

Post Mortem for a Smart Locker

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Abbreviations

NFC	Near Field Communication
NDEF	NFC Data Exchange Format
HCE	Hose-based Card Emulation
RFID	Radio-frequency identification
FPGA	Field Programmable Gate Array
GUI	Graphical User Interface
IC	Integrated Circuit
I/O	Input/output
LED	Light-emitting diode
SPI	Serial Peripheral Interface
SQL	Structured Query Language

Glossary

4 byte positive integer	A specific number that assigned to each locker. Also saved in database for identification.
Trigger	Smartphone's build-in NFC chip are inducted and controlled through our application
NDEF	One kind of NFC forum data format
ID	The specific identification number assigned to each locker and stored in database
Near Field	Devices are very closed to each other's antenna, within a distance of 0.1m
HCE	Emulating an NFC Tag with an Android Device without a secure element

1. Introduction

At the beginning of each semester in universities, such as SFU, students have to finish several steps to require a locker, by sending an email at first. However, is this process efficient? How do we improve this experience and make the lockers become more secure? Since 2011, all smart phones with Android system are NFC built in^[1]. NFC is much cheaper in costs compared to RFID. In addition, NFC's short range communication ensures the security as well. Thus, this project creates an easy-to-use and time saving system based on these factors.

The Smart Locker is an electronic locking system which allows the user to control the closure through smart phones via NFC. Once the user finished registration and login to our customized smart phone application, the user can start to request a locker. Once authorized by the server, the users are able to open the locker by tapping devices on the locker. Moreover, primary user has rights to share access to whomever they want by tapping two smart phones together. For security purpose, user's information and locker's identities are saved in database.

The whole system consists of three main components: an electronic locker with build-in programmable NFC chip, a server and an Android-based mobile application. Detailed specifications for the Smart Locker, proposed by Tap Lock Inc., are described in functional specification and design specification.

2. System Overview

Generally, the Smart Locker consists of three main components: a server, a smart phone application and an electronic locker. In the whole system, the locker component is the only physical component which including an NFC tag, an NFC Shield on Arduino and a metallic lock. The rest parts are all software based. There will be an admin to manage locker usage. Admin will have the highest control of the system. If any problem occurs, the user should contact admin immediately. Figure 1 below is a block diagram that summarizes our system.

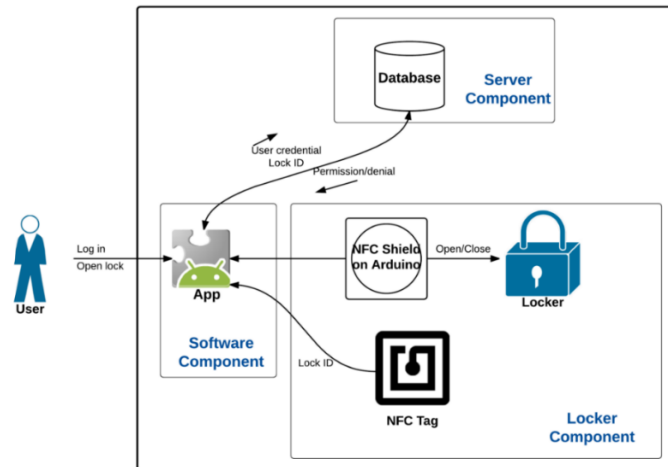


Figure 1: Smart Locker Functional Block Diagram

Physically, the Smart Locker is built with an NFC Tag, an NFC reader, an Arduino microcontroller and a metallic lock. The rest part are all software-based, including a database and a smartphone application. The data is transferred through a Near-Field between lockers and smartphones. The Near-Field Communication is established automatically once the NFC tags are close enough to each other, usually under 4 centimeters ^[2]. The smartphones and database is connected through Wi-Fi. Figure 2 shows how data is exchanged among NFC tags, NFC readers, smartphones and database.

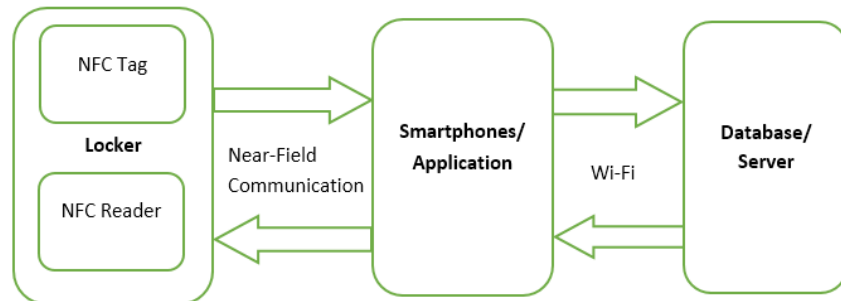


Figure 2: Communication between Locker, Smartphones and Database

2.1 Server

In the Smart Locker system, the server is the database. It saves all authentication information of each user and locker. Stored information is used to check the status of each locker, such as availability and keep in track with authorized permissions. Thus, once the user send out a request, the system can automatically check for availability, identify locker and assign access. In conclusion, the server communicates with the Android application to verify credentials, add new users, provide digital locker keys and etc. Figure 6 shows the components in sever.

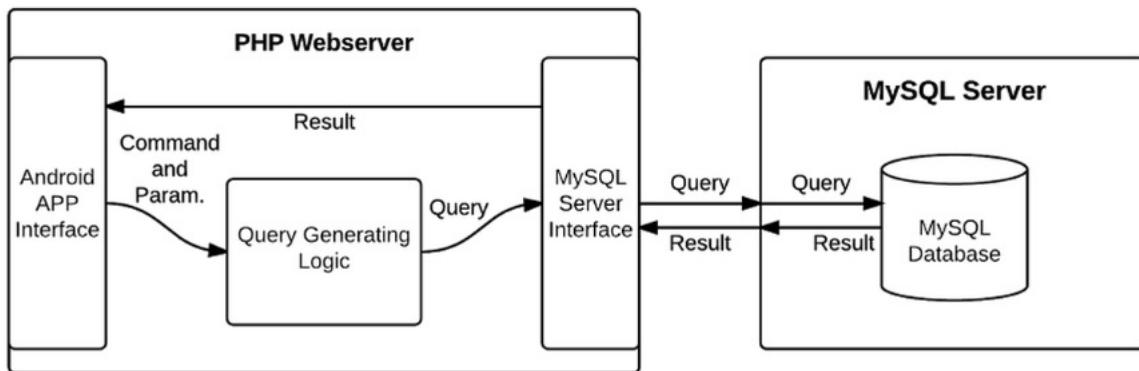


Figure 3: Server Component

2.2 Electronic Locker

For our project, we use Arduino to program the NFC tag in order to naming all the lockers. The locker identification numbers are stored in the Server with the corresponding locker’s physical location. Also, the microcontroller reads and analyzes data from the NFC reader to decide whether to open the locker or not. Smart Locker use an add-on called “NFC shield” which is mounted on an Arduino Uno, sending command to open/lock. In addition, Arduino uses a specific language called robotic-c, which is similar to C and C++. Table 1 is a list of hardware components that we used to build our electronic locker.

Table 1: Hardware Components

Name	Quantity	Usage
NTAG203 Type 2	1	Save the specific ID of each locker
NFC Shield	1	Read data from smart phones (ex. command to open/lock)
Arduino Uno R3	1	Read and analyze data from NFC Reader
LEDs	2	One green LED to show the accepting state and one red LED to show the denying state
Electromagnetic lock	1	Lock the locker

2.3 Android-based Application

We use Android SDK to develop our Android application. This interface establishes communication between lockers and database. The Android Application consist of four major components beside the GUI, the Server Interface, the Tag Reader, the Host-based Card Emulator and Main Logic. The Server Interface issues commands to the Server, and receive results of the command executed. The Tag Reader reads the NDEF message containing the Locker ID from the NFC tag inside the locker. The Host-based Card Emulator emulates the Android device as a NFC tag containing a digital key to open the locker as a NDEF message. The Main Logic consist of the navigation of the GUI and the corresponding actions when the user interacts with the GUI.

More generally, once the user tap the smartphone on the locker, the embedded system will start scanning the built-in NFC chip inside the locker to communicate with the server component. Once the request has been approved, the server will send a NDEF message to the locker component and give permission to open the closure. Multiple functions are designed to perform various tasks, such as sending closure requests and share access. Figure 5 and Figure 6 shows how the interface will look like.

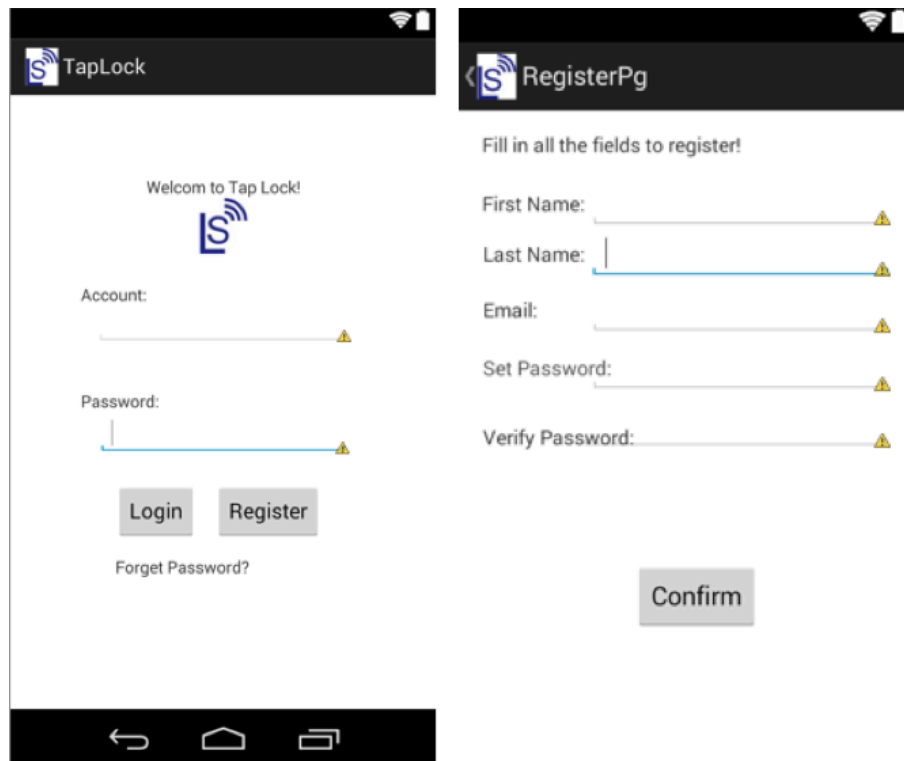


Figure 4: Login and Registration Pages

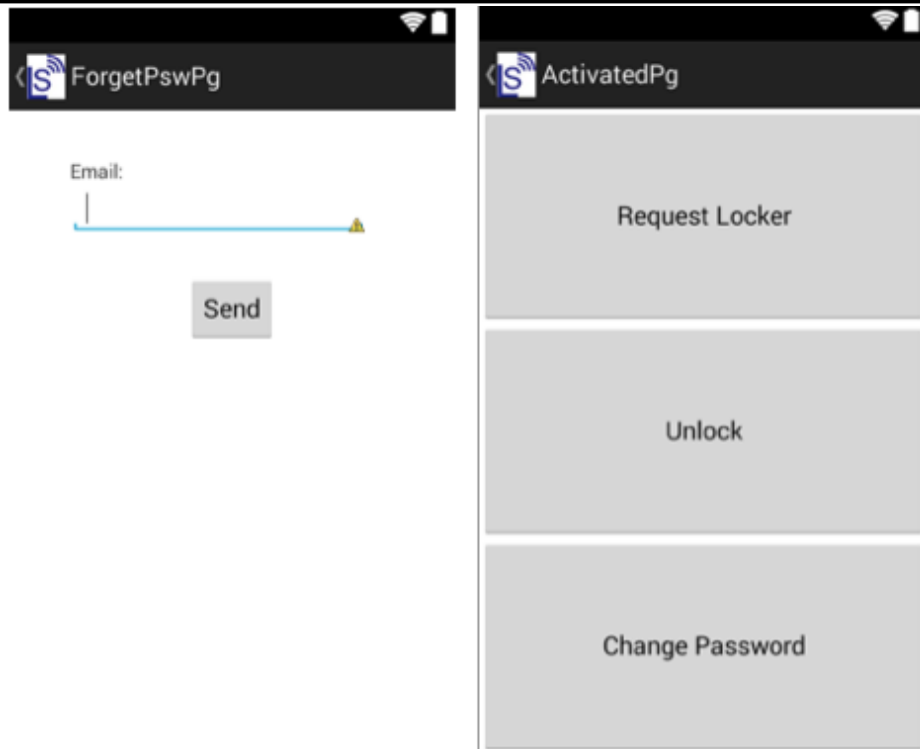


Figure 5: Forgot password and Activity Pages

3. Material and Costs

At the beginning of the project, we set the budget at \$300. So far, we have purchased all the required parts involved in our projects. The following table details our expenses. In addition, our project received \$150 from ESSEF Fund. So we have \$160.2 remains from the budget and fund. These money can be used for future development and unexpected costs such as defective components. The actual costs actual increases a little bit during the project, which is include in the physical locker body costs. Extra money are spent on screws and wood board.

Equipment	Expected Cost
NFC Shield x2	\$ 59.80
Arduino UNO Rev3 x2	\$ 60
NFC tags	\$ 10
Mailing Fee	\$ 70
Physical Locker Body	\$ 30
Single door magnetic lock with 60Kg holding force x2	\$ 60
Total Cost	\$ 289.8

Table 2: Excepted material and costs

Equipment	Actual Cost
NFC Shield ×2	\$ 59.80
Arduino UNO Rev3 ×2	\$ 60
NFC tags	\$ 10
Mailing Fee	\$ 78.77
Physical Locker Body	\$ 25.54
Single door magnetic lock with 60Kg holding force ×2	\$ 60
Total Cost	\$ 294.11

Table 3: Actual material and costs

4. Schedules

Figure 7 shows the estimated and actual project progress. As shown in the chart, all research, designs and documentations are following the schedule and finished in time. Since we prepared quite well at the beginning of the project, we are able to finish most of the tasks very efficient without any delay. As we can see in the chart, we spent more time on the PHP server and SQL testing. Thus, we spent more time on the integration than we estimated.

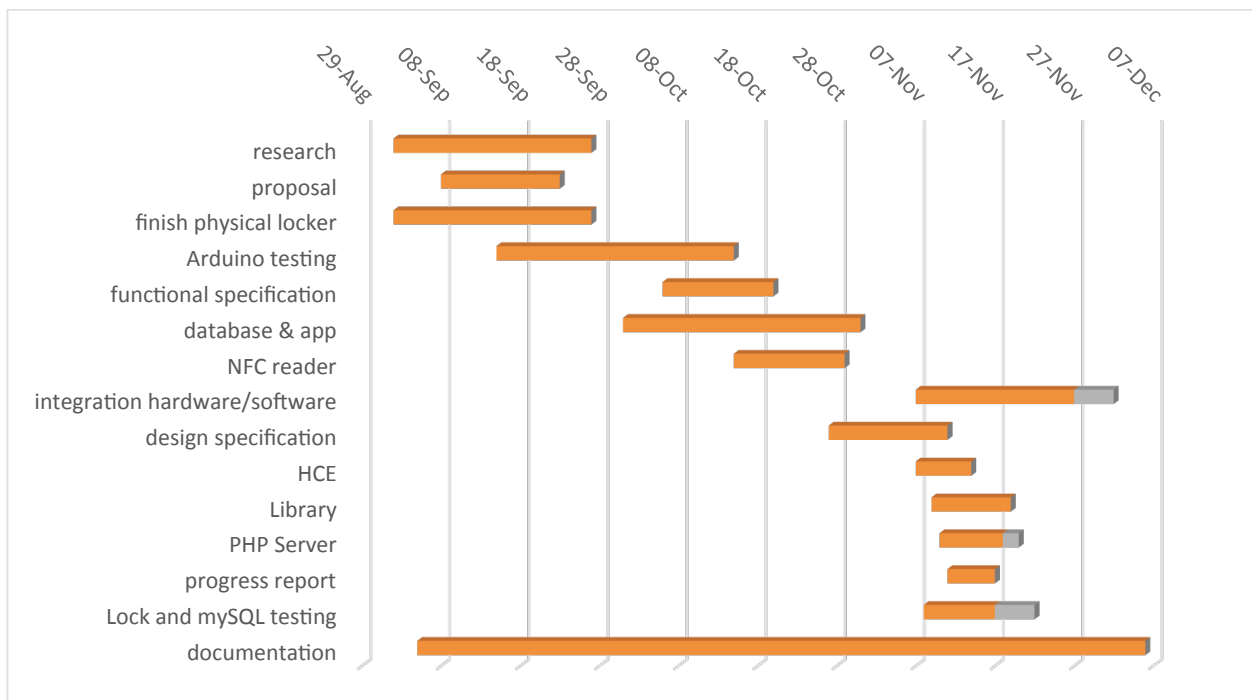


Figure 6: Estimated and Actual Progress

5. Challenges

5.1 Reading NTag 203 with NFC Shield

The NFC Shield in its default configuration cannot read our choice of NFC tag type, namely NTag 203. We needed this feature to test our software, so we figured out we have to tweak the NFC Shield Library for the shield to read NTag 203. We found out that the tag type is identified by the UID at the beginning of the NDEF message stored in it, so we located the tag reading function and changed the UID and hence solved the problem.

5.2 Comparing Key in Arduino

The NFC Shield's library only provides functionality to display the content of a NDEF message, but part of the message cannot be mapped to the ACSII character set, and thus lost in the translation process. We had to change the visibility of the payload and payload length in order to compare the full message with the locker key.

5.3 Host-based Card Emulation

We needed the phone to emulate a NFC tag in order to pass the locker key to the NFC shield, but we were not able to let the Shield evoke our Android application that implements the emulation. After weeks of struggle we chose an alternative to use Android Beam instead.

6. Group Dynamics

Tap Lock Inc. is fund by five third and fourth-year engineering science students with experiences in embedded system design, database, mobile application development and signal processing. Moreover, our members have did co-op jobs in various high-tech companies, such as RIM and Ericsson. Different academic backgrounds and working experience provide our team with good innovation and technical skills. Every member contributes to the project and the work load was assigned equally and fairly. The overall cooperation is very good and we all hope to work together in the future.

7. Individual learning

Zheng Gao

Working on the Smart Locker has been a series of valuable experiences in terms of both technical and transferable skills. As one of the team member responsible for the software component of our system, I have gained experience in Android APP development, Database Structure and much more, our five-member team also taught me a lot about teamwork and interpersonal skills.

Working in a team is not always easy, we have to keep everyone on the same page, listen understand and respect our teammate's ideas and thoughts, and find time in everyone's busy schedule to work together. I gained strong verbal communication skill to clearly communicate my idea to my team, and have also come to learn to better use graphs to make information clearer. I have also worked closely with the Hardware team to integrate our parts, and we quick and clean job in that.

In terms of the technical skills, I leaned used the Android SDK with Eclipse to build the Android Application, which is a good skill to have since APP market is booming during the last few years, I learned to use varies APIs in the Android SDK including NDEF adapter we used to read NFC tags on the locker, android beam to transfer the locker key to the reader, and http client to connect the Application to our PHP server. I learned how to build an activity to respond to a specific intent so the right activity would be evoked when scanning a tag, write an Asynchronous task to read and parse a NDEF message from a NFC tag. I have send NDEF message from an Android Application to a NFC reader via Android Beam. I know how to connect my Android Application to a PHP Webserver, and how to write a PHP script to bridge the communication of an Android Application to a MySQL Server. I have also learned the basics of the Structured Query Language, how to retrieve, insert and delete data inside a database.

The Smart Locker project proves to be quite challenging, most I have managed to solve, like the Android Application used to start new instances of itself when a NFC tag is scanned, but I set up proper foreground dispatch and corrected it's behavior, others I have found a work-around, like when we switched from Host-based Card Emulation to Android Beam to carry the locker key from our Application to the reader. Also there are issues that is unsolved, like the conflict of NFC tag and the reader, so we are forced to put them in different positions on the locker. For the challenges I have learned to work hard to solve problems, think flexibly around an issue, and to deal with frustration.

This project gave me a valuable and challenging experience that may help me greatly in the future, and I am very thankful to my teammates and everyone who helped in any way.

Kaiqi Li

With 4 months' working on this Capstone Project, I was able to apply many aspects of knowledge I have learnt throughout my academic study.

My main role in this project is to in charge of the software application development. In the beginning, I had no experience on Android application development, nor did I have any software programming skills. Therefore, I had to start my work from lots of fundamental research. From gaining basic understanding of our software requirements, I had chosen Android SDK as my main developing tool as it comes with all the important features, such as Eclipse, API libraries and lots of plug-ins. After that, I started a simple project by following the online tutorial. Since Android application is written mainly in two languages: XML and Java, I had to spent time learning them and writing the program little by little. Although the beginning was hard, this learning experience has provide me useful research skills and build up my software mind of thinking which helps me very much in the future.

Also, I'm also responsible in server setup. Similarly, I have never done this before and I have never even thought about how server works. Slightly, I picked up this material by researching online and following tutorials online. Finally, I was able to setup both the PHP server and MySQL server. Also, I was able to successfully communicate both servers with my Android application UI.

Overall, our team has really good collaboration. I enjoy working with my team members very much as they are all very hard working, enthusiastic and dedicated to this project. In the beginning of this project, we have set up a milestone for the project and assigned different roles to each person. Although everyone in the team has a lot of courses, everyone still spend efficient time into this project and ensure a great quality of work. During discussion in the meeting, everyone is very open minded and willing to listen to each other although different people may have different ideas. We expect each other and value each other as a team.

Thanks to this project, I have gained lots of valuable experience. In the future, I will be more capable to take challenge in real life, such as self-taught ability, research ability, collaboration and programming skills. So in the end, I really want to thank my team members. This project will not be successful without everyone's effort and all the time spent is very worthy.

Wangyi Zhu

As the CEO, I have learned a lot this term. Several semesters ago, I saw my friend who was taking 440 and they couldn't finish the project, I realized that I should be very well prepared when is my turn. That's why our group started brainstorming before summer semester to make sure we have enough time for the project. I came up with an idea of developing a robotic car when I was doing a coop job about robotics. This robot can manage all the home facilities such as TV and lights at home. All my group members seemed ok with this idea and we started doing the project. But at the end of summer semester, I found out that the microcontroller we purchased is lack of documentation and the hardware board is very complicated to use. Therefore, in the beginning of September, I discussed it with everyone and we agreed to change to another topic. It is a great experience for me because I made a right decision at that time. It is hard to give up what you have done and move toward to a new subject.

Moreover, we have an excellent team work this term and everyone keeps the milestone we made at the beginning. Also, not only individually, software team had a great relationship with hardware team. Thanks to Kevin, we could successfully use Android Beam to communicate instead other methods which are not working. Team members are all very nice to each other and we always discuss and study together.

For tech part, I also learned a lot. Last term I learned some basic idea of Arduino. Arduino is a very good hardware to create some fun and small project. This term I finally have the chance to implement it into a real project. We need to use robotic C to program the Arduino and let the microcontroller to communicate between NFC shield and smart phone. Because of the large number of I/O ports on the Arduino board, we can use that to control multiple LED lights and some other features such as buzzer and light sensor. It was a very fun experience to program Arduino. Although I'm not the one who is responsible for the NFC communicate part, I have learned a lot about NFC technical. Through researching, I have a deeper understanding of NFC and how it works. If I want to write any other application for using NFC I will have some experiences. NFC is really popular right now and it sure will become even hotter in the future. Having a development experience using NFC technology will definitely become a spotlight. Finally wood works. At the beginning of the semester, building a wood box was at the last position of my checklist. I thought it will be very easy to build. However, when I really try to build the physical locker, it brings me a lot of trouble. First of all, wood board material selection. We went to the home depot and realized the thick wood board is too big to carry. We could only choose thin and small boards. According to this, we can only choose small nails. It becomes a big trouble because the boards are too thin to put nails in. I also got the chance to learn how to use the machine shop.

To sum up, this capstone project really is an excellent chance for me. I need to thank all my group members and all Profs and TA. Because of you guys I have a great memory of my last term of my university life.

Haishuo Zhang

From this project I gained a lot of valuable experiences on technical skills and communication skills. As one the hardware member, I have learned the Robotic C to program Arduino, the protocol of NFC and also some other electrons components such as relay. I also gained the teamwork skills and communication skills.

This project is different from other project I have done in school. In this project, we have to make sure everyone is on the same page. We need to separate the job very clearly and make sure everybody could finish their work on time and we need more meeting to share the idea and check our process. Though this project, I improved my time management skills and communication skills.

In term of the technical skills, since we needed to read and write NFC message from smartphones, I learned the protocol of NFC and the different types of NFC tags. It is very useful because NFC technology is more and more popular. I can apply my knowledge to any NFC products.

Also I learned the Robotic C language which is very similar to C++. I haven't use C++ since I finished my first year course. Thus this is a great chance for me to refresh my memory and learn more knowledge of Robotic C and C++. By changing library and read our own code, I expanded my knowledge of programming. I learn the access specifier, string, pointer and a lot more. That is quit useful for finding a good job because now most of jobs ask candidates to have experience of C or C++. Now I am more competitive than before.

I also learn some electrons components. I know how relay works and where I should use a relay. Also I know the principle of light sensors. By doing this project, I practice my soldering skills as well.

Though this project, I learned a lot and gained valuable experience that could help me in my career and I am very thankful to my teammates and everyone who helped me in my project.

Yangyang Li

During this semester, I had a wonderful experience of working and learning together with other highly skilled students from different engineering backgrounds. Through the capstone project, we shared ideas, learned from each other and assisted one another whenever challenge occurs. I gained not only technical skills but also interpersonal skills. This experience was very valuable to me and I would like to work with my group members again in the future.

Technically, I assisted in designing the hardware parts of the Smart Locker, such as Arduino programming using robotic C. I had never did a project with Arduino before. However, my experience of FPGA microcontroller helped me a lot when designing on an Arduino board. This experience gave a chance to learn and utilize different functionalities of Arduino. For example, I learned how to control the LEDs, buzzer and light sensors. In addition, I gained lots of fun when doing research about different types of NFC tags and readers. I also had a chance to learn how to set up a database and design an Android based software application. For instance, I gained knowledge about using Eclipse and NDEF adapter. During the design progress, I became more detail-oriented and dedicated. I improved my researching skills so that I could pick up the most useful information quickly.

The most difficult part I found in hardware designing is the Host-based Card Emulation. Since I didn't have any background knowledge or working experience about this, I had a hard time doing researching and got stuck. However, after discussed with team members and made my own efforts, the issues were solved. This challenge would become a valuable experience.

Moreover, as the main editor in the group, I made lots of efforts on documentation. In order to make the reports look more professional and more attractive, I learned many new skills of Microsoft Office, becoming more skilled in using Office, Excel and PowerPoint. Except for the written skill, my verbal skills were also improved through presentation and demonstration. Since the capstone project has a very heavy work load, it was quite challenging for me to finish the assigned tasks on time at the beginning. So I tried many different ways to do time management. Fortunately, I could work more efficiently now. I also realized that rather than struggling by myself, it was better to share ideas with others and solve the problems together.

Except for the technical skills, I also gained interpersonal skills. Since there are five people in our group, we often had different opinions. I learned how to communicate and collaborate with different group members to increase the efficiency and atmosphere.

Moreover, doing capstone projects provides with experience to think and work like a real engineer. I had a chance to control the budget and research for user experience. Finally, I would like to thank my groups. Without their contribution, I wouldn't have such a wonderful experience in university.

8. Work breakdown

High-level Task	Wangyi Zhu	Yangyang Li	Haishuo Zhang	Kaiqi Li	Zheng Gao
Research	x	x	x	x	x
Financial control	xx	x	x	x	x
Mechanical Engineering (eg. Wiring and assembling)	x		x		x
NFC reader/tag design	x	x	xx	x	x
Arduino Design and Testing	x	x	xx	x	x
Server Design and Testing	x	x	x	x	xx
App Design and Testing	x	x	x	xx	x
Integration of hardware and software	x	x	x	x	x
Shopping for hardware components	x	x	x	x	x
Documentation planning and editing	x	xx	x	x	x
Documentation	x	x	x	x	x

x = some or equal responsibility

xx = primary responsibility

Note: Mechanical engineering includes works such as wiring and assembling all the physical parts together.

9. Conclusion

The Smart Locker project is well on its way to completion and under budget. Every member contributes to the project and finished most of the tasks on time. We had a great cooperation during the design progress and did our best to make improvement.

In the future, we propose to design a customized system for universities which not only provides students with access to lockers but also assign access to lab entrance and other electronic equipment such as printers. Furthermore, we aim to develop our application to supply more functionalities such as contactless payment. Through this, students can use smartphones to make a payment for using lab equipment. The material for locker will be some strong metal to make sure it is safe enough to store things. The size of locker can depend on user because user can put several cells into a large block of lockers. The final product must have some connection between cells to make sure it is enough strong and will not fall or course something bad.

10. References

- [1] A. Lella, "Smartphone Subscriber Market Share", 2012. [Online]. Available: <https://www.comscore.com/Insights/Market-Rankings/comScore-Reports-June-2014-US-Smartphone-Subscriber-Market-Share> [Accessed 29 October, 2014]
- [2] L. Francis, "Radio frequency identification: security and privacy Issues", 2010. [Online]. Available: http://link.springer.com/chapter/10.1007/978-3-642-16822-2_4 [Accessed 3 November, 2014]

11. Appendix: Meeting Agendas

Meeting Date	Place Time	Present	Items for Discussion
Sept 2, 2014 Tuesday	Lab 1 1HR	Wangyi Zhu Haishuo Zhang Kaiqi Li Yangyang Li	We first decide to do something about robotic car during the summer semester, and we thought this topic might not able to finished in one term. Thus, we are thinking about changing the project topic.
Sept 3, 2014 Wednesday	Lab 1 1HR	Wangyi Zhu Haishuo Zhang Kaiqi Li Yangyang Li	We voted for topic changing. Finally majority of us are agree to pick a new topic. Brainstorming about new topics: NFC, robotics
Sept 5, 2014 Friday	Lab 1 1HR	Wangyi Zhu Haishuo Zhang Kaiqi Li Yangyang Li Zheng Gao	Come up with an idea to create something using the build in NFC chip in smart phones. Finally we decided to build a locker which is controlled by NFC.(Sending approval to prof)
Sept 9, 2014 Tuesday	Lab 1 1HR	Wangyi Zhu Haishuo Zhang Kaiqi Li Yangyang Li Zheng Gao	Discuss about the details of the NFC locker: Purpose, main functionalities and our budget
Sept 11, 2014 Thursday	Lab 1 1HR	Wangyi Zhu Haishuo Zhang Kaiqi Li Yangyang Li Zheng Gao	Starting research about NFC, hardware and software. Decided that we need 1. database 2. android app 3. NFC reader to create a system. We decide the work load and roles for each person.

			Hardware: Wangyi, Haishuo, Yangyang Software: Kaiqi, Zheng
<i>Sept 18, 2014 Thursday</i>	Lab 1 1HR	Wangyi Zhu Haishuo Zhang Kaiqi Li Yangyang Li Zheng Gao	Start researching about hardware parts. discuss UI features needed
<i>Sept 19, 2014 Friday</i>	Lab 1 1HR	Wangyi Zhu Haishuo Zhang Kaiqi Li Yangyang Li Zheng Gao	Start purchasing hardware components from internet. Doing Project Proposal together.
<i>Sept 23, 2014 Tuesday</i>	Lab 1 1HR	Wangyi Zhu Haishuo Zhang Kaiqi Li Yangyang Li Zheng Gao	Software group start planning how to do database and UI design (including research and main functionalities) So does hardware group (Discuss how to build the electronic lockers technically and researching)
<i>Sept 24, 2014 Wednesday</i>	Lab 1 1HR	Wangyi Zhu Haishuo Zhang Kaiqi Li Yangyang Li Zheng Gao	Got the shipment of Arduino, starting basic tutorial and simple tests.
<i>Oct 3, 2014 Friday</i>	Lab 1 1HR	Wangyi Zhu Haishuo Zhang Kaiqi Li Yangyang Li Zheng Gao	Had a discussion about NFC tag reading and passing signals between the smartphone and NFC shield.
<i>Oct 10, 2014 Friday</i>	Lab 1 1HR	Wangyi Zhu Haishuo Zhang Kaiqi Li Yangyang Li Zheng Gao	Continuous the discussion about NFC tag reading and passing signals between the smartphone and NFC shield. In addition, editing the Functional Specification together.
<i>Oct 17, 2014 Friday</i>	Lab 1 1HR	Wangyi Zhu Haishuo Zhang Kaiqi Li Yangyang Li	Since everybody has midterms, we only shared what we have done so far and call it a day. Researching Host-based Card Emulation.

		Zheng Gao	
Oct 24, 2014 Friday	Lab 1 1HR	Wangyi Zhu Haishuo Zhang Kaiqi Li Yangyang Li Zheng Gao	Check the UI for the app and make comments. Testing that NFC reader now can read from NFC tags.
Oct 31, 2014 Friday	Lab 1 1HR	Wangyi Zhu Haishuo Zhang Kaiqi Li Yangyang Li Zheng Gao	Report current progress and talk about design specification report.
Nov 7, 2014 Friday	Lab 1 1HR	Wangyi Zhu Haishuo Zhang Kaiqi Li Yangyang Li Zheng Gao	Report current progress, everyone talks about their expected finish date of current tasks.
Nov 14, 2014 Friday	Lab 1 1HR	Wangyi Zhu Haishuo Zhang Kaiqi Li Yangyang Li Zheng Gao	Report current progress and keep doing integration of hardware and software currently with testing of every components. Planning for future tasks: set deadline for finalizing date. 1. software and hardware finish by next week Nov17-23 2. separate testing and integrating during week12 and 13 3. everything has to be integrated and done by Dec1 and last week for overall testing) Talk about written progress report
Nov 21, 2014 Friday	Lab 1 1HR	Wangyi Zhu Haishuo Zhang Kaiqi Li Yangyang Li Zheng Gao	Discussing test plan and making final system test plan Report final progress
Nov 28, 2014 Friday	Lab 1 1HR	Wangyi Zhu Haishuo Zhang Kaiqi Li Yangyang Li Zheng Gao	Continue doing integrated and testing of both hardware and software. Testing the prototype.
Dec 1, 2014 Monday	Lab 1 1HR	Wangyi Zhu Haishuo Zhang Kaiqi Li Yangyang Li Zheng Gao	Work on final testing together, finalizing our project. Discuss about demo presentation.

<i>Dec 5, 2014 Friday</i>	Lab 1 1HR	Wangyi Zhu Haishuo Zhang Kaiqi Li Yangyang Li Zheng Gao	Planning and making demo ppt, post mortem and system test plan.
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