Wi-Fi Connected Locker Access System

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Engineers
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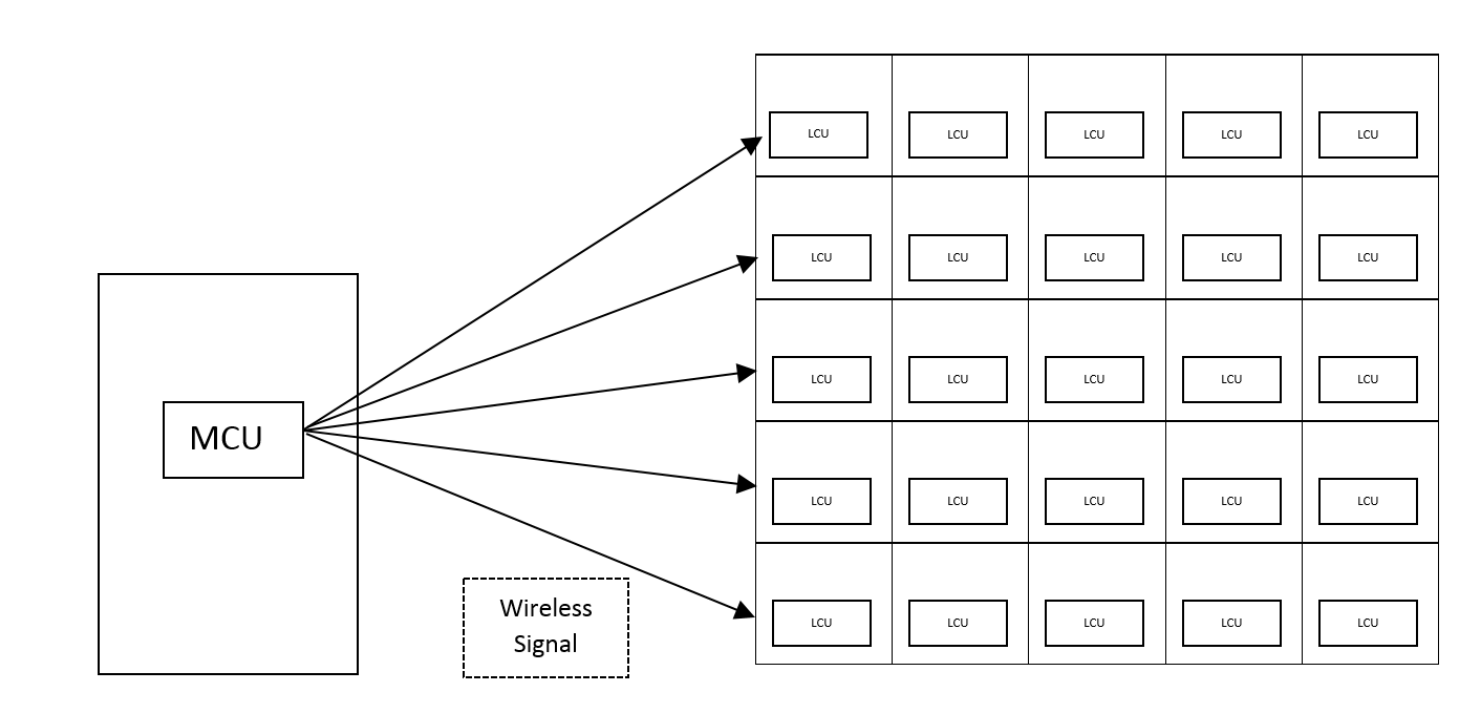
The Problem

- Current Lockers are:
  - Difficult to manage
    - High administrative overhead
    - Must manually assign lockers
    - Must rearrange locks
  - Insecure
    - Padlocks with same lock shared year by year

The Solution



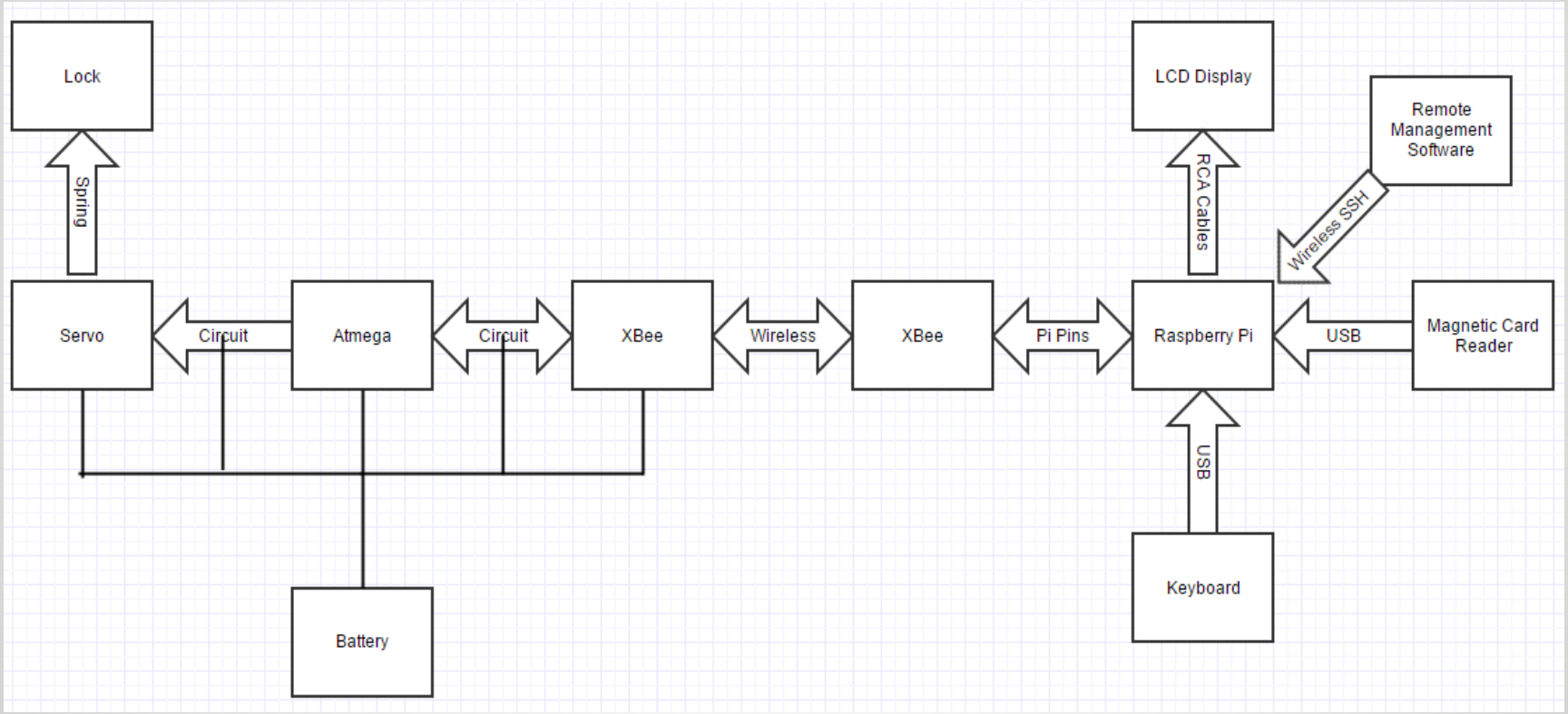
MCU: Main Control Unit

LCU: Locker Control Unit

Requirements (Simplified)

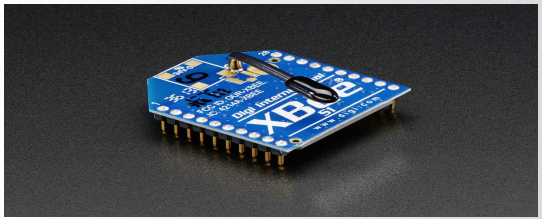
- Read student ID card, open assigned locker
- Student’s without card must be able to get into locker
- LCU and MCU must be self-contained
  - LCU must have no exposed cables, battery powered
- Entire system must be secure
- Allow remote administrative functionality
- Lockers must alert admins if battery is low

Initial Design - Concept Sketch



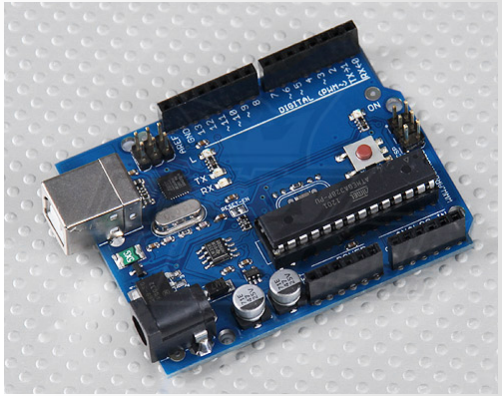
Initial Design

- Selected Major Components
- Design Functionality Decided
  - Basic MCU <--> LCU communication
  - High level circuitry
  - Idea of security
- Used hardware provided by client from previous year



Initial Design - Issues

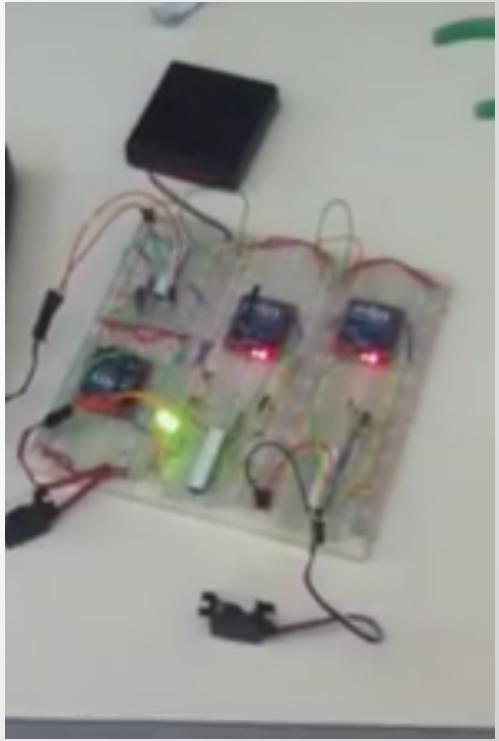
- Expensive
  - Arduino vs ATMEGA
  - Pricey MCU hardware
- Difficult to choose components
- Arduino was not standalone
- Size constraints not taken into consideration



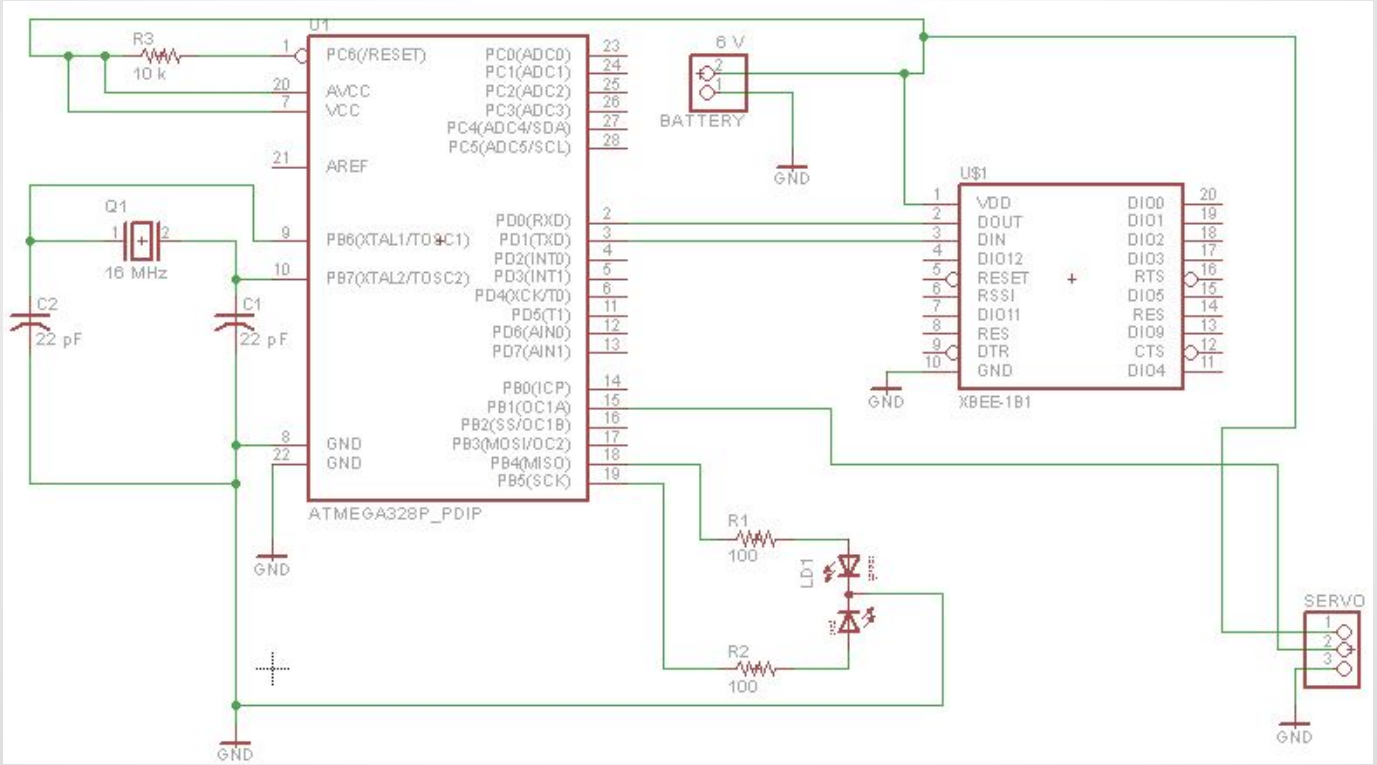
http://hobbyking.com/hobbyking/store/__23767__kingduino_uno_atmel_atmega_328_pu.html

Design - Version 1.0

- Prototype as of 12/31/14
- Corrected most issues from initial design
  - Finalized Components and Batteries
  - Designed functional circuitry
  - Implemented standalone Embedded platform
- MCU <-> LCU communication defined
  - Enough to selectively open lockers
  - No dynamic communication (lockers hard-coded)
- Proof-of-concept

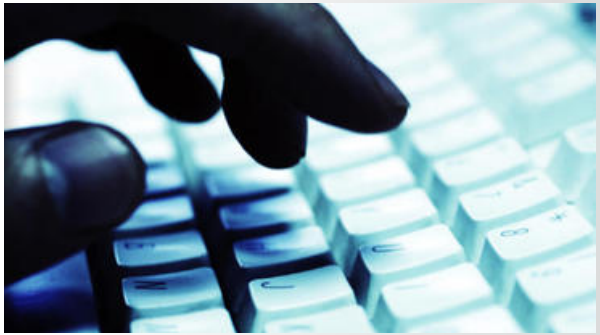


Design - Version 1.0 (LCU)



Hurdles - Version 1.0

- Security Leaks
  - Replay attack vulnerabilities
  - Communication not encrypted
- MCU Raspberry Pi was old
  - Not have enough USB ports
  - Slow Processor
  - Difficult to design around case

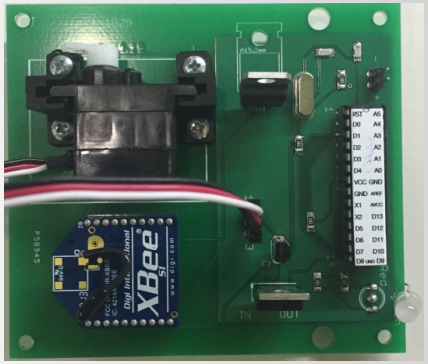


Hurdles - Version 1.0

- Power Consumption
  - Servo continually drawing current
  - Xbee and ATMEGA constantly on
- Operating Voltages
  - Components had differing operating voltages
- Atmega
  - Did not know how to measure battery level

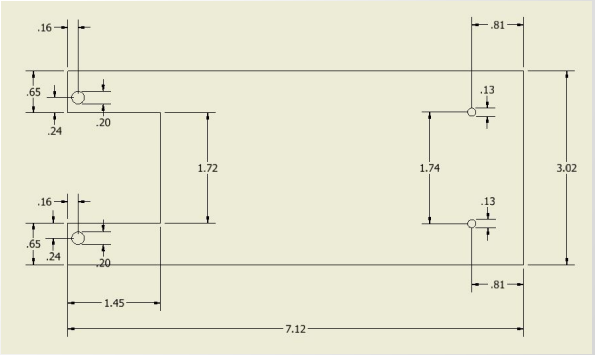
Design - Version 2.0

- Implemented power saving circuitry
  - Disconnect of the motor from the circuit
- Replaced MCU hardware
  - From model A to 2B+
- Sleep functions implemented for resource saving
- Implemented voltage regulators



Further Revisions

- Space Constraints
  - PCB Design
    - Case and mounting holes
    - New servo
- Mechanical Design
  - Support Plate
  - Lock Pull



Current Design

LCU Hardware

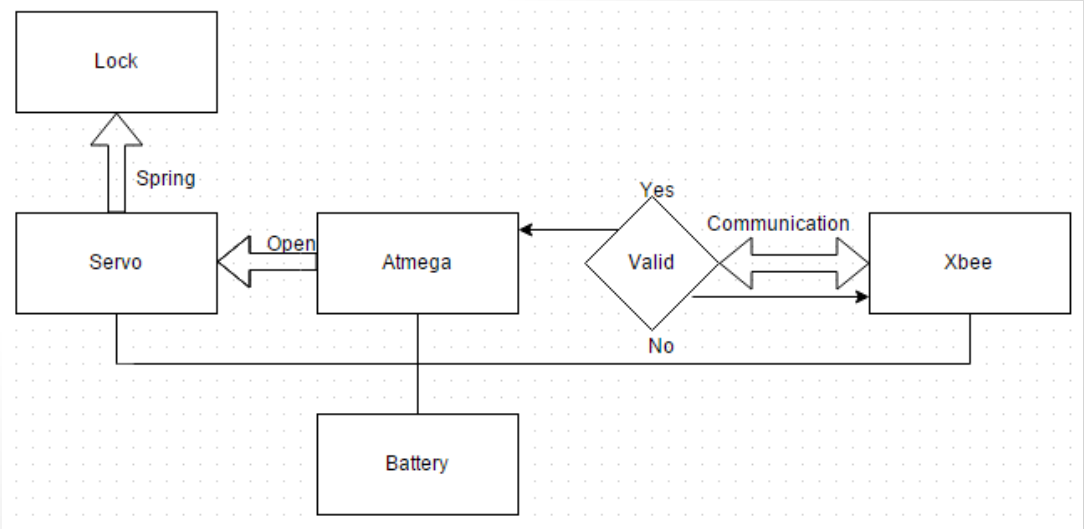
- Mounting Case
- Mounted on Locker

MCU Hardware

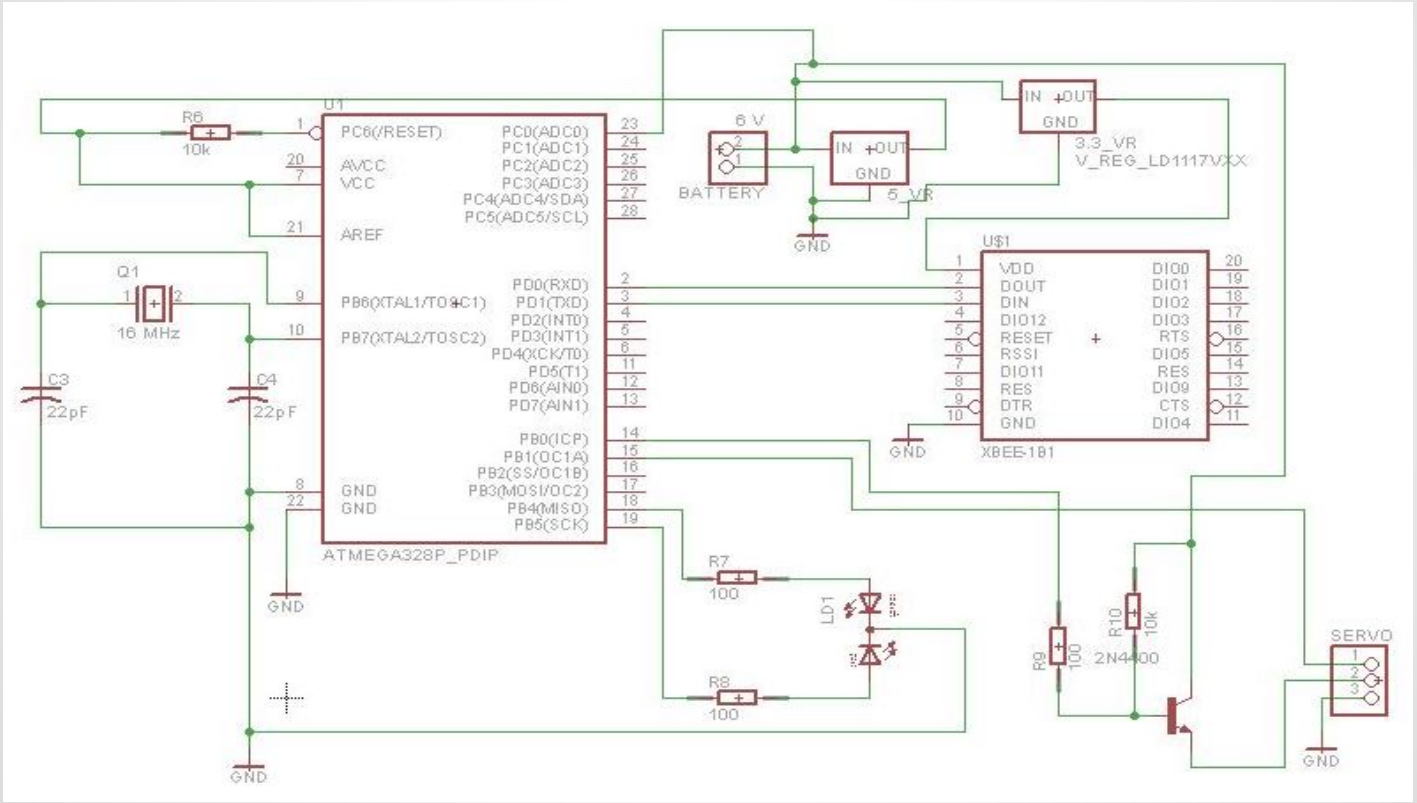
- Display
- Card Reader
- Keyboard
- Rasp. Pi

System Design (LCU)

- Brain
  - Atmega328 processor
- Communication
  - XBee series 1
- Contents
  - Servo motor
  - Bi-LED
  - Battery pack
  - Lock

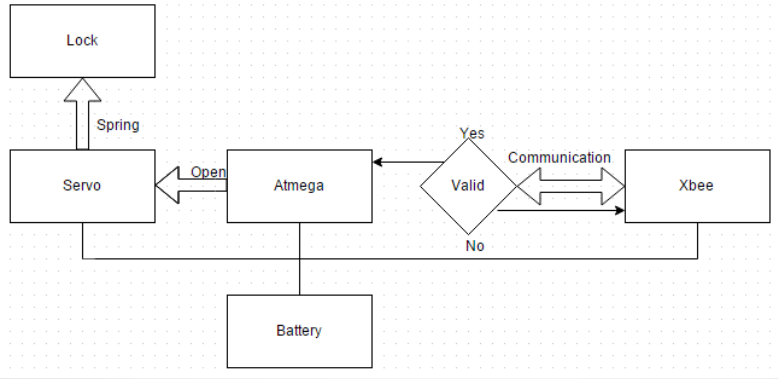


Detailed Design (LCU)



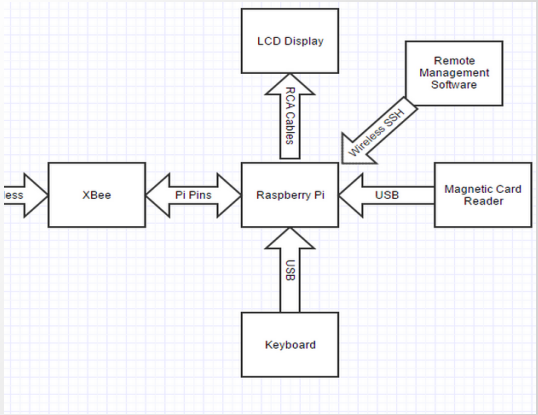
Detailed Design (LCU)

- Sleep to preserve power
  - 128 kHz oscillator - 16MHz clock
  - Xbee - Cycle sleep - Sleeps if no RF
- Poll signals every 5 seconds
  - MCU sends a signal, signal remains in queue



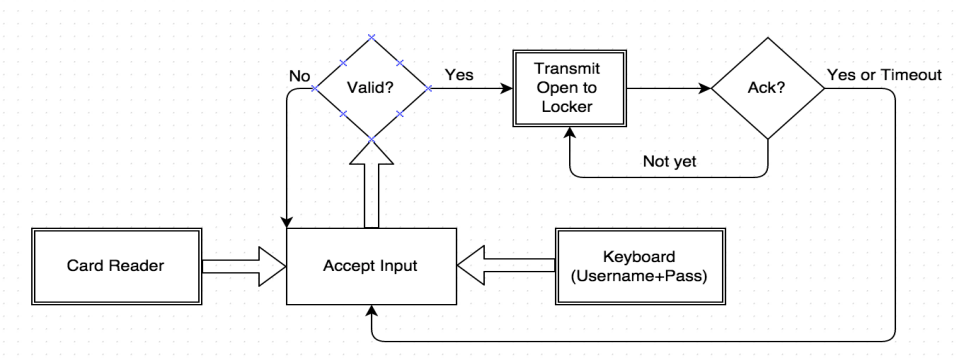
System Design (MCU)

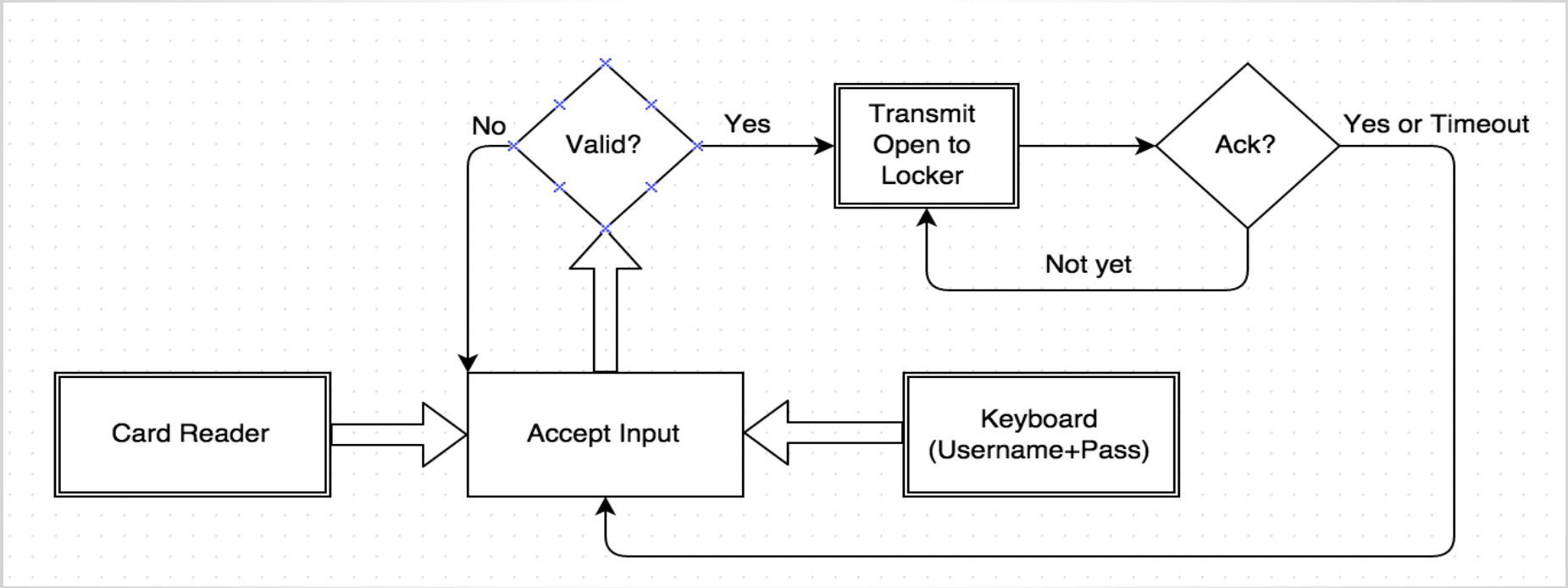
- Brain
  - Raspberry PI Model 2B+
- Communication
  - WIFI USB Dongle & Xbee Series 1
- User Interaction
  - QWERTY Keyboard
  - LCD Display
    - HDMI interface
  - USB Card Reader



Detailed Design (MCU)

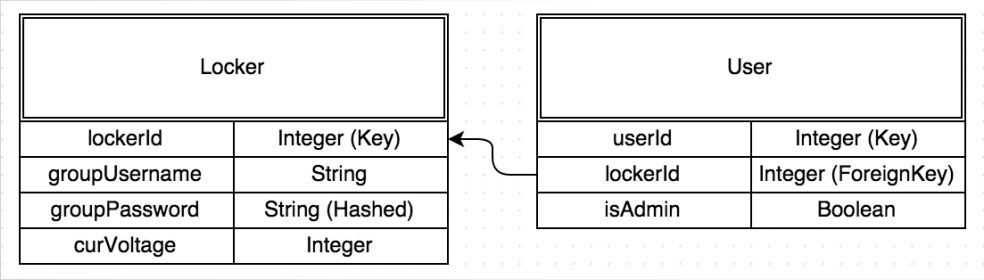
- User Interaction
  - LCD renders simple form with text input
    - User may type into form with keyboard
      - Username/Password is shared amongst the group
  - Card reader accepts ISU ID Cards

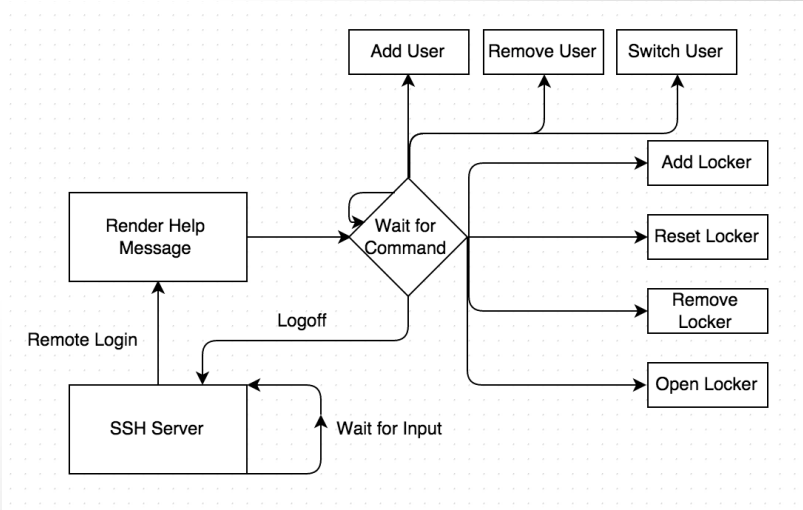


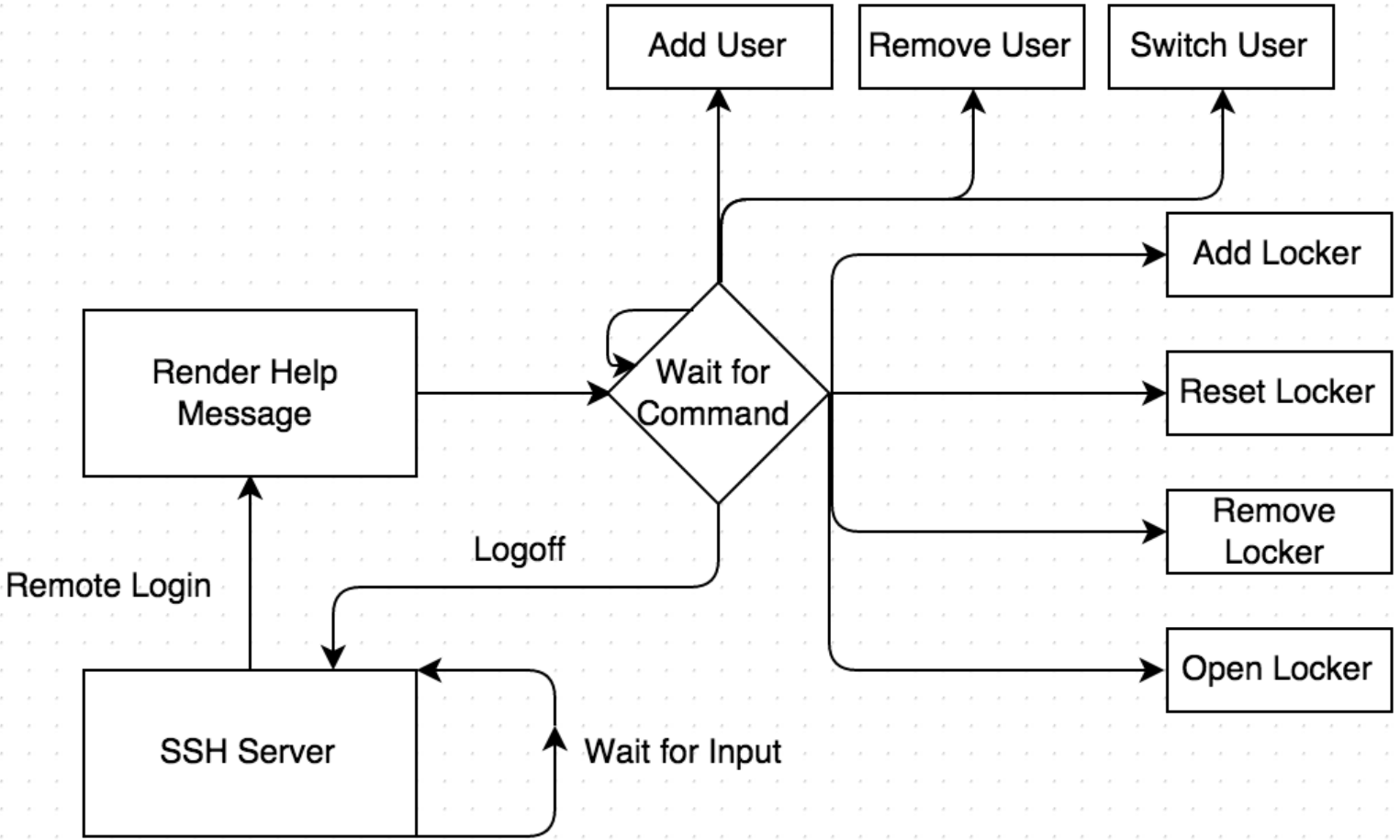

No
Valid?
Yes
Transmit Open to Locker
Ack?
Yes or Timeout
Not yet
Card Reader
Accept Input
Keyboard (Username+Pass)

Detailed Design (MCU) (Remote)

- MCU is managed over an SSH connection
  - Username/Password combination
- A help message is displayed on login for common commands






Add User
Remove User
Switch User
Add Locker
Render Help Message
Wait for Command
Reset Locker
Remove Locker
Logoff
Remote Login
Open Locker
SSH Server
Wait for Input

Detailed Design (Communication)

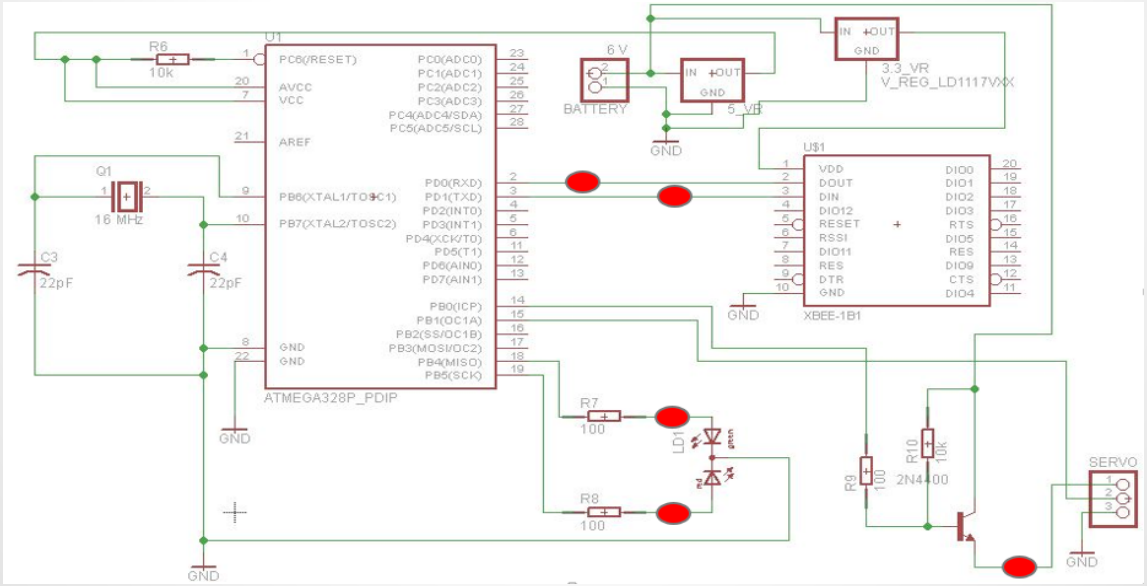
- MCU Opens LCU with OPEN command
  - Packet form: <LockerID> OPEN
  - XBee automatically encrypts data
    - Vulnerable to replay attacks
- LCU transmits battery status back
  - Packet form: <LockerID> <Battery Voltage> batt
- ID and Voltage are 32 bit integer, voltage is measured in millivolts

Design Verification - Electronics

- Mathematically and experimentally verify circuit functions properly
- Simulate circuit using computer software
  - Given circuit edge-values, verify individual circuits function appropriately
  - Eagle Software

Design Verification - Hardware

- Measure power consumption from major components (ATMEGA, LED, Servo, Xbee)

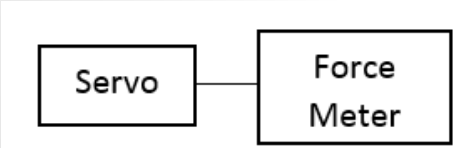


red ovals above indicate where current was measured

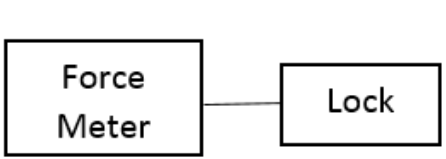
Design Verification - Hardware

- Ensure servo motor can provide sufficient force to unlock locking mechanism using force meter

Test Case to Measure Force Servo Provides

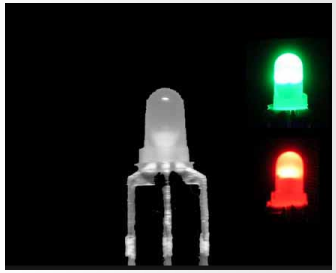


Test Case to Measure Force Needed to Unlock Locker



Design Verification - Hardware

- Verify green and red LED’s illuminate at correct time
- Ensure MCU to LCU communication works at the maximum distance of the room
  - Verify correct lock is unlocking



Design Verification - Software

- Verify data sent is encrypted
  - Attempt to physically capture data, print data being sent into local consoles
- Verify database updates run correctly
  - Automated testing on server startup / code compile
- Verify input edge-cases
  - Authentication cases

Demonstrations

Risks and Vulnerabilities

- Replay Attacks against LCU
  - Data encrypted, however can retransmit same bits to achieve same effect
    - Mitigate by implementing HTTPS protocols
    - Add timestamps on messages
- Social Engineering
  - Steal username/password from administrators
- Battery Usage

Why this project is awesome

- Easily Configurable
- Relatively Cheap
- Easily modified for alternative environments

- Questions?

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Resource costs and Estimates

- Labor
  - 5 Engineers (~30hrs/week)
- Parts - LCU
  - Each unit will cost around $50 (see BOM on next slide)
- Parts - MCU
  - One main control unit will cost around $125 (see BOM on next slide)

Total cost for 30 locker system: $1625

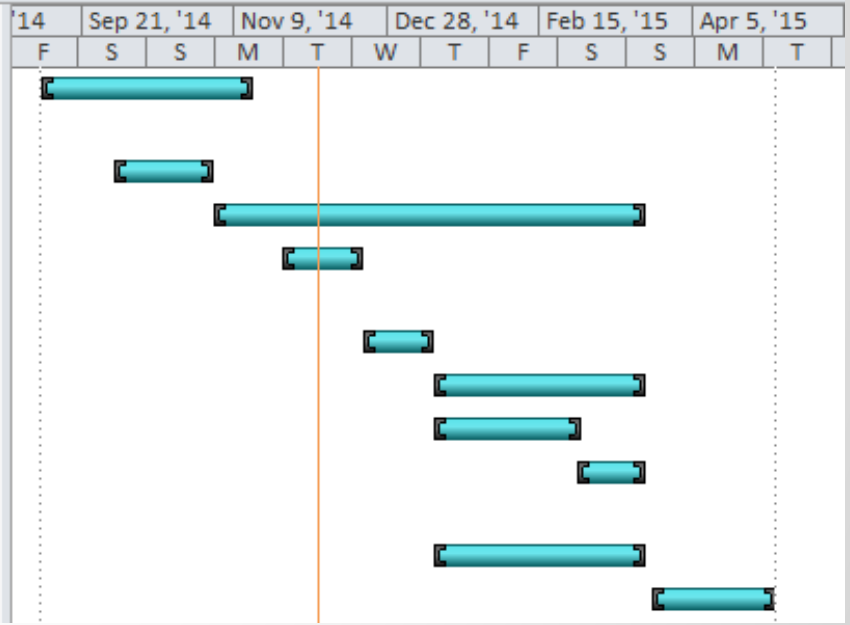
Bill of Materials

Locker Control Unit BOM			
Quantity	Part Number	Part Name	Price ($)/Unit
1	ATMEGA328-PU-ND	ATMEGA328	2.74
1	160-1057-ND	Bi-Colored LED	0.28
2	CF14JT100RTR-ND	100Ω Resistors	0.005
1	CF14JT10K0TR-ND	10kΩ Resistor	0.004
1	CTX1085-ND	16MHz Crystal	0.27
2	BC1034CT-ND	18pF Capacitors	0.25
2	CF14JT100RTR-ND	Resistors (servo tran)	0.005
1	900-00005-ND	Servo	12.99
1	2N3906-APCT-ND	PNP Transistor	0.15
1	MC7805CT-BPMS-ND	Voltage Regulator L7805	0.35
1	497-12822-5-ND	Voltage Regulator LD1117V33	0.63
1	80-C330C334K5R	0.33µF Capacitor	0.49
1	P4725-ND	0.1µF Capacitor	0.19
1	P14373-ND	100µF Capacitor	0.15
1	P10425TB-ND	10µF Capacitor	0.04
1	XB24-AWI-001-ND	Xbee Series 1	19
1	T97B440003	Lock	7.7
AR	N/A	Wire	0
AR	N/A	Metal Fasteners	0
1	ID830	Battery Pack	2.95
4	N/A	AA Alkaline Energizer M AX Batteries	0.8
		Total Price	51.644

Main Control Unit BOM		
Quantity	Part Name	Price ($)/unit
1	Raspberry PI	40
1	Keyboard	12
1	Card Reader	12
1	Display	30
1	Xbee Series 1	19
1	Wi-Fi Chip	10
	Total Price	$123

Schedule of Project

Task Name	Duration	Start	Finish
Research and Design System	50 days	Mon 9/8/14	Fri 11/14/14
Sub-system Testing	24 days	Wed 10/1/14	Sat 11/1/14
System Testing	101 days	Sun 11/2/14	Fri 3/20/15
Prove System will Function with 3 Units	20 days	Mon 11/24/14	Fri 12/19/14
Order Parts	17 days	Sat 12/20/14	Sun 1/11/15
Mechanical Design	50 days	Mon 1/12/15	Fri 3/20/15
Admin Controls and UI	35 days	Mon 1/12/15	Fri 2/27/15
Implement System Security	16 days	Fri 2/27/15	Fri 3/20/15
Verification Testing	50 days	Mon 1/12/15	Fri 3/20/15
System Documentation	30 days	Mon 3/23/15	Fri 5/1/15



Power Calculations

	Scenario Definitions		
	LCU looks for signal from MCU every 'x'	LCU Checks Battery Status Every 'x'	Locker Opens Every 'x'
Scenario 1	5 seconds	1/week	0/week
Scenario 2	5 seconds	1/week	2/week
Scenario 3	5 seconds	1/week	6/week
Scenario 4	5 seconds	1/week	8/week
Scenario 5	5 seconds	1/week	14/week
Scenario 6	5 seconds	1/week	28/week

	Scenario Calculations			
	Current Draw (mA)	Time (hours)	Electric Power Over Time (mAh)	How many academic semesters with 4AA battaries?
Scenario 1	0.155904514	2688	419.0713347	25.77126877
Scenario 2	1.006373505	2688	2705.131981	3.992411489
Scenario 3	1.027328477	2688	2761.458947	3.91097612
Scenario 4	1.037805964	2688	2789.622431	3.871491669
Scenario 5	1.069238426	2688	2874.11289	3.757681209
Scenario 6	1.142580835	2688	3071.257284	3.516475176

Power Calculations (Cont)

	ATMEGA328 Calculations		
	Current Draw (mA)	Time (hours)	Electric Power Over Time (mAh)
Scenario 1	3.50529E-09	2688	9.4222E-06
Scenario 2	0.840006967	2688	2257.93873
Scenario 3	0.840020195	2688	2257.97428
Scenario 4	0.840026808	2688	2257.99206
Scenario 5	0.84004665	2688	2258.04539
Scenario 6	0.840092946	2688	2258.16984

	Bi-LED Calculations		
	Current Draw (mA)	Time (hours)	Electric Power Over Time (mAh)
Scenario 1	0.535	0.044444444	0.023777778
Scenario 2	0.535	0.088888889	0.047555556
Scenario 3	0.535	0.266666667	0.142666667
Scenario 4	0.535	0.355555556	0.190222222
Scenario 5	0.535	0.622222222	0.332888889
Scenario 6	0.535	1.244444444	0.665777778

	Xbee Calculations		
	Current Draw (mA)	Time (hours)	Electric Power Over Time (mAh)
Scenario 1	0.155895665	2688	419.047548
Scenario 2	0.155895665	2688	419.047548
Scenario 3	0.155895665	2688	419.047548
Scenario 4	0.155895665	2688	419.047548
Scenario 5	0.155895665	2688	419.047548
Scenario 6	0.155895665	2688	419.047548

	Servo Calculations		
	Current Draw (mA)	Time (hours)	Electric Power Over Time (mAh)
Scenario 1	0	2688	0
Scenario 2	0.010453181	2688	28.09815
Scenario 3	0.031359542	2688	84.29445
Scenario 4	0.041812723	2688	112.3926
Scenario 5	0.073172269	2688	196.68706
Scenario 6	0.146344539	2688	393.37412