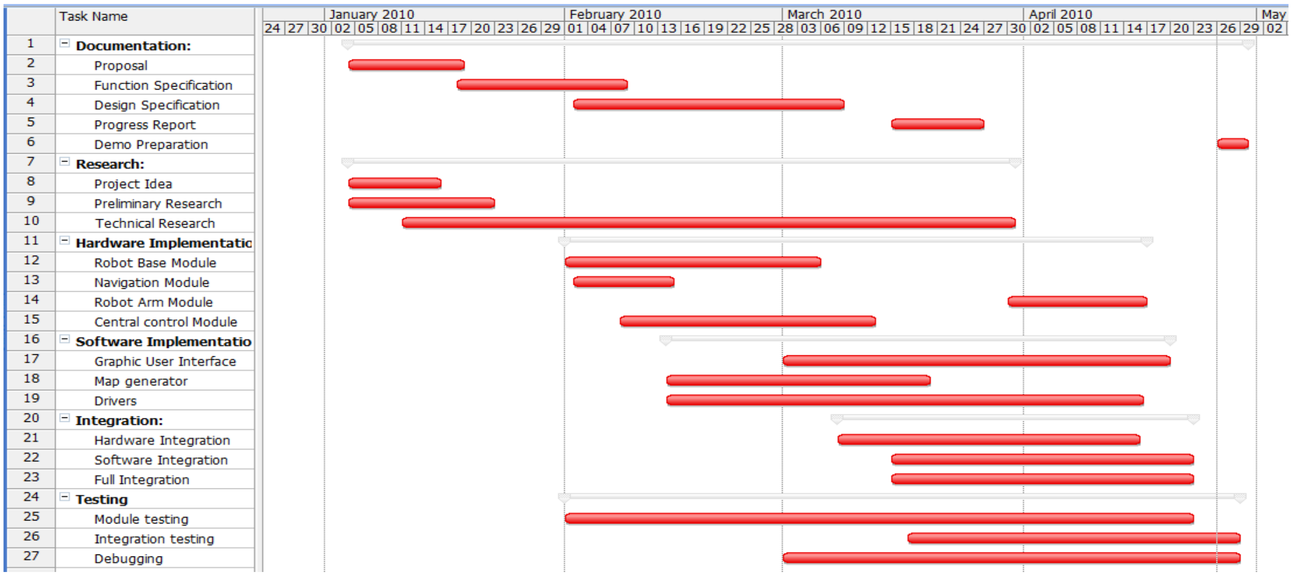

Figure 6 Gantt chart of the Actual Timeline

5 Team Dynamics

Most of the team members had a high commitment for the project and put this project as the highest priority among their course works. From the beginning of the project, the team has been working together closely in the lab even though each team member is responsible with different tasks. We realized that by working in this way, we could generate the maximum productivity because we could exchange technical ideas interactively and discuss concerns right away. Moreover, working together provides a great opportunity to learn from each other and help each other out immediately if needed. In addition, we have formed a tightened bond for the project and maintains positive work atmosphere by witnessing the project progressing toward success. Finally, the most beneficial outcome we receive from working together is that there is a minimized difficulty when we integrate each modules together as the final prototype as a whole.

6 Future Development

6.1 Robotics Arm

As described in the *Deviation from the Original Plan* section, the robotic arm cannot be used to grab a large tray containing desired items as we originally stated in the proposal. In the future development, we plan to realize the feature by revising the mechanical design of the robotic arm and enhancing the grab strength by upgrading to stronger servo motors.

6.2 Automatic Map Generation

Currently, the user could monitor the current location of the robot that displays on the pre-defined map that corresponding to the actual route placed in the house. Moreover, by clicking on the map, the user could arbitrarily set the starting location of the robot and the end location for the robot to arrive. In the future development, we will enable the auto map generation feature that operates as the following steps: at the first of use, the robot will travel along with all the placed routes in the room and upload the trace to the client, and then, the client will generate the Map using the trace data and display it on the GUI Interface.

6.3 Webcam Mount

Currently, the webcam is mounted on the robot and it is facing in a fixed direction. To extend the practicability, we plan to design a dedicated webcam mounting station consists with two servo motors to allow the user to rotate and tilt the webcam.

6.4 Image Processing

The robot identifies different items by using the RFID. We are exploring the possibility of achieving the same goal by processing the image captured by the webcam.

6.5 Fully Automatic Sequence

At present, user has to wirelessly control the platform and arms monitored through the webcam in order to grip the item. In the future, we can improve our software to execute the whole set of motion sequence without users' input. It means that as long as user specifies the item, the robot will go to retrieve it and return it back to the user automatically, without further control from the user.

7 Individual Reflections

7.1 Steven Choi

This is the very first time that I have been doing soldering work and breathing the smoke for more than a month continuously. I am responsible for all electronics circuitry design and assembling for the robotic system. I even spent one day doing SMT chip soldering. It also takes me a long time to develop drivers and run sanity test on all sensors and actuators before it is ready to be used reliably. I have been changing circuitry design due to different request from the software team over the time. On the other hand, I have been designing the robotic base and implementing it with all the sensors and actuators.

Without software, the hardware I have designed is useless. In this project, I have learned how to implement better hardware for easier software programming so that my teammates can work with it. I have been working with Richard most of the time to discuss how his robot server works so that I can correctly fill in the blanks for low level driver program. Kenta worked with me on the other times on wiring and robot base assembling.

I am very pleased by Jason's and John's navigation algorithm and GUI. I do not need to work on software programming in this limited time period; otherwise, I might be dead already.

Over the last three months, I feel sorry for my team because they picked my idea, automatic item retrieval system that made us worked so hard every day and night. I appreciate my teammate that they don't give up in the middle of the road and do not blame on me.

7.2 John Ogawa

I worked on the client GUI program using Visual Studio C++. Other than the interface, the client program evaluates the path between the user and the table, which Jason and I sent a lot of time developing. Richard and I communicated regularly about the server-client protocol to ensure that the server and client could properly process each other's data. In order for everyone to work in parallel, we discussed about the hardware plan so that we could develop the software before the hardware was ready. Richard, Jason, and I simulated how the robot might work, but the hardware standards changed constantly, thus we modified our software standards accordingly to the hardware almost every day. Because I had to spend a lot of time at home with my mother, I only worked on the client program. I greatly appreciate the time and effort my teammates spent in order to compensate for my lack of accomplishments.

I gained further experience on Visual Studio and Linux. More importantly, I learned the effective team structure to work in parallel and run simulated tests. Steven, Kenta, and Richard discussed about the hardware standards, and Richard implemented the server program. We kept all the codes up-to-date on repository, so Jason and I could confirm that both server and client properly worked with the latest hardware standards.

From this course, I learned to appreciate the importance and difficulty of team work. At the beginning of the semester, we had difference of opinion on how we would approach the project. We worked toward different directions, so it was difficult for the team to make accomplishments. Eventually, the team worked in harmony, and we were making one accomplishments after another. I realized that a team could not produce anything if they could not work together, no matter how smart and talented each member was. I feel fortunate to experience both the bad and good team work because that was the only way to learn the importance of it. I never put so much thought about team work from courses, and even co-op.

7.3 Jason Tsai

I really enjoyed being part of team because everyone is so motivated and hardworking. The most unique characteristic for our team is we are able to work together with a healthy team dynamics. In fact, I occasionally overhear people discuss about how our team could come to the lab so early and leave so late together almost every.

During the course of the past 4 months, I mainly worked with John for the client side programming using Visual C++ with .NET Framework. We often discussed together and solved problems that we encountered. In particular, I developed the path finding method and moving direction control for the robot. In addition, I learned multithread programming, soldering and circuitry debugging from working with Steven, Kenta, and Richard. Besides technical skills, the most important thing I learned from this project is to be open-minded and positive. At the beginning of the course, I am stressed out for completing such a huge project that requires so much extensive knowledge, and yet with so limited resource. However, as the project progresses, I have been influenced by other members' positive work attitude toward the project. Moreover, I realized even though our project is huge, we could still manage to complete it as long as we break the project into small subsystems.

From this course, I have also learned the importance of communication. In the beginning of the semester, I sometimes feel discouraged when I know I have been wasting time with John approaching some tasks that other team members have already taken over. After not long, I started to understand how my teammates' plan their tasks by experience and by exchange ideas.

Overall, this project is a great experience that I could not gain from textbooks. I have also learned how to be more open-minded and positive when facing difficult problems. I am really appreciated with my teammates' hard work and I am really thankful for their patient and understanding for me being less productive in stressful situations. Freedom Innovation Research has together successfully delivered the project prototype and I am very proud to be part of this team.

7.4 Kenta Yuan

This is the strongest team I have ever had in all the project courses. Our group mates have been known each other for five years and hence we worked pretty close to each other. Everyone is so motivated and hard working that I believe we can accomplish any possible project. For example, the project we chose is very complicated but we still believe that we can finish it and we do. We made it.

We pretty much spent more than 12 hours a day for the project, 7 days a week. Hence, we stayed pretty late at school and we felt tired. However, we still were able to have fun while working hard together. We know that it's impossible to finish such a complicated project without spending extra hours. The one more minute we spent on the project, the one minute closer to the success.

Throughout the project, we encounter different problems and sometimes we have different approaches and opinions. Since we are very open-mind to each other, we always discussed and end up with the best solution to the problems. We trust and respect each other.

My main contribution to the project is mechanical construction such as robot base, platform, and arms. I also involved with circuitry soldering, hardware development, software development, and final product testing and calibration. One of the hardest things in the project is the fabrication. Even though we have designed a good dimension, due to the inaccuracy of fabrication, we always encounter some miss matches. With the accumulation of inaccuracy, we have to figure out some way to compensate the error. At the end, we have to use limited resources to solve unexpected problem. Our project involved with lots of circuitry and hardware connection, I learned a lot from my group mates. From this project, I also learn a lot about how to establish communication between hardware and software. As well, I noticed that a good design always come with a safety protection first. For example, always use a fuse in your circuit.

All in all, I had a very great time and enjoy the project very much. Despite one of our members is having a family issue, we are willing to share the load and take consideration for each other. ENSC 440 is very meaningful to me. Not only the technical part had I learned, but also a better friendship between us.

7.5 Richard Zhang

The last three months is the most challenging time I ever experienced. We no longer have status meetings because the team spent most of the time working and living together, which makes allocating time for meeting awfully redundant. We always occupy the best benches in lab1 because we are always the first team to arrive and the last team to leave. Starting from early April, our fellow students started to describe our project as "insane" and they wonder how we can pull this thing off in only three months. The specs of the project looks very ambitious: it has 12 degrees of freedom, each to be controlled in real-time; it has three different processors that need to be programmed (including the client PC); it featured a remote controlled car, a wireless webcam streaming server, a collision avoidance system. Each of these could be made into a standalone 440 project. We have a great team, no doubt, as we do not only get the skills but also get the guts to accept such a suicidal mission. In the end we survive the grim battle with the following formula proved:

skill + determination + planning - sleep = successful 440 project (1)

In the team, I'm the person primarily responsible for Linux programming and the coordinator between hardware and software development. I wrote 80% of the robot server code and I was extensively involved in the design and implementation of the robotic arm platform. By doing this project, my knowledge of real-time embedded programming and my machine shop skills are greatly improved. But more importantly, I had the opportunity to extensively work out my communication skills. The Linux software I created need to implement the drivers for the hardware platform as well as communicate wirelessly with the windows client program. Since the development of the hardware and the software do not directly overlap, it's falls into my responsibility to bridge the two development tasks and address any design conflict or misunderstanding between them. I have to learn about how our hardware works from the driver level and translate it into abstracted API commands for the client software team. I have to design and document the communication protocols between the robot and the client, which is not taught in any of the courses I've taken.

Overall, I couldn't be more satisfied with my team. Each member of the team are dedicate and understanding. One unique point of my team is that all team members have their own ideas about how thing should work but we all know when we should be firm on our ideas, and when we should back off. Everyone of the team has developed outstanding listening skill and persuasive skill, which is what makes the intra team communication smooth and efficient.

8 Conclusion

The Freedom Innovation Research is proud to say they completed a very successful project for this semester. The Robotic Item Retrieval System was a complex and challenging project that requires most knowledge learned in the five years in SFU and from the Co-op workplace. The team also realized that the true object for this course is not only to design and build a working prototype, but also to learn how to work as a team.

In the end, we would like to thank Andrew and Steve for their kind guidance and thank Lucky for helping us in circuit design. We also wish to express our thanks to ESSS and Wighton Fund for making this project possible.

