Universal Bike Sharing Lock

ECE 445 Final Paper

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12/13/17

Abstract

The following report outlines the design, building process, motivations, and results of a bike locking system designed to widen the scope of bike sharing services to other automobile-alternatives like scooters and mopeds. In practice, this bike locking system would consist of both a physical device with electronic internals and a web application to handle bike rentals and returns. The focus of this project is on the electronic components for the locking device itself.

Table of Contents

1 Introduction

1.1 Background

Bike sharing services, especially in urban areas, are increasing in popularity all over the world [1]. However, as proposed at the beginning of the semester, vehicles like scooters and mopeds are comparably environmentally-friendly and potentially better-suited for the environment, but there exist no widespread ride sharing services for them [2].

1.2 Objective

This project attempts to solve this problem on a larger scale by creating a device that would allow for bikes, scooters, and mopeds to be shared in a ride sharing service without the need of specialized racks or bikes. The main functionalities needed for the device are responsive unlocking for rentals, instant and secure locking for returns, and a constant source of power to maintain proper functionality and the security of the bike, with aims to emulate ride sharing services like Divvy and Zipcar [3][4].

2 Design

2.1 Design Procedure

The main motivators for the design was to make sure the locking mechanism was easily responsive, and that the bike would be constantly secure. A push-pull solenoid was chosen for the locking mechanism due to its rapid response time for opening and closing, and electricity being the only method of opening and closing it (which would be directly handled by the control unit). On the other hand, because the locking mechanism always requires a source of power to function properly, it added some extra strain to the power requirements of the system, but its benefits outweigh the costs in the end.

Another important factor in the design of the device was considering how each of the various components would work together as a cohesive system. Using Bluetooth for ensuring deliberate unlocking the device and RFID for locking it instantly seemed like good choices on their own, but the real challenge came from having these and the remaining components communicate with each other to achieve complete functionality, hence the choice for a powerful out MCU to handle this sort of communication.

Finally, to keep the device constantly powered for security, an AC source (then converted to DC) was chosen as the primary source of power for the system due to it providing constant power and planning for the device to be stationary in an urban setting where such AC outlets are more likely to be available. To further power the device, a rechargeable backup battery was later added in case of emergency power loss, along with the ability to send an alert over Wi-Fi to a remote server in case this scenario occurs.

2.2 Design Details

The system features four main blocks, with their connections and individual components illustrated in Figure 1 below. A sketch of a physical manifestation of a completed device is included later in Figure 2. The work done in the class focused on completing the blocks from a functional standpoint and integrating them together as the internal system of the device.

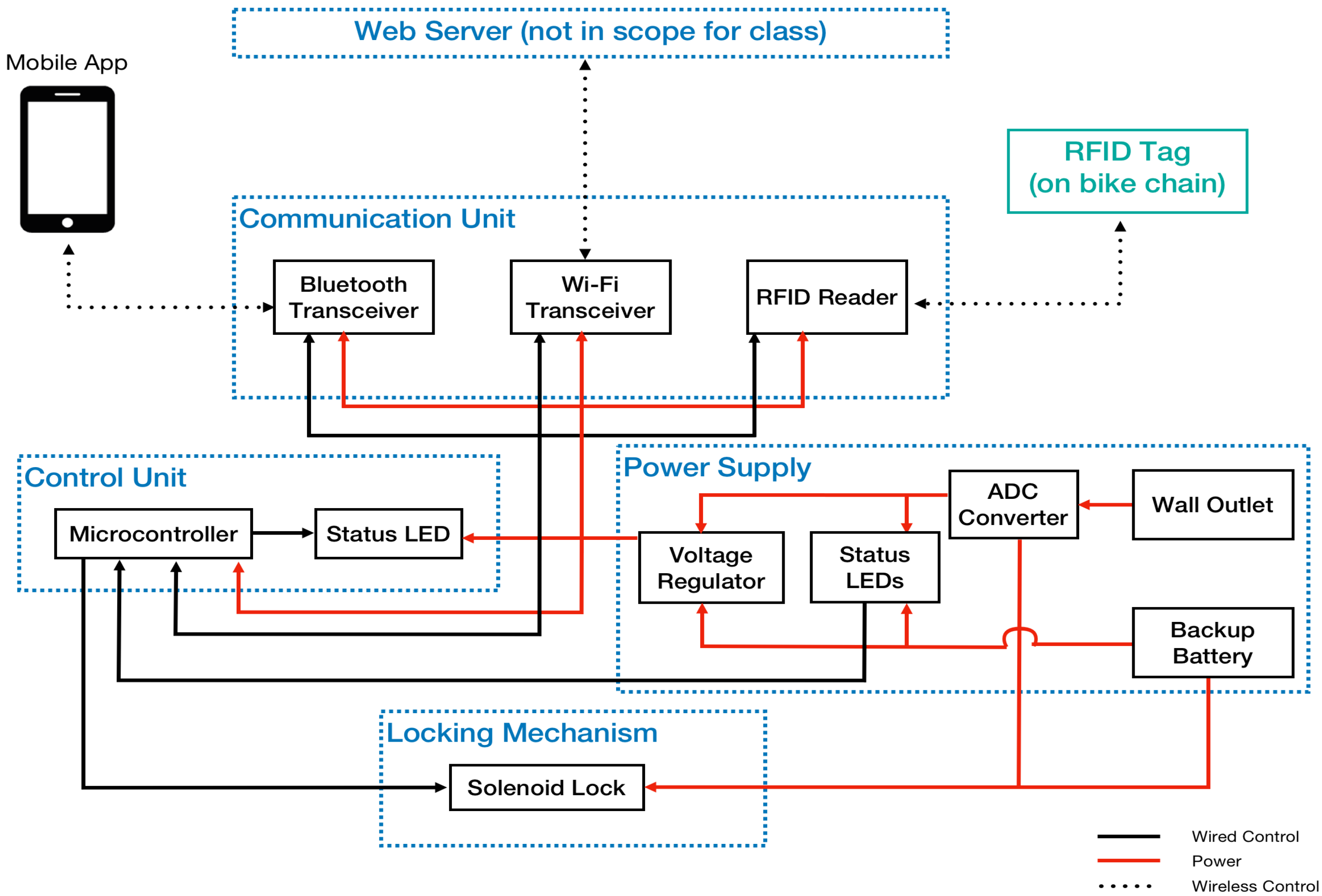

Figure 1. Block Diagram of Complete System

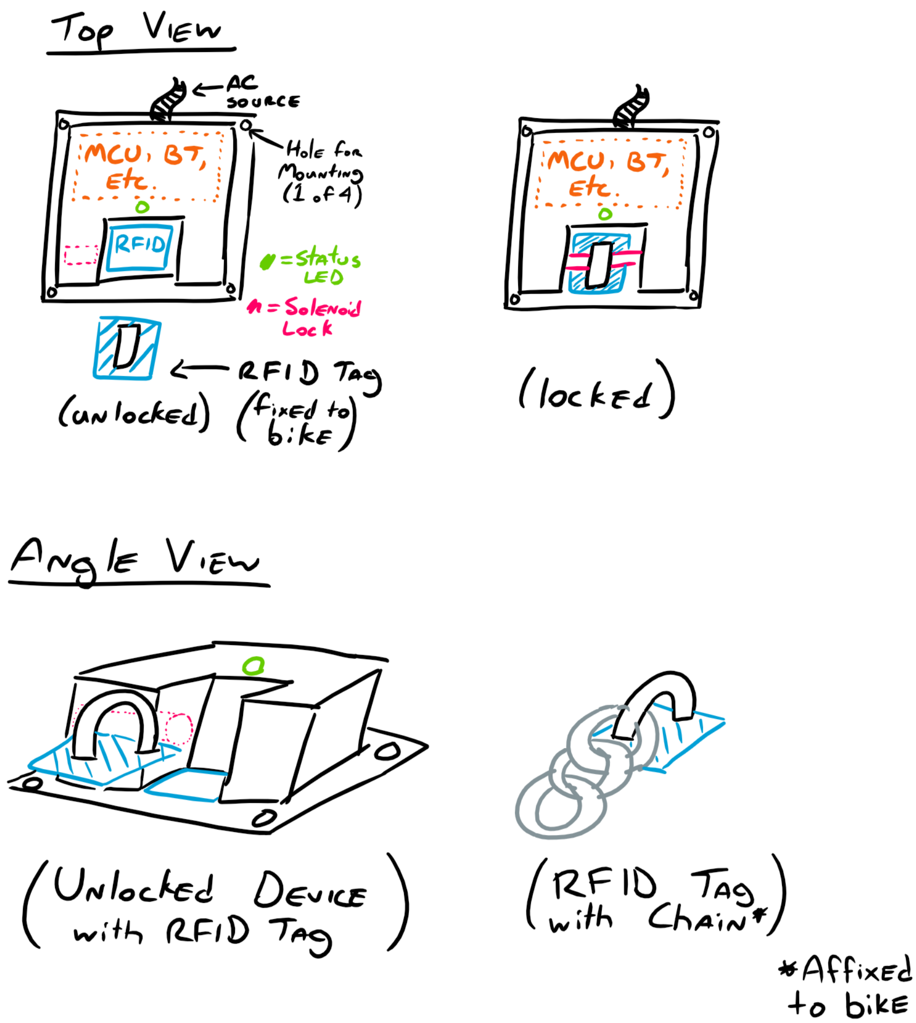

Figure 2. Sketch of Physical Design of Fully Developed Device

2.2.1 Locking Mechanism

As mentioned previously, a push-pull solenoid was chosen as the epicenter of the locking mechanism due to the automatic nature of its operation (via the amount of current flowing through it). It is driven with a special BJT-diode circuit, which constantly receives the minimum amount of voltage to control the solenoid (rated at 12V, but able to operate at voltages greater than 3.11V), while the I/O pin of a MCU allows the solenoid itself to be switched open and closed, illustrated in Figure 3 below.

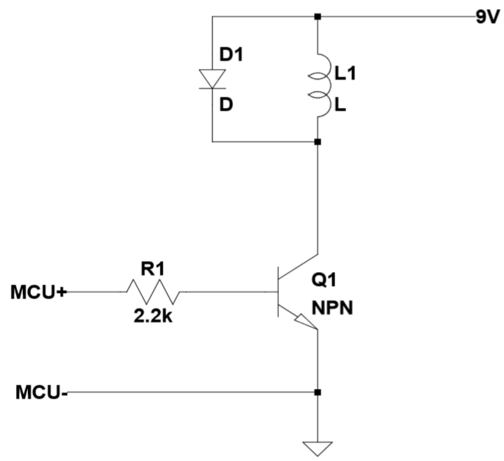

Figure 3. MCU-Controlled Solenoid Circuit [5]

2.2.2 Power

The system uses a constant source power from an AC outlet, then converts it to DC with a transformer. The various electronic components of the system need different levels of voltage, so several voltage regulators are used to step down the direct source to necessary levels, as illustrated in Figure 4. A backup battery is also directly connected to the circuit, and is switched in as the primary source of power if the DC source is cut (via a series of diodes). The voltage is stepped down to levels of 9V, 5V, 3.3V, and 1.2V. The 9V is used to power up the solenoid, 5V is for an Arduino controller (used in tandem with RFID implementation due to time constraints), and the MCU requires both 3.3V (I/O supply) and 1.2V (Core supply).

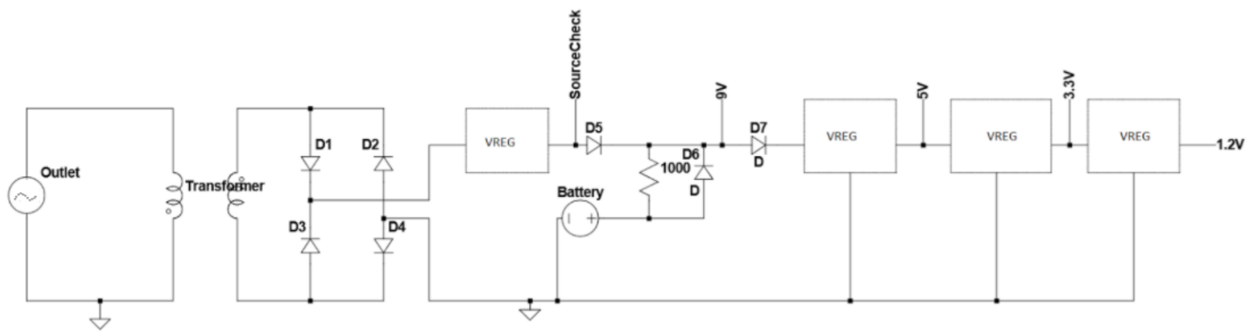

Figure 4. Complete Power Circuit

2.2.3 Control Unit

With several components necessary to be integrated together for full system functionality (including driving the solenoid, three communication channels for Bluetooth, Wi-Fi, and RFID, and reading from the DC source to determine power failure), the microcontroller used needed to be capable of handling many operations simultaneously and responding very quickly, especially for the case of a user wanting to easily rent or return a bike. The Texas Instruments C2000 Delfino Dual-Core MCU was chosen for its high operating capabilities, multiple communication channels, and internal flash for running more complex programs [6].

The control unit as a whole executes the rental, return, and DC power detection logic (explained in Figures 6, 7, and 8 respectively), along with sending data through the communication unit's Wi-Fi module. In practice, the MCU drives the solenoid and detects the presence of DC power through its digital I/O ports, along with interfacing with the communication. Alternatives to the TI MCU would be using cheaper microcontrollers such as the ATMega2560 (commonly used in Arduino), but the faster processing power and internal flash memory better suited the complexity of integrating all of the components as one full system.

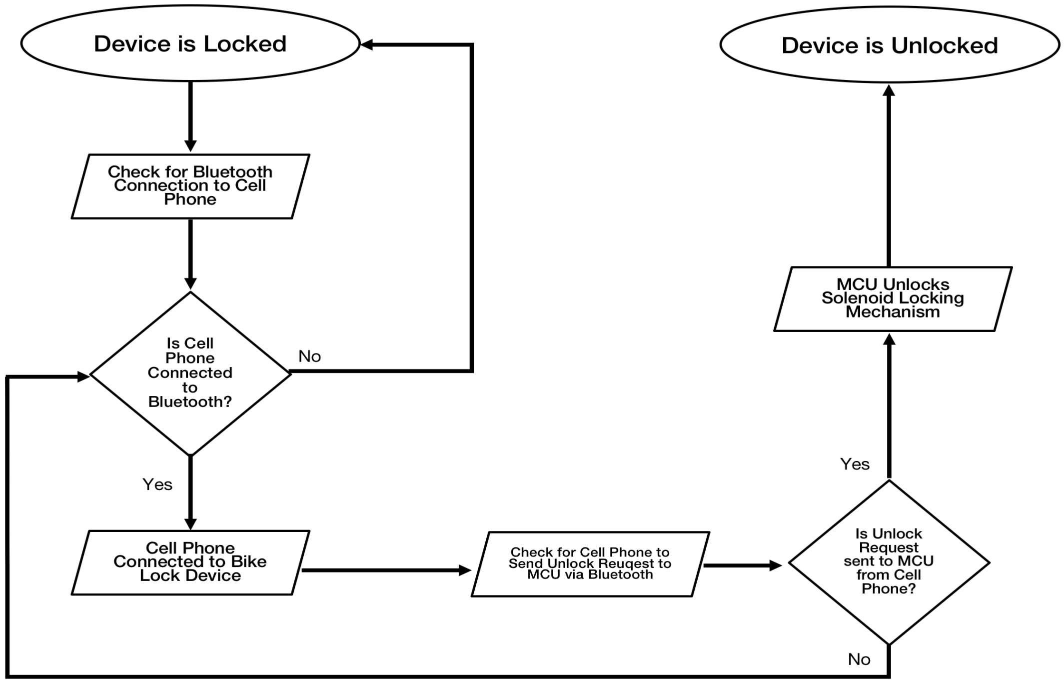

Figure 6. Logic Diagram for Unlocking via Bluetooth Module

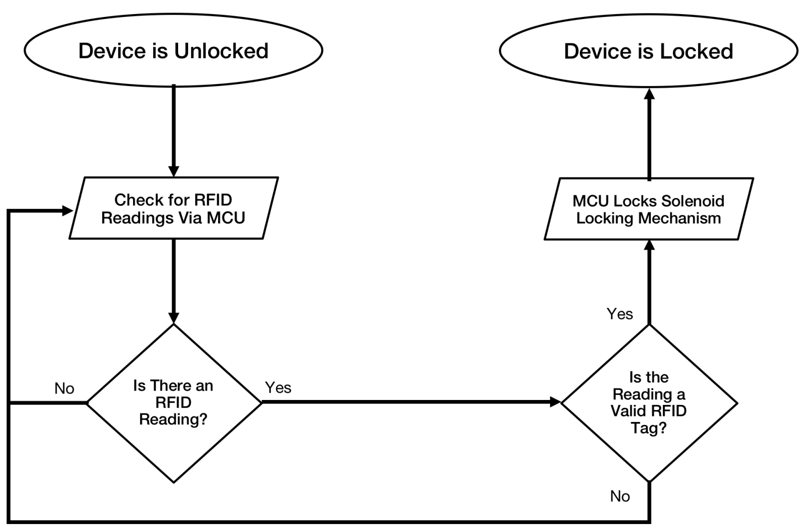

Figure 7. Logic Diagram for Locking via RFID

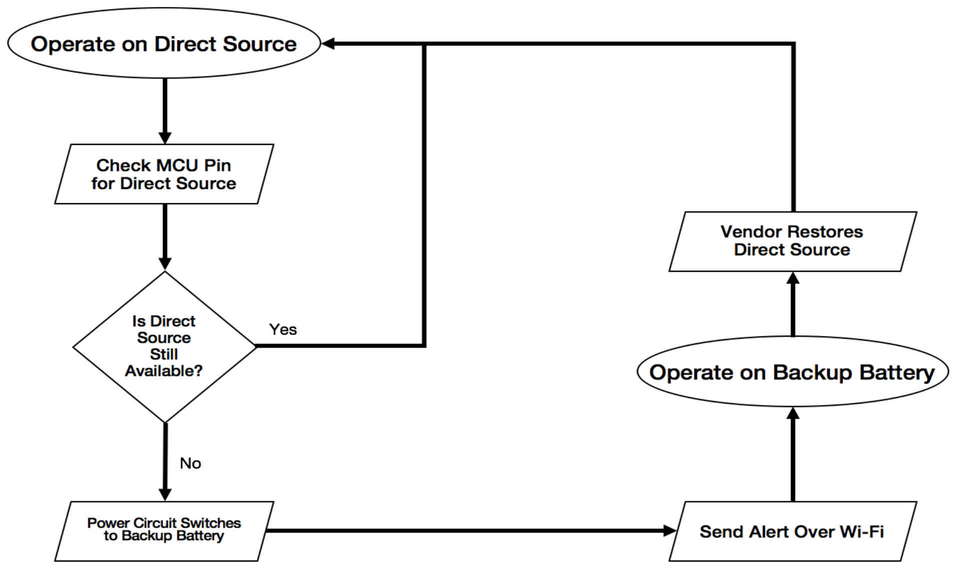

Figure 8. Logic Diagram for Power Loss

In the case of power loss, the MCU has a low-power mode in order to better conserve energy and reduce the drain on the backup battery. The differences in power and electrical quantities based on the state of the MCU are as follows:

$$Static\,power\,dissipation(P) = Potential\,difference\,(V) * Current\,Consumption\,(I)$$ **Eq. 1.1**

$$V = 1.2\ Volts\ for\ MCU$$

$$Maximum\ dissipation\ at\ active\ state = 1.2V * 440mA = 528mW$$ **Eq. 1.2**

$$Minimum\ dissipation\ at\ active\ state = 1.2V * 325mA = 390mW$$ **Eq. 1.3**

$$Maximum\ dissipation\ at\ IDLE\ state = 1.2V * 210mA = 252mW$$ **Eq. 1.4**

$$Minimum\ dissipation\ at\ IDLE\ state = 1.2V * 105mA = 126mW$$ **Eq. 1.5**

2.2.4 Communication Unit

The communication unit allows a user to interact with the device, whether it's for renting/returning a bike, or for receiving information from the device itself. For remote unlocking via Bluetooth, the HC-05 Bluetooth module, which utilizes UART communication was used for the final iteration due to its ease of use [7].

For instant returns through an RFID reader, the MFRC522 module was chosen for both its simplicity, but also its fast response time. The module utilizes SPI communication, and has a passive RF signal with a range of about 1 inch for reading standard RFID tags [8]. For the iteration used in the final demo, due to the increased complexity and CPU usage of SPI compared to UART, the RFID reader was used with an Arduino microcontroller and a specialized SPI library, and the info scanned is sent to the MCU from the Arduino via UART.

For Wi-Fi capabilities, the TI CC3200 Wi-Fi MCU was used mainly for its use of UART communication, making interfacing with the MCU more seamless and preserving computing power for other needs. It's rated at 13Mbps for a TCP connection, which works in line with sending an alert for DC power loss as soon as possible [9].

3 Requirements and Verifications

The following are the final results the requirements and verifications (fully described in Appendix A) set upon initial completion of the design.

3.1 Locking Mechanism

- **Requirement 1:** The current through solenoid will reach 1.0A within 500ms after connecting it to the voltage source.

Verification: The verification of this requirement was done by observing the response time of the solenoid after powering it.

Result: Success. The solenoid opens and closes immediately.

3.2 Power

- **Requirement 1:** Must be able to regulate incoming DC voltage within ± 5% for each component

  Verification: The verification of this requirement was done by using a voltmeter to measure the voltage after each regulator.

  Result: Success. The 9V, 5V, 3.3V, and 1.2V all meet the 5% requirement. The largest deviance was 1.25V resulting in a 4.1% change

- **Requirement 2:** Must be able to supply power for the circuit at least an hour

  Verification: Supply the entire system with battery power and time how long it operates.

  Result: Failed. The batteries used could only supply power for 40 minutes (mainly due to the current flow of the moving solenoid). To fix this, batteries with a longer-lasting capabilities would be used.

- **Requirement 3:** Must be able to activate immediately after wall outlet power gets cut

  Verification: Measure the time it takes for the system to be powered up after the outlet power gets cut.

  Result: Success. There was no interrupt in power, and all the systems stayed fully functional when the wall outlet power was cut.

3.3 Control Unit

- **Requirement 1**: Must be able to send/receive 10Kb of data to Wi-Fi microcontroller through UART channel at the baud rate of 9600 or greater.
  Verification: The verification of this requirement was done before the system was integrated to prevent any side effect from power connection failure. Manually triggered the power failure routine on MCU by connecting detection pin to the GND. Wi-Fi microcontroller was connected to serial terminal on PC by the second UART channel.
  Result: Success. Power failure warning confirmed as delivered to the terminal from a Python TCP server.

- **Requirement 2**: Must be able to send/receive 10Kb of data from Bluetooth microcontroller through UART channel at the baud rate of 9600 or greater.
  Verification: The verification of this requirement was done before the system was integrated to prevent any side effect from power connection failure. The solenoid switch pin to an LED to confirm it was triggered. A predetermined command is sent to MCU through Bluetooth terminal to trigger solenoid unlock routine.
  Result: Success. MCU turned LED off after receiving the command.

- **Requirement 3:** Must be able to receive a hardware interrupt from the backup battery when the power from outlet is cut, and then get into the low-power mode to have no more than 200mA core current consumption.
  Verification: Manually triggered power failure service routine by connecting detection pin to GND, and monitored power supply.
  Result: Success. Current reduction was from 187mA to 155mA (the current consumption was already lower than 200mA due to inaccuracies in the

datasheet) However, considerable drop in current consumption was observed when the power failure was detected.

$$Current\ Draw\ Reduction = 187mA - 155mA = 32mA$$ **Eq. 2.1**

$$Static\ Power\ Saving = 1.2V * 32mA = 38.4mW$$ **Eq. 2.2**

- **Requirement** 4: If direct source is cut, server is notified by the control unit through Wi-Fi module within 20 seconds after backup battery kicks in.
  Verification: Manually triggered power failure service routine by connecting detection pin to GND, and monitored server's console for alert message.
  Result: Success. Power failure alert message was sent to terminal console of the server instantly after pin was switched off.

3.4 Communication Unit

- **Requirement 1**: Must be able to communicate with a user's phone mobile app from 1-3ft away.
  Verification: Solenoid unlock command is sent to control unit through Bluetooth serial terminal on user's mobile device. Monitored the state of solenoid. Unlocking solenoid is sufficient for verification.
  Result: Success. Solenoid was unlocked when user sent command to control unit through bluetooth application.

- **Requirement 2**: Must be able to communicate with an independent web server at 8 Mbps.
  Verification: The team could not find a software to accurately measure throughput for the demo. The verification was instead done by receiving alert

message at the server by manually triggering power failure service routine.

Result: Success. After detection pin detected power failure, server was instantly notified of the power failure incident.

4 Costs and Labor

4.1 Total Labor

(Salary of $35/hour) * (3 members) * (12 hours of work/week) * (8 weeks) = $10080 **Eq. 3**

4.2 Total Costs

Part Name	Quantity	Unit price	Total Cost
Texas Instruments TMS32028377D Microcontroller	1	$36.16	$36.16
Texas Instruments CC3200 Wi-Fi Microcontroller	1	$10.80	$10.80
HC-05 Bluetooth Transceiver	1	$5.79	$5.79
Kemet JMK105BJ474KV-F 0.47uA Capacitor	22	$0.10	$2.2
TDK C3216X7S1A226M160AC22uF Capacitor	12	$0.90	$10.80
NXP semiconductors MFRC-522 RFID module	1	$7.99	$7.99
LD1117V33 (3.3V Regulator)	1	$1.95	$1.95
LM7812 (12V Regulator)	1	$0.95	$0.95

Triad Magnetics TCT50-01E07AE (Transformer)	1	$18.09	$18.09
Miscellaneous Circuit Components (Wires, Resistors, etc.)	N/A	$20	$20
Rechargeable 9V Battery (NiMH 3 Pack)	1	$17.00	$17.00
Total Cost			$158.46

5 Conclusions

5.1 Project Summary

Overall, in terms of functionality, the entire system was completed. All of the blocks met requirements individually, but the real challenge came with integrating them together. Due to the large number of components connected to each other, one of the MCU's I/O pins was damaged due to excess current, but this was solved with more proper current-limiting circuitry. While there were some design pivots to meet the eight week deadline for project completion (i.e. using an Arduino to interface with RFID, weaker than expected backup battery, etc.). While the complete physical device (encasing and all) was not finished by the deadline, the actual internal system functioned as initially designed and followed the proper rental/return logic in testing.

5.2 Ethical Considerations

As discussed in the initial design document (especially by IEEE's ethics standards), one of the main aims of the project is "to avoid injuring… [others'] property", by protecting the vendor's bikes and scooters from theft [10]. In terms of the locking mechanism properly opening and closing, this security has been achieved.

Along with proper functionality in terms of implementation, the device also needs a constant source of power to keep functioning, and in one way, this was partially achieved with the constant AC to DC power source and automatic backup battery, although there is potential for improving in this respect with a stronger battery or a less power-dependent system for more passive security.

One aspect of security not particularly addressed was the security of the various Bluetooth and Wi-Fi signals. While not within the scope of the initial project iteration, if these mediums of device communication were hacked, then the entire safety of the bike could be compromised. In practice, with Wi-Fi especially, rental service data would be relayed to the server, so protecting signals would be a must for true safety if this device were to be introduced into market in a completed state.

5.3 Future Improvements

While the entire electronic system was implemented to function as one unit successfully, there are definitely considerations and idea for improvements. For one, while the backup battery was only partially sufficient to power the device in case of DC power loss, a design that relies less on constant power would better alleviate this problem. A solenoid does provide immediate open and closing, but a mechanical solution that has the same response time but provides more passive security in case of power loss.

For the communication unit, ass mentioned earlier, if implemented, the Wi-Fi and Bluetooth modules would need greater security due to the importance of information they are transferring (i.e. rental data, passwords, etc.). As for RFID, a module with an active RF signal instead of the currently used passive one could allow for easier scanning, but may further add strain to the power block.

In terms of the control unit, in some ways, the TI MCU used may almost be too powerful for the system, and better utilizing a smaller, cheaper one, could make the entire device more efficient. Having Wi-Fi capabilities in the MCU itself instead of a separate module could also increase efficiency or ease of integration.

Overall, while the system implemented achieves the basic goals of the Universal Bike Lock design, there is room for improvement for the device as a whole to increase its performance and safety, while also better preparing it for a potential entry to market.

6 References

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[8] NXP Semiconductors, “MFRC522” [Online]. Available: https://www.nxp.com/docs/en/data-sheet/MFRC522.pdf. [Accessed: 03-Oct-2017]

[9] Texas Instruments, “CC3200 SimpleLink Wi-Fi and Internet-of-Things Solution, a Single-Chip Wireless MCU” [Online]. Available: http://www.ti.com/lit/ds/symlink/cc3200.pdf. [Accessed: 03-Oct-2017]

[10] IEEE.org, "IEEE Code of Ethics", 2017. [Online]. Available: http://www.ieee.org. [Accessed: 19-Sept-2017]

Appendix A

Requirements and Verification Tables

Power Supply

Requirements	Verification
Voltage Regulator: 1. Must be able to regulate incoming DC voltage within ± 5% for each component	Requirement 1 • A DC source of 9V will be emulated with a power source • A multimeter will be used to check the regulator drops the source down to 3V ± 5%
Backup Battery: 2. Must be able to supply power for the circuit at least an hour [5]	Requirement 2 • Measure the lifetime operation on battery to see if the device will work properly for an hour or more.
3. Must be able to activate immediately after wall outlet power gets cut	Requirement 3 • We can manually remove the outlet power source and measure the voltage to see no drops to 0V

Table A.1 Power Requirements and Verifications

Control Unit

Requirements	Verification
Microcontroller: 1. Must be able to send/receive 10Kb of data from Wi-Fi microcontroller through UART channel at the baud rate of 9600 or greater. 2. Must be able to send/receive 10Kb of data from Bluetooth microcontroller through UART channel at the baud rate of 9600 or greater.	Requirements 1 and 2 • Connect a JTAG debug probe to the microcontroller and turn on debug console. • Initiate a transmission from Bluetooth/Wi-Fi to CPU1 and CPU2 respectively. The content is a sequence of integers with predetermined pattern. • Print out the number sequence to console from both CPUs. • Connect debug probe to Wi-Fi/Bluetooth MCU and repeat the same routine in opposite direction
3. Must be able to receive a hardware interrupt from the backup battery when the power from outlet is cut, and then get into the low-power mode.	Requirement 3 • Cut the voltage supply from the power outlet. • If the current measured from VDD to GND with a multimeter does not exceed 200mA, requirement is met. (Typical operating current is 325mA, maximum is 440mA)

4. If direct source is cut, server is notified by the control unit through Wi-Fi module within 20 seconds after backup battery kicks in.	Requirement 4 • Make sure MCU and server have synchronized time • Cut the direct voltage supply from the power outlet to trigger hardware interrupt routine • In the hardware interrupt routine, record the time the interrupt is triggered. • Send the recorded time to the server, and compare it with the time the message arrived to the server

Table A.2 Control Requirements and Verifications

Locking Mechanism

Requirements	Verification
Solenoid Lock: 1. The current through solenoid will reach 285mA within 500ms after connecting it to the voltage source.	Requirement 1 • Manually connect and disconnect solenoid to voltage source and measure time of push and pull operations through oscilloscope (5 times for each) • Measure current through solenoid via multimeter to verify the value is within the required range

Table A.3 Locking Mechanism Requirements and Verifications

Communication Unit

Requirements	Verification
Bluetooth Transceiver: 1. Must be able to communicate with a user's phone mobile app from 1-3ft away	Requirement 1 • Initiate the test program on Bluetooth MCU through JTAG debugger • Initiate the test program that executes simple reception/response routine

Wi-Fi Transceiver: 2. Must be able to communicate with an independent web server at 8 Mbps.	• Send 1kb of predetermined data packet from mobile device • Verify that mobile device receives the same data it sent to Bluetooth when mobile device is 1-3ft away from the Bluetooth transceiver Requirement 2 • Set up a simplified web server on a computer • Send 10Kb of data over Wi-Fi to the server • Check that web server received the data with no loss and use a network monitor software to verify the transmission rate

Table A.4 Communication Requirements and Verifications

Safe Practice for Lead Acid and Lithium Batteries

Document Prepared By: Spring 2016 Course Staff
ECE 445: Senior Design Project Laboratory
Last Revised: April 13, 2016

I. Introduction

Hello senior designers! If you are reading this document, you are probably planning on designing a project using some form of battery! Batteries are a great way to store energy for later use in portable devices or backup systems. One often overlooked problem with batteries is that they are dangerous. Additionally, different batteries are dangerous for different reasons. In this document, we will challenge students to justify why they need a battery, introduce dangers inherent to all batteries, explain the dangers that are unique to two common types of batteries (lead-acid batteries and lithium batteries), present some suggestions for charging batteries, and end with a discussion of the ECE 445 procedures for minimizing the risks of projects involving batteries.

II. Do You Need a Battery?

Due to the danger, the course staff would like to stress that students should ***avoid batteries if at all possible and use the very nice voltage supplies that are provided at every single lab bench***.

III. Dangers Inherent to all Batteries

To prevent runaway current, your batteries must always be stored in a secure location with the terminals covered by insulating material to ensure that there is absolutely no way that a short circuit can present itself. Both of these battery chemistries are capable of delivering unbelievably high currents (>5000A) and will overheat and possibly ignite (lead acid via ignition of evaporating hydrogen and lithium via decomposing cathode and eventual exposure to oxygen) if they become too hot. Additionally, proper ventilation should be allowed such that any gas can dissipate itself. If your circuit requires a battery, you must be able to demonstrate that your circuit will not have any conditions where a failure results in a short circuit.

IV. Unique Dangers of Lead Acid, SLA, Gel Mat, etc. Batteries

Lead acid batteries are the same types of batteries in your car. They are very high capacity and capable of outputting tremendous amounts of current at a reasonably low voltage. As the name implies, they are full of lead (bad) and acid (also bad). What's worse, the acid inside of a non-SLA or non-Gel Mat battery is in a liquid form and these batteries have valves to allow vapors to evaporate from the battery, meaning they pose a severe risk of spewing acid everywhere (VERY bad). For these reasons, if your project involves a lead-acid battery of any type, you will be *REQUIRED* to find the Material Safety Data Sheet (MSDS) and data sheet for your battery before you can acquire the battery and you must keep this documentation with you at all times in the laboratory. If possible, it is advised that students purchase a battery with protection against chemical spills (SLA is typically the most effective for student projects relating safety and cost) in order to minimize the risk of chemical leakage occurring.

V. Unique Dangers of Lithium-Ion, Lithium Iron Phosphate, etc. Batteries

Lithium batteries are the type of batteries found in your mobile phones and laptops. They are generally smaller and lighter than comparable capacity lead acid batteries, but they are also *substantially more flammable*. Unlike the lead acid battery where cell damage typically translates to reduced capacity, cell damage in a lithium battery translates to *a particularly nasty chemical fire*. Lithium Iron Phosphate batteries tend to be somewhat more fire resistant on account of different cathode material; however, they are still extremely flammable. For this reason, if you elect to use a lithium battery in any capacity, you will be required to complete additional fire safety and fire extinguisher training before proceeding with the course. Additionally, you will be required to incorporate some circuit to prevent your battery cell voltage from decaying below 3.0 $\frac{V}{cell}$ (2.5 $\frac{V}{cell}$ for $LiFePO_4$) or exceeding 4.2 $\frac{V}{cell}$ (3.65 $\frac{V}{cell}$ for $LiFePO_4$). Any charge or discharge tests must be performed while the battery is inside of one of the specially design lithium safety bags and any protection or charging circuits must be approved by your TA **AND** one of the power-centric TAs before they are so much as tested on a breadboard. These procedures are in place in order to protect you, others, and the brand new ECEB from being reduced to a smoldering pile of ashes. ***IF YOUR BATTERY BEGINS TO SWELL, FEEL HOT OR MAKE FUNNY NOISES: disconnect the battery IMMEDIATELY and place it in a battery bag FAR AWAY FROM FLAMMABLE STUFF. You should then report the issue to your TA and a power-centric TA IMMEDIATELY either in person or via a phone CALL to dispose of the battery as soon as possible.***

Swollen Battery = Time Bomb

There are several ways to damage a lithium cell. They include:

- Over charge
- Over discharge
- Over current (charge or discharge)
- Excessive heat
- Internal or external short circuit
- Mechanical abuse

Always check the battery specifications before purchasing or using them!
To minimize the risk associated with lithium batteries, the following precautions should be followed:

- Written work instructions and checklists should be generated for testing procedures
- Remove jewelry that may accidentally short circuit the terminals
- All dented batteries should be disposed of immediately (Contact your TA AND Casey Smith (217)-300-3722; cjsmith0@illinois.edu))
- Cover all metal work surfaces with insulating material
- Batteries should be transported in non-conductive carrying trays
- Always ensure the the open circuit voltage is within the acceptable range for your battery

VI. Charging Lead-Acid Chemistry Batteries

Charging a lead-acid battery is a non-trivial task. The course staff strongly suggest that if you must build a charger, you use some kind of integrated circuit (IC) solution. Additionally, you must familiarize yourself with the battery's charge characteristic and maximum charging current. Lead-acid batteries are inherently safer than lithium chemistry batteries. While an overcharge or overdischarge will cause extreme damage to your battery, the damage will be limited to internal calcification of the plates, reducing your capacity to a fraction of what it originally was. For this reason, ***the course staff strongly suggests that you use a lead-acid type battery if your project requires a battery and is not weight or size sensitive***.

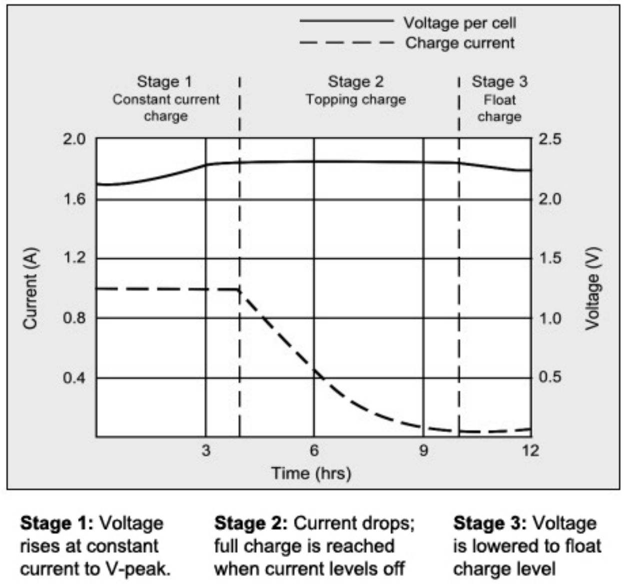

Fig. 1: The Generic Charging Characteristic of a Lead Acid Battery. Source.

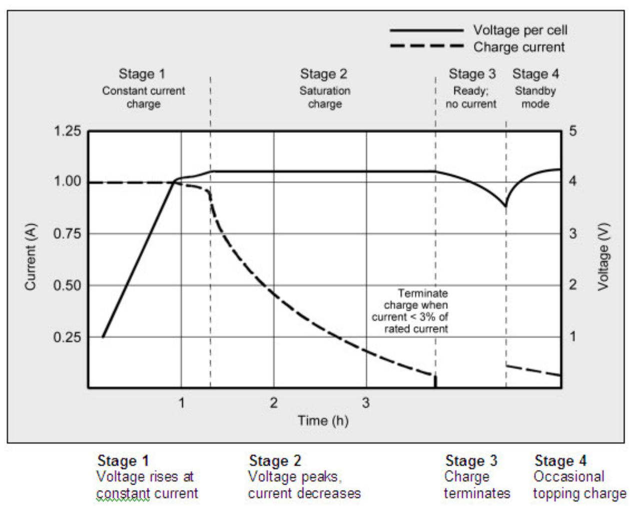

Fig. 2: The Generic Charging Characteristic of a Lithium Battery. Source.

VII. Charging Lithium Batteries

Charging a lithium battery is also a non-trivial task. The course staff continue to strongly suggest that if you must build a charger, you use some kind of IC solution. You must also familiarize yourself with the charge characteristic and maximum charge current. *Any circuitry you design that involves a lithium battery must be approved by your TA **AND** one of the power-centric TAs before they are so much as tested on a breadboard.* As an addition, it is important to note that batteries, which we can model as ideal voltage sources, charge with ideal current sources. Having an ideal current source and voltage source in parallel with the load is fine! Problems arise if we instead have two voltage sources in parallel. Any mismatch in the voltage will break KVL, which leads to a sudden rush of current from one source to the other in order to try and balance the voltages. This is a very unstable and hazardous methodology, therefore we always charge our batteries with current driving sources.

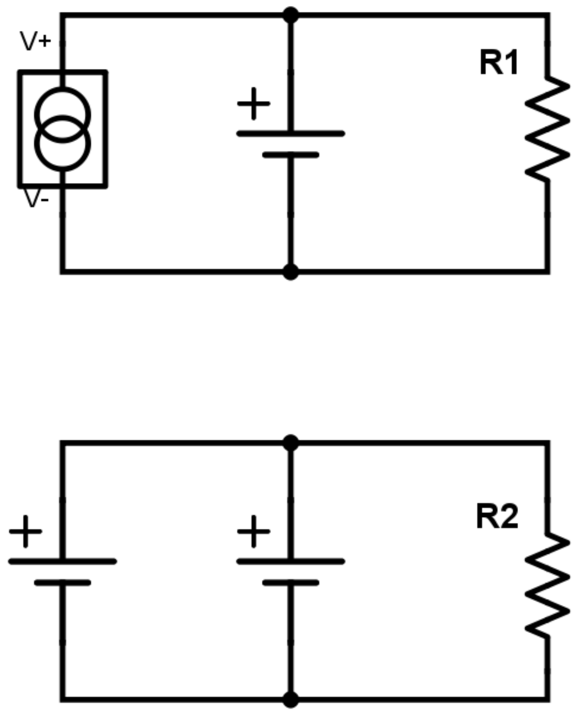

Fig. 3: Top: the proper way to think of charing your battery. Below: a risky way to do so.

VIII. Charging Suggestions and Testing Requirements

If possible, we strongly suggest purchasing and incorporating a fully featured charging suite if your project requires batteries. Those must meet rigorous safety standards in order to be sold in the USA. If this is not possible for any reason (your project is cost sensitive because it is for the developing world, you are using solar panels to charge a battery, etc.), we strongly suggest using an integrated circuit solution. As a last resort, you may attempt to design your own charging circuit. Regardless of the route you choose to take, due to the inherent danger of charging these batteries, everything must be approved by your TA and one of the power-centric TAs before you even bring your design to the breadboard. Once your charging design has been approved, its functionality must be validated to your TA in a demonstration before the battery is connected to the system. Initial testing of the charging circuit with the battery connected should be done in the senior design lab with a TA present and proper protective and emergency equipment easily accessible.

TABLE I: A Short Table of Suggested Charging ICs. (Google is Your Friend)

Chemistry	**Suggestions**
1S-2S Lithium	MAX1551/5, LM317 (see datasheet)
3S+ Lithium	LT1505, LT1512, LM317 (see datasheet)
Lead Acid	LM317 (see datasheet), LTC4020, LT3652

IX. ECE 445 PROCEDURES

1) Justify to the course staff that your project requires a battery.
2) Determine the appropriate chemistry for your project. Spill-resistant lead acid is vastly preferred.
3) Obtain safety documents:
   a) If you are using a lead-acid battery: obtain the MSDS and battery data sheet.
   b) If you are using a lithium battery: obtain additional fire safety and fire extinguisher training
4) In this order:
   a) If your project allows for it: search for a commercially available charger.
   b) Search for ICs that will perform the entire charge algorithm for you.
   c) AS A LAST RESORT: Design your own charging circuit.
5) Simulate your circuit in SPICE, even if you plan to use a charging IC.
6) Have your TA and a power-centric TA review and approve your design.
7) Build your design on a breadboard and validate functionality to your TA before attaching a battery.
8) If using a lithium battery, place it in one of the lithium battery bags whenever charging or discharging the battery.
9) To be done only in the senior design lab with a TA present and with protective and emergency equipment easily accessible: connect a battery to your circuit.
10) If your circuit behaves correctly, congratulations! You are done. If not, close is NOT close enough and you will have to return to Step 4.

If a problem occurs in your circuit:

1) Shut off power
2) Locate problem before power is restored
3) If circuit breaker is tripped, report to ece-eshop-repairs@illinois.edu to reset
4) If help is needed, contact Casey Smith ((217)-300-3722; cjsmith0@illinois.edu) or the electronics shop for assistance
5) If the situation is an emergency, **call 911**

A. *Emergency Procedures*

- If a lead acid battery spills: use the Battery Acid Spill Kit located in the back of the lab to clean the spill. Contact Casey Smith and your TA immediately.
- If a lithium battery explodes, **call 911** and evacuate the area.
- If a lithium battery ignites, **call 911** and extinguish it with either of the fire extinguishers located in the lab. They are both rated to extinguish electrical fires and should be at your bench whenever you are actively working with your batteries. Contact Casey Smith and your TA immediately.
- If a lithium battery swells, feels hot to the touch, or makes funny noises but does not ignite, keep the battery in the bag and contact Casey Smith and your TA immediately. The battery cannot be left unattended until it has been properly disposed of.

By signing below, you acknowledge that you have read this document and agree to follow the ECE 445 Course Staff's guidance regarding high capacity batteries and will complete all necessary safety training and adhere to the guidelines set forth in this document as well as additional guidelines as the course staff deems necessary.

Jihoon Lee — 1/OCT/2017

Print Name — Date

1/OCT/2017

Signature — Date

TABLE II: History of Revision

Revision	Date	Authors	Log
A	3/19/2016	Lenz	Creation
B	3/28/2016	O'Kane	Additonal Information, General Revision
C	3/29/2016	SP16 Staff	Collaborative Revisions
D	4/7/2016	Salz	General Revision

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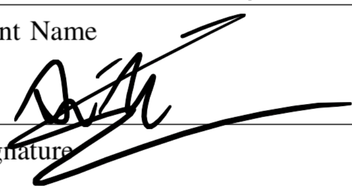
Armin Mohammadi

Print Name

12/13/17

Date



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Patrick ODonnell — 12/13/2017

Print Name — Date

Patrick Odonnell — 12/13/2017

Signature — Date

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