CMPE123 Senior Design Project: NFC-Enabled Lock Management System

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Abstract

This project is for the Computer Engineering Senior Design Capstone, at University of California, Santa Cruz, CMPE123. The project is meant to create an Internet of Things (Iot) capable smartlock to be used in a building. A room with the cloud-connected smartlock installed will use Near-Field Communication (NFC) technology for easy acces. The project emphasizes cloud connectivity, power management, and cost.

*Thanks to Professor Anujan Varma and teaching assistants Sargis Yonan and Sam Mansfield for their guidance during this project

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1 Project Summary (Bowen)

This goal of this project is to create a lock management system that could potentially replace the current BSOE door lock system. In rooms with the project's smartlock installed, an administrator will be able to view live statistics and population of each a room, an element not present in the current BSOE infrastructure. Each lock will have a main microcontroller with internet access to Google Cloud and NFC support. A user can access the room by tapping his or her Android smartphone to the lock. Each lock will access Google Cloud Datastore via Google Cloud Compute using TCP/SSL. Additionally, the entire assembly will be relatively low power, with approximately 6 months of battery life off of two AA batteries with normal use.

User Level Interface

At the user level, many things that happen under the hood are unknown to the user. For the user, using this smart lock should be simple, intuitive, and efficient. Currently, our smart lock can read, authenticate, and unlock a door in less than a second, which is comparable or even faster than traditional hardware locks with physical keys. For the user, fumbling for keys or inserting keys in the wrong orientation is a nuisance that is practically eliminated. The user can simply tap his or her Android phone to the smartlock and the door will unlock.

Entering Room

A user will touch their Android phone to the NFC sensor, which sends a message to the cloud that contains the user and room number. The server checks if the user has access, and the appropriate response is sent back to the lock, which will unlock or remain locked. The cloud server will also login the user for that room, and increment the room's population count. Currently, there is no implementation to account for multiple people entering the room within one unlock cycle.

Leaving Room

When a user leaves a lab or room they will log out of the lab by pressing his or her phone to the door lock. The same message will be sent to the server as if the user was login in. The server then logs the person out, and then decrement the room population. If a user leaves a room but doesn't log out then and they try to access the room later on. They will still be able to access the labs but the counter and login information will not be accurate.

2 Figures and Schematic (Sam)

2.1 Block Diagram

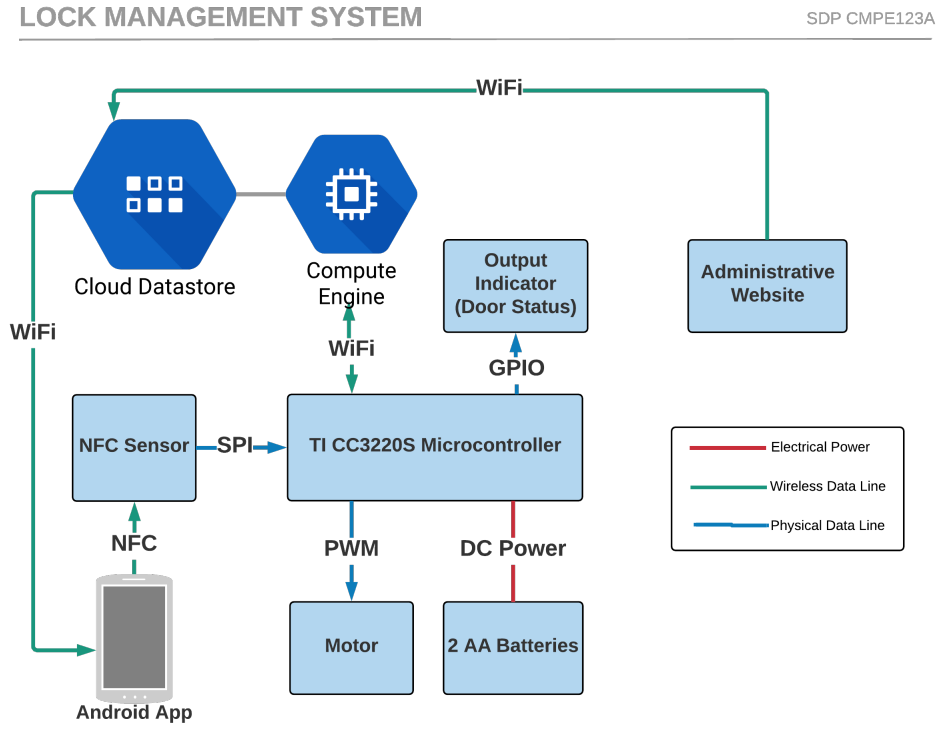

Figure 1: Block Diagram of System

2.2 Overall Software Flow Chart

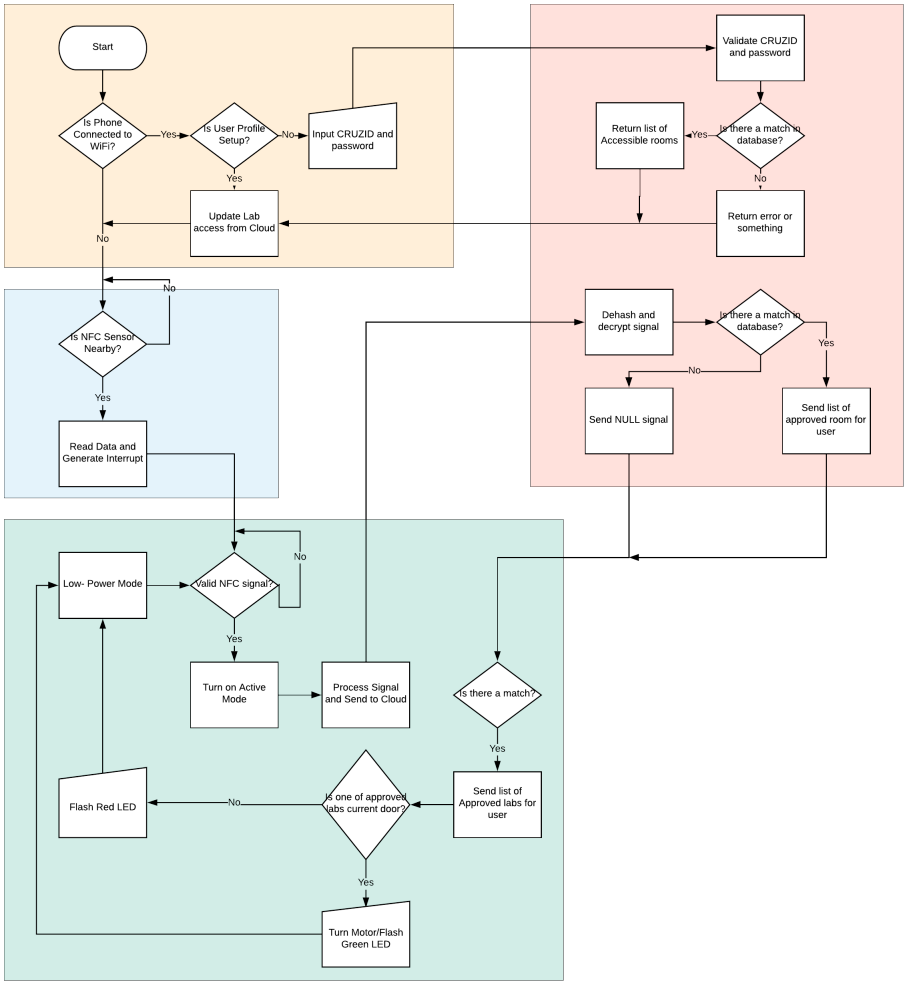

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Figure 2: Yellow: Android app; Blue: NFC sensor; Green: microcontroller; Red: Google Cloud

2.3 Server Flow Chart

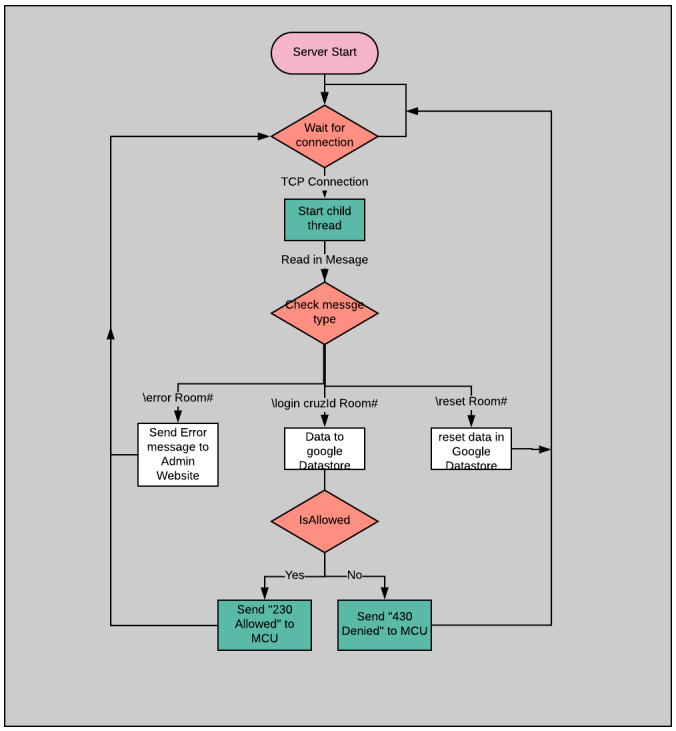

Figure 3: Google compute server flow chart

2.4 Circuit Schematic

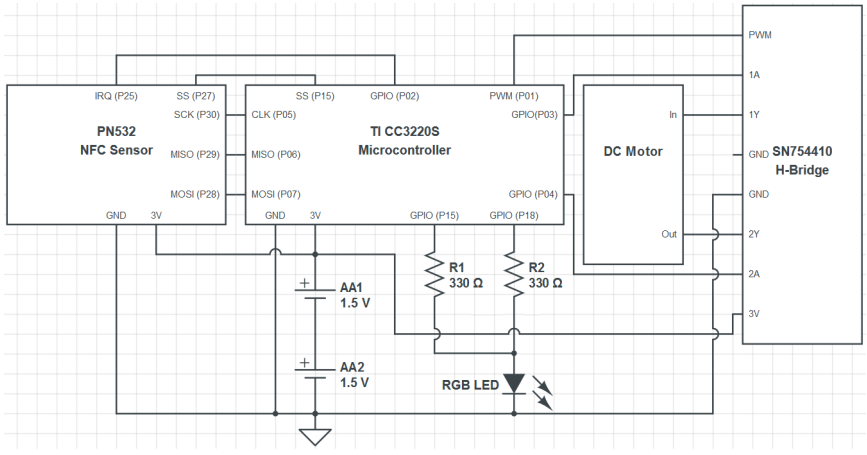

Figure 4: The circuit schematic of the project.

3 Microcontroller (Bowen)

3.1 Microcontroller Overview

The microcontroller is the center of the entire project, as it reads in NFC signals through the peripherals and acts as the network point for WiFi and further communication with the cloud. On the network side, after connecting to the Google Cloud Virtual Machine, the microcontroller connects to the Google Compute Engine, which returns the message code "230 Allowed" or "430 Denied", depending on access. The microcontroller periodically wakes up from low power mode in order to maximize battery efficiency. A DC motor connected to the microcontroller will lock or unlock, in addition to flashing a green LED for unlock, and a red LED for denied access.

One important element of the microcontroller will be the cache. The cache is used so that the user can be let in faster. The cache will be small in size, with a size of approximately 16, and will be stored entirely locally. The main idea behind it is that users that frequently use the room will have their access information stored locally on the cache, and that way, the microcontroller would only have to search for the information locally instead of connecting to the cloud and waiting for a response. In a large system with thousands of users, the latency difference between a local cache search and a cloud search will be tangible.

3.2 TI 3220s API

3.2.1 IsAllowed()

```
int IsAllowed(char *cruzId, char *roomNumber);
```

Function sends the data using a TCP connection. The sent data is in the form of a string "\login cruzId roomNumber" to the gateway it waits for a return message. The to return types are "\logout" which means the user was just logging out or in the form of a message code "230 Allowed" which would unlock the door or "430 Denied" which flashes a red LED. If an error happens on the server side the micro will receive the message "\error". When this happens the micro will attempt to send in the login message again.

3.2.2 BatteryStatus()

```
void BatteryStatus();
```

Function sends the data using a TCP connection. The sent data is in the form of a string "\status battery%" to the server to update the battery information on the admin website.

3.2.3 ReadError()

```
void ReadError(room_number);
```

Function sends the data using a TCP connection. The sent data is in the form of a string "\ReadError room˙number" to the server so it can log the error on the administrative website. This allows for the lock to be fixed faster.

3.2.4 ResetRoomCapacity()

```
void ResetRoomCapacity(room_number);
```

Function will send the reset signal to the server to clear the capacity of the room. The data sent will be a string"\reset˙capacity room˙number". This will make the server reset the room capacity back to zero.

3.2.5 ResetRoomLog()

```
void ResetRoomLog(room_number);
```

Function will send the reset signal to the server to clear all the logs for the lab. This will most likely be done on the admin website but option is given for the micro to clear after a specified amount of time.

4 NFC Sensor (Sam)

4.1 NFC Sensor Overview

The NFC Sensor we are using is the NXP PN532. It supports passive and active tag reading and writing, at ranges up to 4 centimeters.

4.2 PN532 NFC Sensor

The command frame packet and acknowledgment from the sensor is handled by API calls as outlined in 4.3.

4.2.1 Command Frame Packet

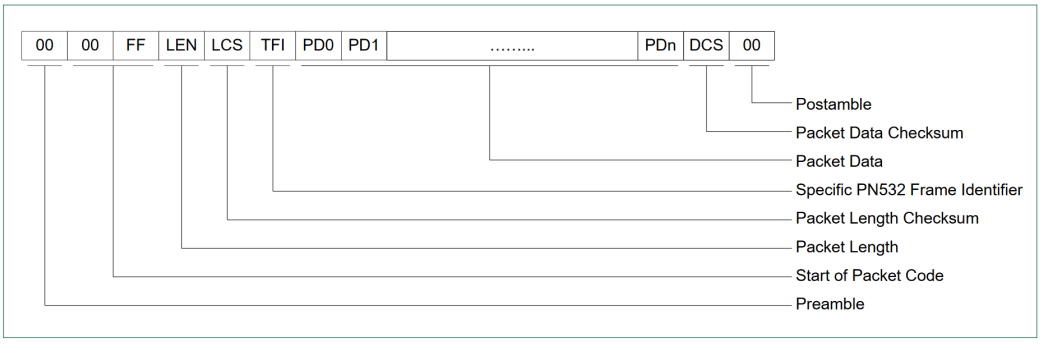

Figure 5: The command frame packet used to send and receive information over SPI

- Preamble: 0x00
- Command Code 1: 0x00

- Command Code 2: 0xFF
- LEN: Number of bytes in TFI, PD0, ..., PDn
- LCS: Checksum such that LCS+LEN=0x00
- TFI: 0xD4 if MOSI, 0xD5 if MISO
- DATA:
  - PD0: command code
  - PD1: first data byte
  - ...
  - PDn: last data byte
- DCS: Checksum such that TFI + PD0 + ... + PDn + DCS = 0x00
- Postamble: 0x00

4.2.2 SPI sequence for communication

1. Send a command
   - Write "Write Data", 0x01
   - Write the command frame
2. Wait for ACK of PN532
   - Write "Read Status", 0x02
   - Read one byte, PN532 is ready if byte is 0x01
   - Write "Read Data", 0x03
   - Read 6 bytes of ACK frame (0x00 0x00 0xFF 0x00 0xFF 0x00)
3. Wait for Response of PN532
   - Write "Read Status", 0x02
   - Read one byte, PN532 is ready if byte is 0x01
   - Write "Read Data", 0x03
   - Read data bytes as outlined in command frame

4.3 Serial Peripheral Interface API Calls

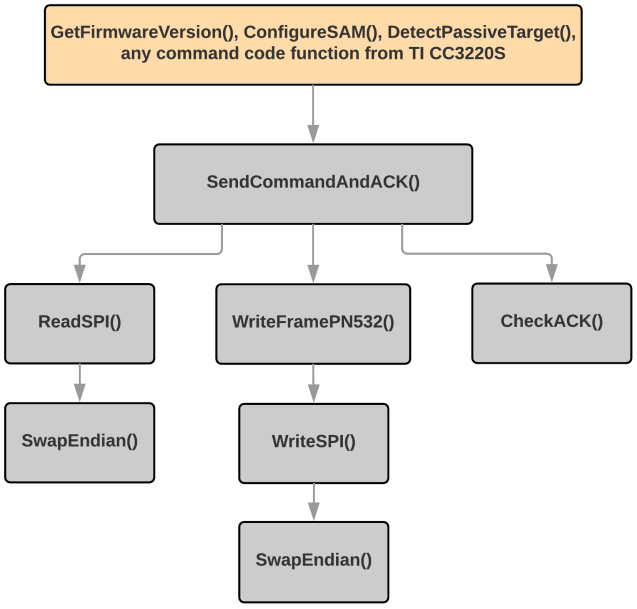

Figure 6: The functions the microcontroller calls to communicate with the PN532 sensor. Each functions has one or multiple subfunction under it.

4.3.1 GetFirmwareVersion()

```
uint32_t GetFirmwareVersion(void);
```

This function returns the firmware version of the PN532 sensor. This should be one of the first functions called just to initiate and make sure the SPI connection is working. Returns 0x0000 0000 if failure.

4.3.2 ConfigureSAM()

```
uint8_t ConfigureSAM(void);
```

Configures the Security Access Module (SAM). This functions turns off the SAM, the default mode. Returns 0x00 if failure.

4.3.3 DetectPassiveTarget()

```
uint32_t DetectPassiveTarget(uint8_t cardType);
```

Returns the card ID of the passive target. The ID is at most 4 bytes. Returns 0x00 if failure. Returns 0x02 if timeout.

5 Network Structure (Bowen)

5.1 Network Overview

The network portion of the system involves using Google cloud compute acting as a server for the micro. The website and android App will talk to the database directly. The overall network structure can be seen in figure 2.3.

5.2 Google Compute Engine

This a virtual machine running in the cloud. IT has a static IP address and will act as the server for the door locks. The connection will be using TCP and SSL for security. The micro will send its room number and the cruzID of the user. When a connection in established a thread is started on the server to handle the users request. This allows the server to handle multiple request. The VM will run a query and send back either a "230 Allowed" or "430 Denied". Once it sends the results it kills the connection and the thread. It then logs the results into the Datastore for the given lab.

5.3 Message layout protocols

Any message being sent to and from the cloud will follow the given format

"\[message type] [other data]".

This way the cloud and micro can easily check for the message type and know how to handle it. The message types

- "\login cruzId room˙number"
- "\reset room˙number"
- "\status battery%"
- "\read˙error room˙number"
- "\error"

5.4 Google Compute Engine API

5.4.1 get_student_classes()

```
def get_student_labs(cruz_id)
```

This function gets all of the classes thats the student is currently allowed access to.

5.4.2 get_classes_for_room()

```
def get_student_labs(room_number)
```

Function returns a query from the Google cloud which list all of the classes that currently have access to the given room.

5.4.3 login˙room()

```
def login_room(room_number, cruzID):
```

This function is called when a user enters a room. The first argument is the room number of which the user enters and the second argument is the cruzID of the user that enters the room. The function logs the enter time and stores it in the cloud. The leave time and cumulative time spent in the room is null.

5.4.4 logout˙room()

```
def logout_room(room_number, cruzID):
```

This function is called when a user leaves a room. The first argument is the room number of which the user leaves and the second argument is the cruzID of the user that leaves the room. The function logs the leave time and stores it in the cloud. The cumulative time is calculated based on the leave time and the last time the student entered the room.

5.4.5 change˙room˙capacity()

```
def change_room_capacity(room_number,entering):
```

This function takes in the room˙number and the a boolean on the direction of the user. From their it will update the current capacity of the room by 1. This function doesn't handle the situation where a user lets multiple people in the room at one time.

5.4.6 reset˙room˙capacity()

```
def reset_room_capacity(room_number):
```

This function takes in the room˙number. It will reset the capacity of the room in the datastore back to zero.

5.4.7 reset˙room˙log()

```
def reset_room_log(room_number):
```

This function takes in the room˙number and deletes all the logs for that given room.

6 Google Cloud (Bowen)

Students, Faculty and rooms are all stored in Google Cloud. The cloud will respond from results from the microcontroller which will determine if a user has access to the rooms. The cloud storage can only be updated and from the administrative website. Students and rooms can be updated at anytime giving real-time access to the rooms. The cloud also logs all the login information for each room and which can be view on the administration website.

6.1 Google Cloud Entities (Sam)

6.1.1 Room Entity

The room entity lists every lock-equipped room. This entity will hold the room location, which specifies the building and room number, along with all groups and individual users that have access to it.

Room Entity			
ID	Room #	Groups	Users
name=index0	E2-399	[”BELS”,”AMS147”,”CMPS101”]	jsmith
name=index1	BE340A	[”CMPE123A”,”CMPE123B”, ”CMPE129B”]	

6.1.2 User Entity

The user entity lists every user in the system. Additionally, each entry will include the cruzID of the user and the groups the user is in.

User Entity			
ID	Name	cruzID	Groups
name=index0	Samuel Wu	sazwu	[”AMS147”,”CMPS12B”]
name=index1	Bowen Brooks	bojbrook	[”CMPE123A”]

6.1.3 Room Logs Entity

The room logs entity will log entry and exit times for each user. There will be a cumulative time for each unique user in the room. The log in each room can be cleared and the enter time, exit time, and cumulative time will be reset. Each room will have its own log.

BE340 Log Entity					
ID	cruzID	Enter Time	Exit Time	Delta time	Cumulative
name=sazwu0	sazwu	02-07 17:26:55	02-07 17:27:02	0:00:07	0:00:07
name=bojbrook0	bojbrook	02-07 17:26:55	02-08 11:30:22	18:03:26	18:03:26
name=sazwu1	sazwu	02-08 11:27:19	02-08 11:27:57	0:00:44	0:00:51
name=hello0	hello	02-08 11:31:02	null	null	null

7 Administrative Website (Sam)

7.1 Administrative Website Overview

The administrative website allows the administrators to add, remove, or modify access for users and rooms. The website offers a live population count of each room and other useful data, such as histograms of enter and exit times, or average time spent in a room. Additionally, the website will allow the administrator to check on the battery life and errors that may have occurred with certain locks.

7.2 Administration API

7.2.1 AddNewUser()

```
def add_new_user(index, name, cruzID, priority, class_list = []):
```

This function adds to the "User" entity. The first argument is the index in the database, which acts as the key in case it needs to be accessed later. The second argument is the name of the student, with first and last name separated by a space. The third argument is the cruzID of the student without the ucsc.edu following it, i.e. sazwu. The fourth argument is the user priority. Highest priority is given to the lowest number. For now, admin priority = 0, faculty priority = 1, grad priority = 2, and undergrad priority = 3. The last argument is a Python list of classes the student is in i.e. CMPE167, AMS147.

7.2.2 AddNewRoom()

```
def add_new_room(index, room_number, class_list = []):
```

This function adds to the "Room" entity. The first argument is the index in the database, which acts as the key in case it needs to be accessed later. The second argument is the room number of a room that has an a lock on it, i.e. BE301, BE340A, E2-599. The third argument is a Python list of classes that have access to the room i.e. CMPE123A, CMPE121, CMPE167L.

7.2.3 ModifyRoomEntity()

```
def modify_room_entity(lab_index, room_number, class_list = []):
```

This function modifies an existing "Room" entity. The entries in the entity must all be specified in the arguments. The first argument is the index in the database. The second argument is the room number in a room with an accessible lock. The third argument is a Python list of classes that have access to the room.

7.2.4 ModifyUserEntity()

```
def modify_user_entity(user_index, name, cruzID, class_list = []):
```

This function modifies an existing "User" entity. The entries in the entity must all be specified in the arguments. The first argument is the index in the database. The second argument is the first and last name of the student separated by a space. The third argument is just the cruzID of the student, and the fourth argument is a Python list of classes the student is in.

7.2.5 QueryAllRoomsEntities()

```
def query_all_rooms_entities():
```

This function simply prints all "Room" entities and the information in each.

7.2.6 QueryAllUserEntities()

```
def query_all_user_entities():
```

This function simply prints all "User" entities and the information in each.

7.2.7 DeleteRoomEntity()

```
def delete_room_entity(lab_index):
```

This function deletes an entire "Room" entity specified by the index passed in as the first argument.

7.2.8 DeleteUserEntity()

```
def delete_user_entity(lab_index):
```

This function deletes an entire "User" entity specified by the index passed in as the first argument.

7.2.9 LogInRoom()

```
def login_room(room_number, cruzID):
```

This function is called when a user enters a room. The first argument is the room number of which the user enters and the second argument is the cruzID of the user that enters the room. The function logs the enter time and stores it in the cloud. The leave time and cumulative time spent in the room is null.

7.2.10 LogoutRoom()

```
def logout_room(room_number, cruzID):
```

This function is called when a user leaves a room. The first argument is the room number of which the user leaves and the second argument is the cruzID of the user that leaves the room. The function logs the leave time and stores it in the cloud. The cumulative time is calculated based on the leave time and the last time the student entered the room.

7.2.11 CountRoomPopulation()

```
def count_room_population(room_number):
```

This function counts the number of people in the room specified by the first argument. It counts the number of people by counting the number of indexes in the room with a null value in the exit time.

7.2.12 ClearRoomLog()

```
def clear_room_log(room_number):
```

This function clears the entity and log of the room number specified in the first argument. This function could probably be used at the end of the day or end of the quarter.

7.2.13 HistogramEnterTime():

```
def histogram_ente_time(room_number):
```

This function gives a Python list of size 24 with the frequency of time entered. Each hour interval corresponds to an index in the list. The function requires the first argument to be the room number of the room of which the histogram is desired.

7.2.14 HistogramExitTime():

```
def histogram_exit_time(room_number):
```

This function gives a Python list of size 24 with the frequency of time exited. Each hour interval corresponds to an index in the list. The function requires the first argument to be the room number of the room of which the histogram is desired. Any user in the room will have a "null" value for exit time, and thus will not be counted.

7.2.15 AddClassToRoom()

```
def add_class_to_room(room_number, classes = [])
```

This is a helper function for parsing the CSV file when using function ParseCSVRoomEntity(). It takes in the room number and the classes to add. For example, if room "BE-340" can now be accessed by classes "CMPE167 and AMS114", the function would take in "BE-340" as the first argument and the list "CMPE167 and AMS114" as the second argument.

7.2.16 ParseCSVRoomEntity()

```
def parse_csv_room_entity(file)
```

This function parses a CSV file to create and add to a room entity. The first row of the .csv file is not read, as it is meant to label the columns. The first column of the file should be the room number and the second column of the file should be a list of classes that can access the room, separated by spaces.

7.2.17 CSVToCloudRoom()

```
def csv_to_cloud_room(file)
```

This function calls ParseCSVRoomEntity() and adds the data from the .csv file to the "Room" entity. The first row of the .csv file is not read, as it is meant to label the columns. The first column of the file should be the room number and the second column of the file should be a list of classes that can access the room, separated by spaces. The only argument should be the .csv file name.

7.2.18 AddClassToUser()

```
def add_class_to_user(user, info_list = [])
```

This function adds a list of classes to the user, and is used as a helper function for ParseCSVUserEntity() and CSVToCloudUser().

7.2.19 ParseCSVUserEntity()

```
def parse_csv_user_entity(file)
```

This is a helper function used by CSVToCloudUser(). Refer to section CSVToCloudUser().

7.2.20 CSVToCloudUser()

```
def csv_to_cloud_user(file)
```

This function takes in the data from a .csv file and puts it directly in the "User" entity. The .csv file should have the information name, cruzID, priority, and classes in that order. If there are multiple classes, the classes can be separated by spaces while staying in that column.

8 Android Application (Bowen)

8.1 Android Application Overview

The android application allows for a user to sign in using their CruzID and password. When the phone is tapped against an NFC sensor the application will transmit the CruzID to the microcontroller. The application will have access to the Google cloud in order to view which rooms they have access to. To access the datastore the Android App will use HTTP calls to the data store to get the list of labs the user has access to.

8.2 Android Application API Calls

8.2.1 GetListOfLabs()

```
ArrayList<String> GetListOfLabs(String cruzId):
```

This function asks the Google datastore using HTTP calls to get the list of labs the user has access to with the cruzID. It return a list of all the labs they can get into for the quarter.

8.2.2 GetLabsCapacity()

```
ArrayList<Integer> GetLabsCapacity(String cruzId, ArrayList<String> Labs):
```

This function asks the Google datastore using HTTP calls to get the current capacity for each lab. The cruzId will be passed in to ensure that the user has access to the lab. The function return an Arraylist that contains the current lab capacity.

8.2.3 WriteCruzId()

```
void WriteCruzId(String cruzId):
```

Function writes the cruzId to the nfc sensor. The sensor only reads in a hex number so the string is hashed and written to the sensor. Which will be un-hashed on the other side.

9 Battery (Sam)

9.1 Battery Overview

The battery consumption is theoretical at this point, and is based off of a weighted sum of the manufacturer's specification in the datasheet for the TI CC3220S microcontroller and the NXP MFRC522 sensor. $amps_{total}$ is the weighted sum for amps used in a day.

9.2 Battery Calculations

$$\begin{aligned} &amps_{total}(\#logs) \\ &= \frac{(\#logs)(time_{log})}{60*60*24s}(amps_{log}) + \frac{60*60*24s - (\#logs)(time_{log})}{60*60*24s}(amps_{sleep}) \end{aligned} \tag{1}$$

$time_{log}$ is the total time it takes to do one complete log, including the time to turn sensor on, transmit over WiFi, and then receive over WiFi.

$$time_{log} = time_{sensor} + time_{tx} + time_{rx}$$

$$\begin{aligned} &amps_{total}(\#logs) \\ &= \frac{(\#logs)[(WiFi_{tx})(time_{tx}) + (WiFi_{rx})(time_{rx}) + (sensor_{on})(time_{sensor})]}{60*60*24s} \\ &\quad + \frac{60*60*24s - (\#logs)(time_{log})}{60*60*24s}(sensor_{sleep} + micro_{sleep}) \end{aligned} \tag{2}$$

$$\begin{aligned} amps_{total}(\#logs) = &\frac{(\#logs)[(266mA)(1s) + (53mA)(3s) + (100mA)(1s)]}{60*60*24s} \\ &+ \frac{60*60*24s - (\#logs)(5s)}{60*60*24s}(10\mu A + 1\mu A) \end{aligned} \tag{3}$$

$$\begin{aligned} amps_{total}(\#logs) &= 4.884*10^{-6}(\#log) + 11*10^{-6} - 6.366*10^{-10}(\#log) \\ &\approx 11*10^{-6} + 4.884*10^{-6}(\#log) \end{aligned} \tag{4}$$

AA batteries are typically anywhere from $2000 - 3000mAh$, so taking the lower bound, our 2 AA batteries in series will have approximately $4000mAh$ worth of charge.

$$time_{months}(\#logs) = \frac{1}{24*30} * \frac{amphour}{amps_{total}} \tag{5}$$

$$time_{month}(\#logs) = \frac{5.555*10^{-3}}{11*10^{-6} + 4.884*10^{-6}(\#logs)} \approx \frac{1137.39}{\#logs + 2.252}$$

9.3 Battery Graph

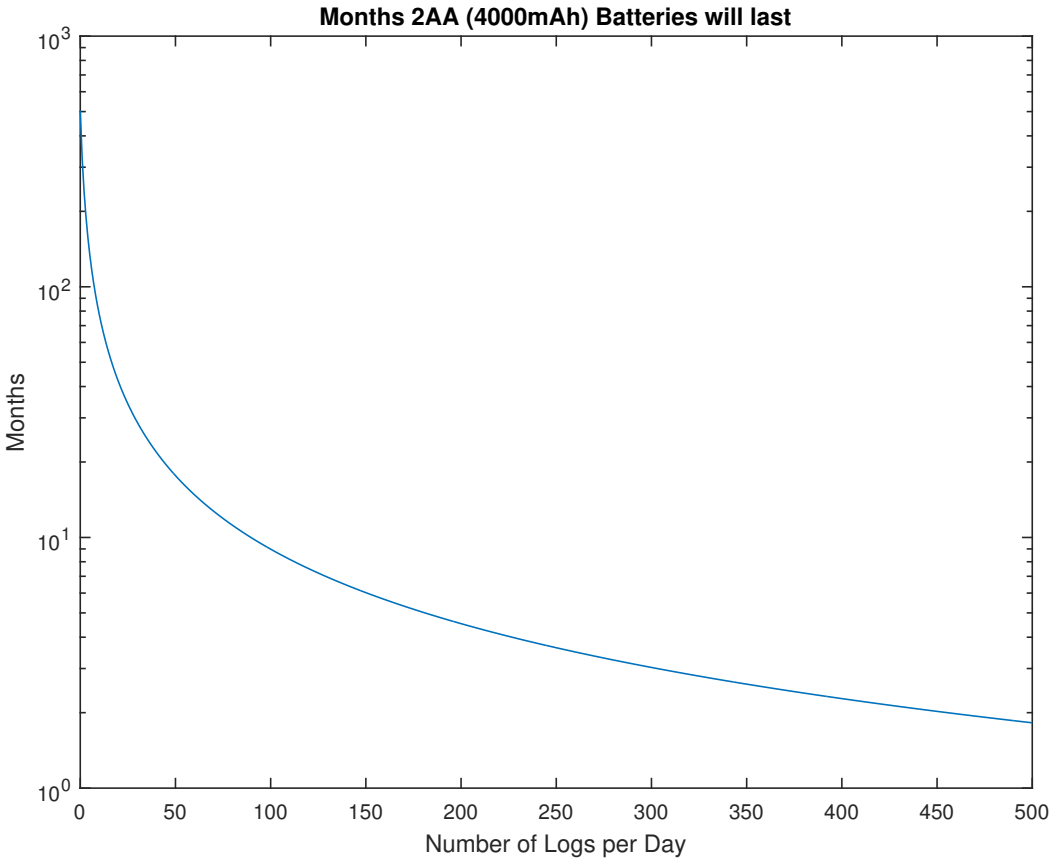

Figure 7: Theoretical Battery life using 2 AA batteries (4000mAh) and the NXP MFRC522 Sensor

10 Schedule (Bowen & Sam)

10.1 Winter Quarter

10.1.1 Quarter Goals

By the end of the quarter, the cloud and microcontroller should be able to transmit and receive information from each other. Additionally, the microcontroller should be able to differentiate unique RFID tags.

10.1.2 Tasks for the Quarter

1. RFID/MCU communication
2. Cloud/MCU communication
3. Database
4. LEDs

Bowen	
Week 4	Design database, Design cloud API, Populate database
Week 5	Design cloud API
Week 6	Cloud AUTH/access, Design cloud API
Week 7	MCU Push/pull database, MCU Log interaction
Week 8	Cloud push results to MCU
Week 9	Finish MCU, Cloud clean up
Week 10	Start API calls for website

Sam	
Week 4	Learn basic Google Cloud, Design database, Design cloud API
Week 5	Populate the database
Week 6	MCU internet access, SPI interface for sensor
Week 7	MCU/RFID communication (PN532)
Week 8	Write PN532 Library (read/write/wakeup/sleep)
Week 9	Debug PN532 Library
Week 10	Get RFID tag data, RFID type

10.2 Spring Quarter

10.2.1 Quarter Goals

Everything should be completely finished. This includes full functionality of the Android App for communicating with the cloud and the NFC sensor with a *NFC* signal. Additionally, there will be an administrative website that pulls data from the cloud. The website will have administrative functionalities such as: adding, removing, or modifying user privileges. The administrator will also be able to navigate a clean UI to view analytics and data.

10.2.2 Tasks for the Quarter

1. Power Management
2. DC Motor/H-Bridge
3. Website
4. NFC/App communication
5. Web/Cloud communication
6. App/Cloud communication

Bowen	
Week 1	Familiarize with Android API, Design UI
Week 2	NFC/App communication
Week 3	NFC/App comm, App/Cloud comm
Week 4	App/Cloud comm, start design for website
Week 5	Finish app, cleanup app UI, website UI
Week 6	Website/cloud comm, website UI
Week 7	Finish website, debug all comm
Week 8	Debug all comm, debug any small things
Week 9	Buffer week, start report/presentation
Week 10	Finish everything

Sam	
Week 1	DC Motor/H-bridge
Week 2	App/NFC comm, clean up MCU code
Week 3	App/NFC comm, App/Cloud comm
Week 4	App/Cloud comm, power
Week 5	Power Consumption
Week 6	Website UI, Web/Cloud comm
Week 7	Cleanup App UI, website UI
Week 8	Debug everything, buffer week
Week 9	Start report/presentation
Week 10	Finish everything

11 List of hardware components (Bowen)

Component	Cost	Quantity	Total
TI CC3200S	$39.99	3	$119.97
Battery Case	$1.50	2	$3.00
Op Amp	$0.95	4	$3.80
Resistor Kit	$7.95	1	$7.95
NFC Sensor MRFC522	$9.99	0	$0.00
AA battery 20 pack	$8.54	1	$8.54
NFC Sensor PN532	$12.99	2	$25.98
DC Motor	$1.95	2	$3.90
LEDs 5 Pack	$2.95	1	$2.95
H-Bridge	$2.35	2	$4.70
Total Cost			$180.80