KAEFI

December 16, 2011

Dr. Andrew Rawicz
School of Engineering Science
Simon Fraser University
Burnaby, BC
V5A 1S6

Re: ENSC 305/440 Post-Mortem for an Office Automated Delivery Robot

Dear Dr. Rawicz,

Attached document contains Post-Mortem for KAEFI's Office Automated Delivery Robot system. Our system will provide convenience in office spaces while securely delivering important documents and other packages from one cubicle to another. This is possible by having lockable compartments with software controlling them. An application installed on PC will offer easy-to-use User Interface which will be used to put in query for the delivery. QR barcodes embedded on the floor will be scanned by the robot for localization of itself. A path-finding algorithm will be developed to find its way through the office spaces.

The enclosed is Post-Mortem for the office automated delivery robot (OADR). This document will include topics such as the current state of the system, deviation from the proposed design, and future improvements for the product. The financial and time factor of the project will be also discussed. The learning experiences of each member are included in the end to summarize what we have gained over the development of our robot.

KAEFI is composed of five senior engineering students with experiences through numerous Co-op(s) in the industry and research projects. We strongly believe that our product will not only be educational but competitive and beneficial, we are Gyu Han David Choi (CEO), Jin Sun Ahn (CTO), Hongbae Sam Park (CFO), Kyu Seo Lee (CMO), and Yongho Choi (COO). Should you have any question about our system, attached functional specifications, please contact us by email at kaefi-support@sfu.ca

Sincerely,

Gyu Han David Choi

KAEFI, Chief Executive Officer

Post-Mortem

For the Office Automated Delivery Robot

Dr. Andrew Rawicz – ENSC 440
Mr. Mike Sjoerdsma – ENSC 305

School of Engineering Science
Simon Fraser University

Gyu Han David Choi
Jin Sun Ahn
Hongbae Sam Park
Kyu Seo Sam Lee
Yongho Choi

kaefi-support@sfu.ca

16/12/2011

Rev 1.5

Table of Contents

List of Figures

List of Tables

Glossary

Microcontroller	The “brain” of the robot. Provides centralized processing capability
OADR	Office Automated Delivery Robot
PC	Personal Computer
PWM	Pulse Width Modulation. Method of controlling motor
QR	Quick Response. A type of barcode that can store information in a two-dimensional graphical form
Server-Client	A model of computer network

1. Introduction

The Office Automated Delivery Robot (OADR) is a solution for the delivery of heavy or important packages within the office-space. It will securely protect the packages during its operation until it reaches its destination. By doing so, we hope to aid in saving time and increase work efficiency in offices. It will be operated via website or smartphone app. It will be controlled based on the QR code information which indicates the position of the delivery locations.

Figure 1: Picture of the OADR

2. Current State of the product

2.1 Overall System

Currently, the OADR takes the shape of a box, as shown in *Figure 1*. Broadly, it is divided into two parts: hardware and software. In hardware section, it consists of chassis, drivetrain, microcontroller, power supply and a camera. On the other hand, software section consists of user interface, server and client communication, database, QR code scanning, path finding algorithm, motor controller and data communication between microcontroller and camera. Simply, the whole system undergoes the process shown in *Figure 2*. When the user requests a delivery order through UI, the information is saved in the database. Then, the order information containing the pickup location and the destination location is

passed onto the camera software which scans, detects and decodes the QR code. Based on the decoded QR code and its orientation via data communication, UART, the motor control software instructs the motor to start routing the OADR to the destination.

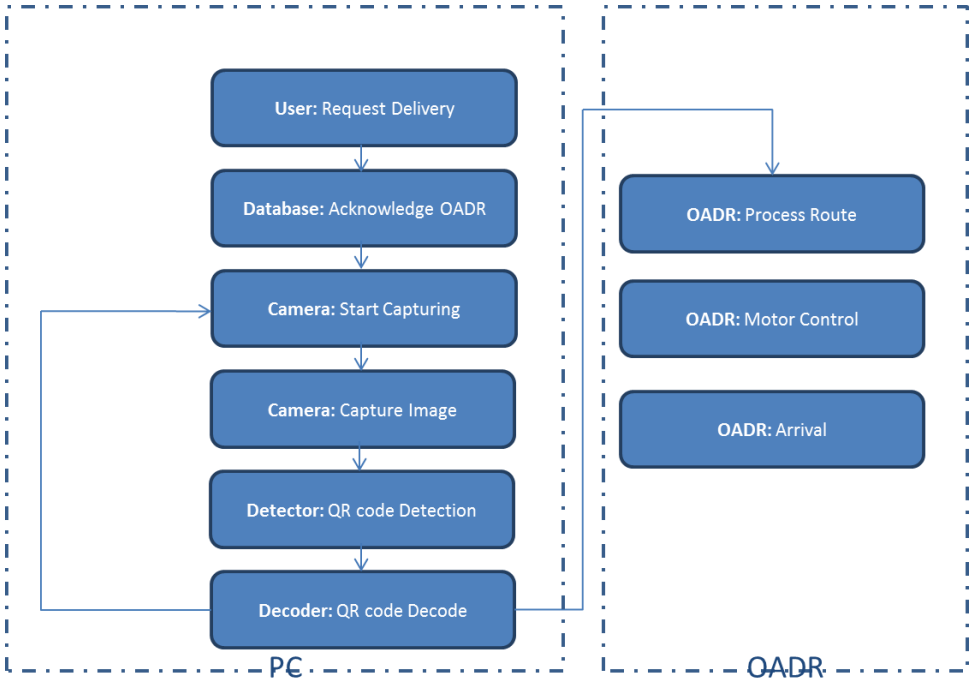

Figure 2: Software Flow Chart

2.2 User Interface Unit

We have the simple website for the user to request the order. After the user submits the valid location information, it is saved in the database to give a reference to the camera software to determine its path.

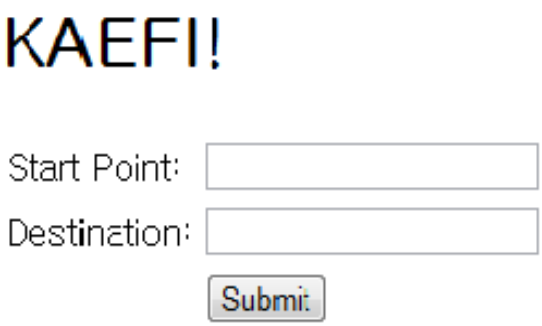

Figure 3: Website UI

2.3 Routing Computation Unit

Based on the delivery information from the database, we needed to determine the OADR how to get to the corresponding location. It is calculated by vector subtraction of destination and the starting location. The (x,y) notation is used for the convention. For instance, the order information of A as a starting point and D as a destination point, since (1,0) – (0,1) = (1,-1), the OADR will proceed to go to the right by one coordinate and down by one coordinate.

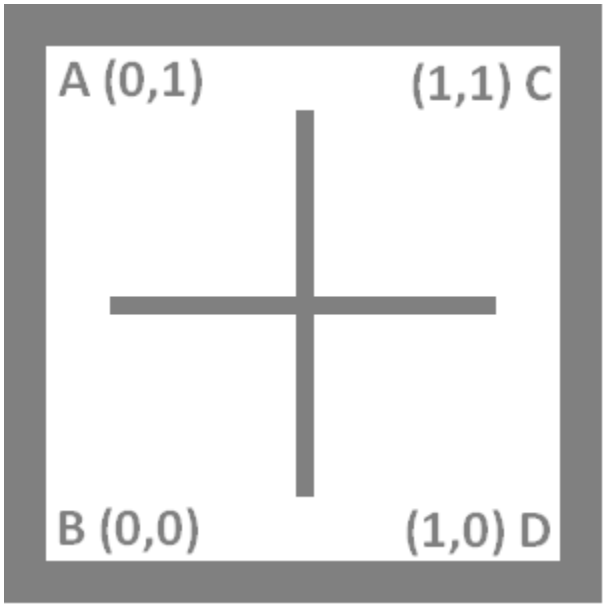

Figure 4: Coordinate of Map

2.4 QR Code Scan Unit

Once the database passes the delivery information, the camera is turned on to detect a QR code and decode the information written in the QR code to give correct instruction to the motor control unit. As it detects the QR code, it calculates the orientation of the OADR to correct its position for the routing. The orientation is determined based on the three square corners of the QR code as shown in *Figure 4.*

Figure 5: QR Code Orientation Determination

2.5 Motor Control Unit

Motor control unit –or motor controller- is implemented on the motor mounted on the OADR. The hardware side of the motor controller is composed of 2 major parts; the microcontroller with a speed feedback and the motor driver, or the h-bridge. Basically, the microcontroller outputs a controlling signal which is then amplified by the h-bridge to a suitable level for the motor. The micro controller outputs five instructions: *Go* straight, Turn *Right*, Turn *Left*, *Spin* 180° turn and *Halt* to stop. The decision to output which of the five instructions is made when the robot scans the QR code. Once the QR code is scanned, the OADR checks with its current orientation and the way-finding algorithm, then the information is processed and which instruction shall be made is calculated on the PC side, and the PC tells microcontroller to make a certain movement (one of the five instructions) via UART communication.

3. Deviations from the Proposal

3.1 Overall System

In our actual implementation, the major difference is the shape of the robot and the number of the storage compartments. The rotating compartment on the top has been excluded due to time and budget constraints (figure 6). Initially, the robot was designed with a cylindrical fairing or a cover around its frame for better impact energy absorption (like a bumper) and ease of installation. However, when we installed the round covering on, we felt that the robot was too wide (70cm in diameter after all) and it might have problems navigating around in narrow corridors in the office environment. Thus, in order to make it slimmer, we decided to just cover the sides of the frame. As shown on the right side of figure 5. This change in shape brought some other changes too, mainly the shape of the lower compartment door. Initially in our CAD rendition, the lower compartment opens sideways with a rounded-out door following the contour of the OADR's cylindrical cover. The door now opens up and down, so that the door does not occupy more space when it opens. The location of the door has changed from front to back, for safety reasons. For example, we wanted to eliminate the possibility of the OADR accidently leaps forward and hitting a person when he/she is standing in front of the robot to retrieve an object from the inside of the compartment. LED's have been added to the robot to give passersby a visual sign that it is in operation, and also to distinguish front from back (blue LED's in the front, red LED's in the back)

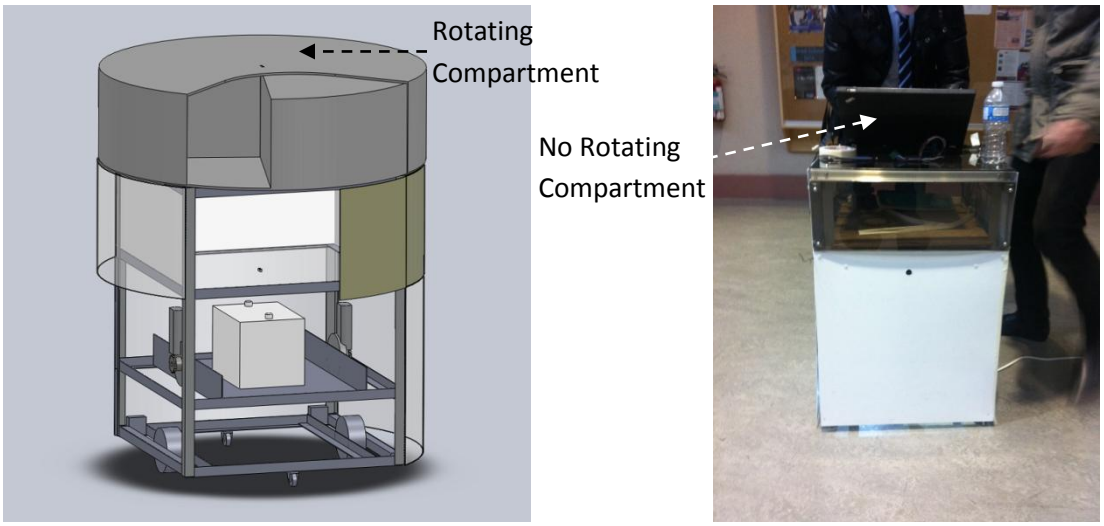

Figure 6: comparison of the shape of the OADR between the CAD rendition and the actual implementation

3.2 Motor Control Unit

Motor controller unit saw a major deviation that the method of extracting the speed of the motor for feedback has changed from optical encoder to a current sensor. The current sensor outputs a linear level of voltage per current, and the current is proportional to the speed of the motor unless there is an unforeseen load or in the case when the motor is in free spin (wheel does not make contact with the ground). Although the optical encoder has better resolution and can offer finer control, we were forced to discard it when we learned that it was mechanically unreliable (kept on interfering with our chain drive system) and it did not make the robot go much more straight than the current sensor. The bumpiness of the floor is too much of a variation for which the motor controller with the optical encoder cannot correct the speed of the motor.

4. Future Improvement of the product

4.1 Overall System

The first purpose of our robot is to deliver object within the office space. However, there will be wider market if we can make the robot to move things in different places. The robot serving foods in a restaurant and bringing the items in a warehouse are some of the examples we can think of.

4.2 User Interface Unit

The user interface that we have made is sufficient for our intension. If the client wants to have a multiple delivery from a single pick-up location, the user interface would need to have more fields to make this possible.

4.3 Motor Control Unit

Currently, we don't have a visual aid for the robot to make it go in a straight line. We have tested a feedback in our motor controller to synchronize the two motors to spin at the same speed, initially with an optical encoder and a current sensor. But we've found that as long as the floor is perfectly flat, it is impossible for the robot to go straight. Because of the bumpiness of some floors, oftentimes one wheel has to travel more distance in the same time as the other wheel, thus altering the course of travel (figure 7). An analogy to this is that if a person shuts his eyes, then he cannot walk straight even though he might have a full control of his legs. To address this, we may have an additional camera that monitors the front of the robot and map out a path, guiding the robot to follow the path. With this feature in the system, the robot will be able to travel in a straight line in a controlled manner.

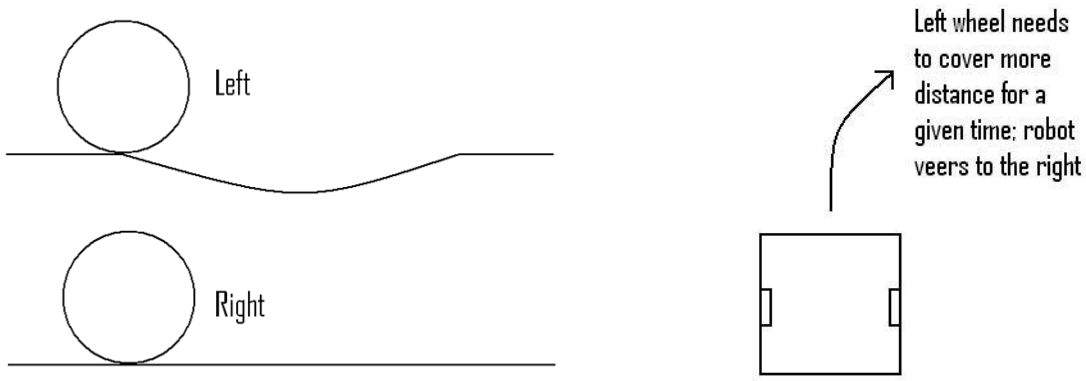

Figure 7: the negative effect of a bumpy floor to robot's movement in a straight line

4.4 QR Decoding Unit

The current QR decoding unit is extremely sensitive to the light. If the lighting is incorrect, the system will fail to decode the QR code. Outcome makes the robot to lose sense of location within the office space. To correct this issue, the housing of the robot may be replaced with thicker material which can prevent light from penetrating into the system.

5. Budget and Timeline

5.1 Budget

Equipment List1	Cost
Webcam : Microsoft LifeCam HD-3000	$55
Microcontroller : MICROCHIP dsPIC33FJ64MC802	$25
Proximity Sensor : LV-MaxSonar – EZ1: MB1010	$30
Banebots FIRST CIM 12V 5280RPM Brushed DC Motor x 2	$50
Wheels x 2	$88
Motors	$70
Aluminum Frame	$120
12 V Sealed Lead Acid Rechargeable Battery	$45
UART Sparkfun FTDI Breakout 5V DEV-09115	$25
Misc. (including bolts, nuts, L-fame bridge, adapter)	$150
Cosmetics	$30
Total Cost	**$588**

Table 1: The overall cost of the OADR

Table 1 shows the final cost of our robot. The cost of OADR has reduced from the estimated amount as reported in project proposal. The table illustrates the final cost is $588 and as a result could be covered

by the $500 funding that was received from Engineering Science Student Endowment Fund (ESSEF). In order to minimize the cost, we have researched various shops and internet sites. Moreover, we have added cosmetics such as different colours of LEDs improve the look of OADR. Even though we have predicted the missing components, there were some equipment and extra parts required to proceed with the projects. Overall, the completion of the project can be considered to have met the estimated budget.

5.2 Timeline

As one can see from the figure 8 of the timeline, the actual project development was adjusted from the proposed timeline. There were numerous factors that affected our project. Uncontrollable things such as hardware component delivery time and change in project plan made it difficult to follow the proposed timeline. However, we tried hard to meet the deadline for the presentation and demonstration. The integration and testing of the prototype were the most time consuming activity in entire project development cycle. The software was ready within a short time, but making sure that software interacts with hardware in correct fashion was the challenging part. Due to the time spent on these activities, we weren't able to implement the rotating compartment on top of the prototype as we proposed before.

Figure 8: Proposed VS Actual timeline

6. Inter-Personal and Technical Experiences

6.1 Chief Executive Officer – Gyu Han David Choi

It has been an exciting 4 months developing a product from ground up. Not every moment was enjoyable; there were days when team members and I have struggled to solve issues that we ran into while creating our robot. Since the day one, I took a part in most of the components. From braining storming what to do for the Capstone project, I put my hands on software as well as hardware units of the system.

My responsibility required me to look at the whole project in general. At the beginning of the development, I worked to enable operation of the QR code scanning for our need. I also created the path finding algorithm. These tasks were done using C and C++.

As we progressed further into the project, I migrated to construction of our robot. Amongst the team members, only two were capable of using the machine tools. Since our objective was to create this from scratch, my partner and I spent hours in the machine shop to cut, drill, and fit everything together to match the proposed form factor.

Due to characteristics of my roles, I had a clear understanding on various aspects of the project. I was able to help debug the problems in the software. I also modified the hardware when the original specification needed to be revised. With the information I gained while working on wide spectrum of the project, the communications between team members was harmonized. I tried to minimize the miscommunication in integration phases.

I learned to work as a team. I have done many group projects before, but none like this. In previous projects, it only required communication between one or two people. Five of us formed a group to work on hardware and software to create our robot; furthermore, it was crucial to have each other updated on what each member was doing. When misinformed, the results may have been disastrous, but we were able to do it well.

This project is a valuable experience for me as well as other team members. We basically made an embedded system of our own in 4 months. From planning to creation of a prototype, we have gone through many obstacles to achieve the goal of making this happen. Sometimes it gave us frustrating moments but, in the end, they were all fun, challenging, and rewarding experience.

6.2 Chief Technical Officer – Jin Sun Ahn

Since the beginning of the brain storming on the product of the company KAEFI, we have struggled to come up with a decent product. As we had set several meetings a week, we came up with the idea of the secured office space delivery robot. In the beginning, we thought only theoretical concepts such as the expected functionalities of the product and the basic requirements of the software and hardware components. As we processed the meetings and implementations, we narrowed down the detail in both software and hardware.

From the meetings, we decided to divide the major parts. I have been taking care of the software system on the OADR's eyes and brains since I had some experiences on the computer programming and digital image processing. However, despite of the fact that I previously had some knowledge, I have learned much more detail in the practical world. My basis on these knowledge only guided the way to implement while I was designing the program.

I learned the importance of teamwork and the communication amongst linked parts. By this, I mean that since we divided our sections to focus on, we needed to discuss the constraints that we faced during development. For example, if the physical shape of the robot was determined to be changed due to some constraints, then all of us needed to be informed from the meetings so that we could modify the relevantly and accordingly. Thus, to avoid panic from unknown changes, we needed to communicate enough to understand their intentions and the effect on my parts.

I also learned another importance of planning and developing ahead. Without planning and setting up the milestone, we could not estimate how long it will take to come up with successful outcome. Thus, we needed to plan the whole outline and target to meet the outline. It was always the best to spend time on development and test as early as possible so that we could handle some unexpected circumstances such as failures after integration testing.

Throughout 13 weeks, I improved and refreshed my software programming languages and hardware circuitry design. In addition, I reminded the important components of other skills within the group work such as planning the milestone, communication between each other, and skills for the tasks. It was very remarkable experience and now I have confidence in working in a company, the practical world.

6.3 Chief Financial Officer – Hongbae Sam Park

I am studying systems engineering at SFU. My position at KAEFI is CFO. My responsibilities as CFO include keeping and balancing books and planning expenditures according to our budget, but in reality I've done more work as a motor controller developer and hardware designer. I would like to briefly mention our mechanical design achievements. Our OADR system consists of two motors, and each motor drive a wheel on each side. This configuration of the wheels makes it easy for the robot to turn about its own body. To level the front and back of the robot, a caster wheel is placed at the front and back each. The motor and the wheel are linked by a metal chain. The drive system is attached to a rigid and light aluminum frame to minimize flexing. The maximum speed of the robot is near 37cm/s when the motors are spinning at 70rpm. The motors are controlled using a microcontroller, whose output is amplified through a motor driver (h-bridge), which powers the motors with a set of sealed lead-acid batteries. In essence, the microcontroller provides only the controlling inputs (i.e. control of the spinning direction of the wheel) and the batteries practically provide the energy needed from the motors. My work as a motor controller developer and hardware designer was to implement a feedback controller for the motor, integrate the motor controller with the other side of the system which consists of the database and the way-finding algorithm, and building the framework of the robot and ensure that the robot functions properly mechanically.

In the course of ENSC440 project, namely the Capstone Project, I've learned how much teamwork means for a successful completion of this project. While it may seem like a no-brainer saying that teamwork is important in a group project, so far it has been harder in reality than said. I found that the most important component of teamwork is communication. I've had my shares of problems arising from miscommunication. For example, when I was building the frame, there was a misunderstanding between myself and our team members as to where to mount the camera that is needed for scanning the QR code. Upon what we had discussed in our earlier meetings, I thought the camera was supposed to be mounted at the same level as the motor (25cm from the ground), and I installed a platform to secure the camera at that level. Some weeks had passed since then, and the frame was completed and the camera platform was filled with other components such as the batteries and circuits. It turns out, our camera guys wanted to mount the camera good deal higher than the then-current position (at 50cm from the ground) and they thought I had agreed to their plan. So I had to take down the frames and cut a hole in the platform in order to not obstruct the field of view of the camera. This event delayed the project at least a week, but eventually we've managed to make up for the loss of time by working twice as swift. I have gained a valuable lesson throughout this project and I've enjoyed working with my dearest KAEFI members. I can't wait to apply the knowledge and skills earned to other projects in the future.

6.4 Chief Marketing Officer – Kyu Seo Sam Lee

This Capstone project has led me to see various point of view of development. Working as the Chief Marketing Officer and software development of Database, I had experience overseeing the product's technical perspective and non-technical aspect of the project. Also I have learn how to communicate with other member and deal

On technical side, my duties for the project consist mainly on website development and database management. From my Co-Op experiences helped me to be organized with document as well as knowledge of Database development skills. Honestly, I was afraid that I could forget database skills that I have learned from Co-Op. It was amazing experience that I could freshen up my skills, learned in depth, and now feel confident about my database skills.

As a group, we have separated parts that everybody has participated toward project. Since working as a group everyone was willing to step up for contributions. Although not everybody was perfect on each other we were able to understand each other and have created strong bonds. After all, I have thought myself and realized that working as a team is critical lesson on this Capstone project. This lesson is something that can apply into daily life too.

However there were hard moments with integrating software and testing for each trial. Every member was so sensitive about the due date and their own schedule toward semesters. I remember a moment that when our first trial every members were screaming and hooray. Throughout the whole project, I have realized working as team is really important and improvements about different types of languages. Thanks again to this Capstone project for giving out unforgettable memories with our project team members.

6.5 Chief Operation Officer – Yongho Choi

As the COO of KAEFI, one of my roles was to setup software environment such as SVN, Eclipse, MinGW, OpenCV, MySQL, Zxing, Boost, and etc. for team members so everyone can start the project quickly. Also, I was in charge of organizing meetings, emails, and Facebook group messages, ensuring that the project is on the right track and on the schedule.

On the development level, I have created KAEFI's order website which is made by PHP and HTML. Also, I have created software algorithm on C++ side that reads the data in the database so whenever there is new order from the user, the OADR can start operating.

As we progressed further, I have focused on developing software communication system between PC side and Microcontroller (MC) side. I was responsible for the data transfer algorithm which transfers QR's decoded results to MC so it can control the motor driver. In general, I have integrated all software systems into one since I have experiences on both C and C++ which are basic languages for both PC side and MC side.

One of the most important experiences I have gained from this project is how to work properly within a team environment. I learned how to work within a team of a small size. It was really important to respect all team members and their opinions. Definitely, my communication skill has improved a lot.

Also, my overall programming skill on Windows environment has also improved. I have developed basic knowledge of communications protocols such as USB and RS232.

Working for KAEFI over the past 4 months has been a great experience. I have spent long hours on this project and dealt with various problems throughout the whole development cycle, but all problems I faced were now beneficial experiences for me since I have learned and enjoyed a lot during the past 4 months.

References

[1] Bloomberg Businessweek, “The Robot in the Next Cubicle”
Available: http://www.businessweek.com/magazine/content/11_04/b4212069774202.htm.
[Accessed Oct. 10, 2011]

[2] DP Technology Consulting Group, “Server Overview for Small Businesses”
Available: http://davidpriede.com/images/Server-client.jpg. [Accessed Sept. 21, 2011]

[3] AME Motor, “AME 218-Series 12V 212 in-lb LH Gearmotor– Long Shaft”
Available: http://www.robotcombat.com/products/AME-218-1003.html. [Accessed Oct. 10, 2011]

[4] Proximity Sensor, “30mm Diameter Inductive Proximity Sensors”
Available:http://www.asi-ez.com/member/x228-30mm-Inductive-Proximity-Standard-Sensor.asp.
[Accessed Oct. 10, 2011]

[5] Personal Computer, “The Birth of the Personal Computer”
Available: http://www.pvld.mobi/adults/the-birth-of-the-personal-computer. [Accessed Oct. 10, 2011]

[6] Webcam, “What is a Webcam?”
Available: http://behindthescreen.wikispaces.com/Webcam. [Accessed Oct. 10, 2011]

[7] Motor Specification, “AME 214-Series Motor”
Available: http://www.robotcombat.com/products/images/AME-214-1001.pdf. [Accessed Oct. 10, 2011]

[8] QRStuff, “Get your QR codes out there” Available: http://www.qrstuff.com/.[Accessed Nov. 17, 2011]

[9] KAEFI, “Functional Specifications” Available: Functional Specs 1.7 – KAEFI.pdf [Accessed Nov. 1, 2011]