ECE OpenLab Automated Equipment System

ECE445 Design Document

Team 12
Aditya Bawankule
David Hickox
Alex Ortwig
Abigail Starr
TA: Dhruv Mathur
02/27/2020

Table of Contents

1 Introduction

1.1 Objective

The objective of this project is to create an automated checkout system that would allow students in the ECE OpenLab (OpenLab) to checkout and return equipment without requiring the assistance of a lab monitor, freeing the lab monitors to do more productive tasks during their shifts. The system will handle equipment checkout/return, logging of data, and validation the return of a piece of equipment. The system will consist of lockers that store equipment, unlock to allow access to the contents when necessary, a user identity authentication system (eg. HID Prox [1]) that controls access, a screen for equipment selection, and an interface that logs system use.

OpenLab equipment access control is a tedious process that consumes valuable time from paid OpenLab employees — time which could be spent more productively on improving the lab. There is a multistep process to checking out lab resources which includes recording i-card information, retrieving the piece of equipment, and ensuring that the equipment checked back in is complete. This process takes several minutes, is prone to human error, and is a distraction to the lab monitor.

1.2 Background

The OpenLab has a large backlog of projects that need completion. Due to the lab monitor work schedule it is difficult enough to achieve any meaningful progress in 2 hours, much less with 30% or more of their time going to equipment access control. The automation of the process of checking out lab equipment would allow for more uninterrupted time spent on projects for the OpenLab. Currently lab equipment is only available for checkout when a lab monitor is present; oftentimes students need to work on projects outside of these hours. Automating this system would also allow for greater utilization of the lab's resources during off-hours.

Commercial systems that can fulfill similar roles exist, such as the systems from Meridan [2], Assa Abloy [3], and Kiosk Information Systems [4], but would not be cost effective for the lab to purchase, as more money would go towards the lockers then would be saved by better utilization of the lab monitors' time. Additionally, while off the shelf systems are configurable to a certain degree [2], they do not have support for reporting the condition of items, which is a feature required by the lab since the lab kits can become disorganized or be returned incomplete. Almost all commercially available systems have metal doors but our lockers can be configured to have transparent locker doors when required by the lab. For our purposes, having the modularity in lockers, and collecting data that will be useful on a day to day basis for the lab monitors, and the reduction in cost is ultimately more important than buying a premade system.

1.3 High-Level Requirements List

- The system must be able to identify whether returned equipment is within the equipment's target weight range.

- The system must validate a student's identity, check out an available item of their choice to them, associate the checkout/check in with their student ID, and make this data available to lab monitors through an SD card.
- The system must lock and unlock lockers to allow access to the stored equipment when appropriate. Additionally, it should be locked in the case of power loss.

1.4 Pictorial Representation

Figure 1. Pictorial representation. This shows a user opening a locker after interacting with the keypad system.

2 Design

The hardware portion of the system consists of a set of lockers with a checkout interface and user identity authentication system attached. The lockers will be locked/unlocked by the system when appropriate using magnetic locks. Additionally, each locker will be capable of measuring the weight of its contents in order to ensure that the materials were properly returned.

The software side will handle authenticating users for checkout/return, sending the commands to lock/unlock lockers using CAN (Controller Area Network) as described in ISO 11898-1:2015 [5], and logging all checkouts and returns. The physical interface on the device will allow users to select equipment for checkout and to report missing materials.

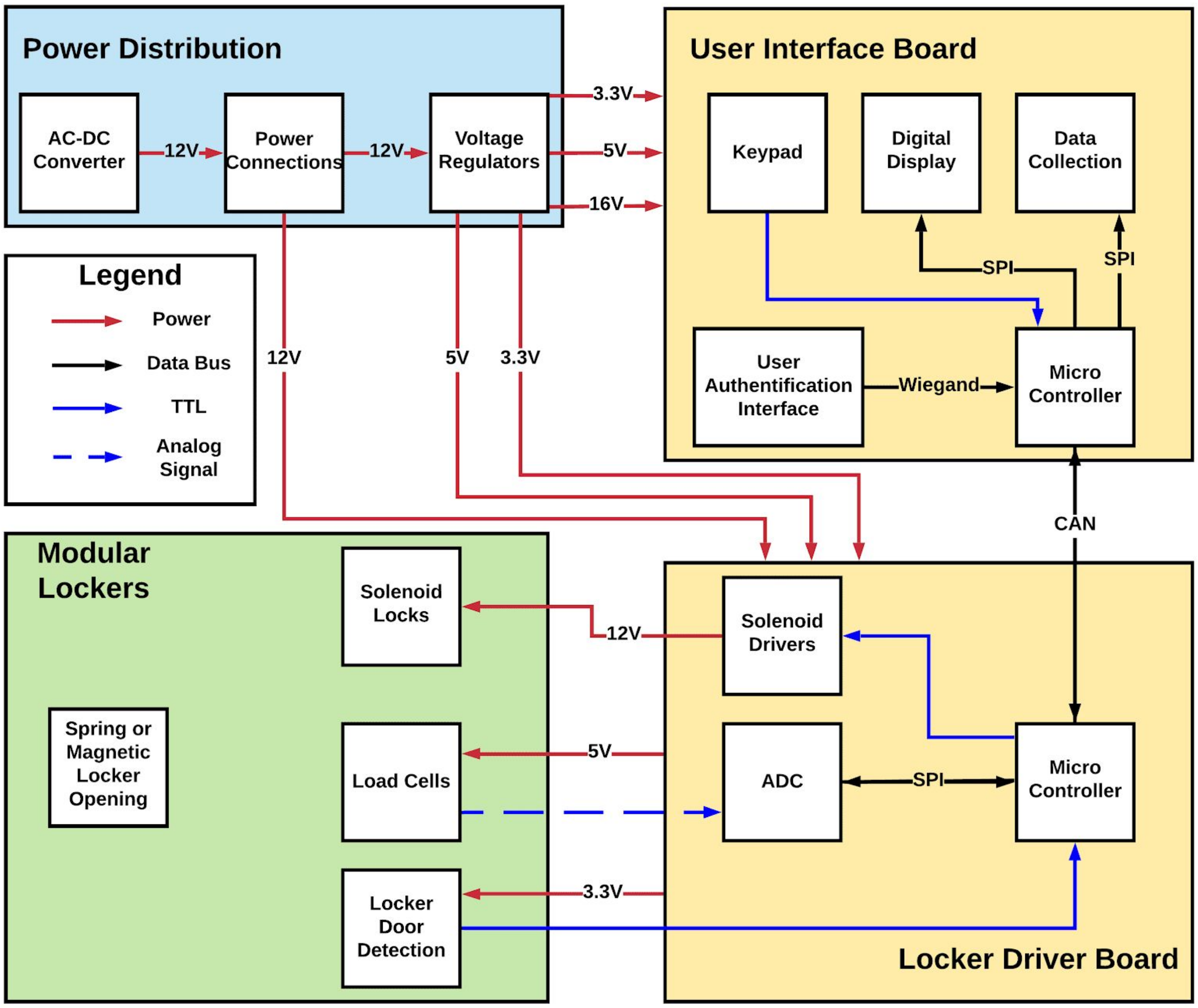

Figure 2. Block Diagram This shows the interactions between systems for our project. User Interface, Locker Driver, and Power Distribution will all have their own PCBs, while Modular Lockers is a physical system. In addition to PCB and mechanical systems, the Locker Driver Board and the User Interface Board will also have software components to them.

2.1 Physical Design

Figure 3. Locker Dimensions. These are the lockers that have been ordered from ULINE [6] that will be used for the system, each locker containing one item.

There needs to be space in the locker for the solenoids and the electronics. Extra space can be created on one of the sides of the lockers to have a spot for the solenoid and the electronics, which will be protected from the user by a secondary wall, so the user cannot tamper with the electronics while the locker door is open.

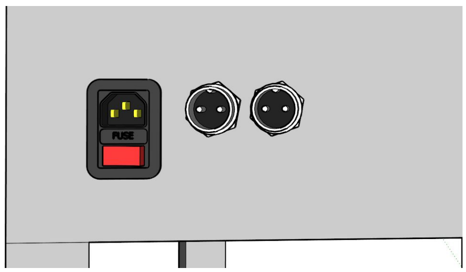

Figure 4. Locker false back connectors

This is a depiction of the CAN and power ports on the back of each locker such that lockers can be daisy chained to each other.

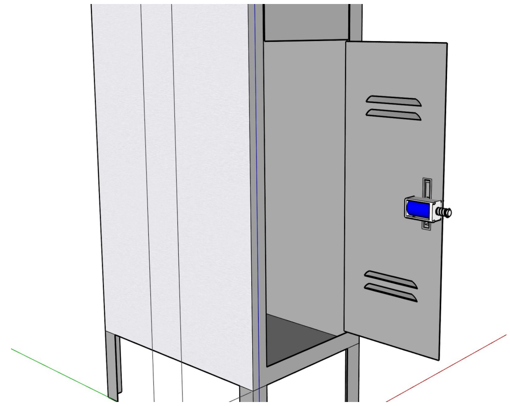

Figure 5. Locker Solenoid Mounting

This is a depiction of the location of the solenoid on the locker door.

2.2 Power Distribution

2.2.1 AC-DC Converter

The AC-DC converter will be responsible for providing the locker system with a 12V DC rail from North American mains AC. The converter is one of the most important pieces of the design due to its effects on safety and system stability. The converter will be required to maintain an output of 2A for 5 minutes in case of a lock driver failure.

Requirements	Verification
1. Converter accepts an input voltage range of 114 to 126 V_{rms} while maintaining an output of 12V DC within a range of +\-1V and sustaining a minimum of 2A continuous output for 5 minutes. 2. Converter is UL certified [7].	1. a. Use a variac to supply the converter with 114 and 126 Vrms from mains AC. b. Connect the DC output of the converter to an electric load and verify an output of 2A for 5 minutes is capable at both voltage inputs. c. Connect the DC output of the

	converter to a resistive load and verify the converter outputs 12V DC +/- 1V. 2. a. Verify that the converter has been certified by Underwriters Laboratories by the proper markings on the converter [7].

2.2.2 Voltage Regulators

The voltage regulators will be boost and buck converters that step up and down the 12V rail to 3.3V, 5V, and 16V in order to power the microcontrollers, CAN bus [5], digital display, and authentication system. As with the other power systems in this design, these regulators will be operating 24/7 and as such will need to be designed with longevity and safety in mind. Their stability will also be crucial in maintaining stable power for the other electronics in the system.

The buck converter will utilize the LM5160 [8] from Texas Instruments to create 3.3V and 5V rails. The buck converter will see a minimum load of 30mA (the nominal measured current draw from an idle STM32F446RET [9]) and so the design will target an inductor ripple current of 30mA pk-pk. Using a switching frequency of 500kHz the calculated inductor size will be 220uH according to [eq.1] and accounting for standardizing the value.

$$L = \frac{Vout*(1-\frac{Vout}{Vin})*\frac{1}{fsw}}{Iripple} \qquad \text{eq.1}$$

The output capacitance to achieve a tolerance of +/- 0.2V can then be calculated using [eq.2] which yields a capacitance value of 37.5nF. The actual capacitance will be in the uF range to allow for transient response.

$$C = \frac{Iripple*\frac{1}{fsw}}{8*Vripple} \qquad \text{eq.2}$$

The boost converter will utilize TPS61170 [10] from Texas Instruments to create the 16V rail necessary for the digital display. The display has an average current draw of 40mA [10] so the design will target an inductor current ripple of 40mA pk-pk. Given the switching frequency of 1.2MHz, the required inductor value can then be calculated as 62.5uH using [eq.3]. This will be increased to 68uH for standardized values.

$$L = \frac{Vin*(1-\frac{Vin}{Vout})*\frac{1}{fsw}}{Iripple} \qquad \text{eq.3}$$

The output capacitance for the boost converter can be calculated using [eq.4] from the TPS61170 datasheet [10] as 41.6nF which will be increased to the uF range to account for transients.

$$C = \frac{(Vout - Vin)Iout}{Vout * fsw * Vripple} \qquad \text{eq.4}$$

Requirements	Verification
1. Buck converters accept an input voltage range of 11V to 13V DC and convert it to a choice of 3.3V or 5V with a tolerance of +/-0.2V. 2. Boost converters accept and input voltage range of 11V to 13V DC and converts it to 16V +/-0.2V. 3. Voltage regulators can sustain an output of at least 0.5A for 24 hours.	1. a. Provide the buck converter with 11V and 13V DC and verify the capability to output 3.3V and 5V within tolerance under a load of 1A. 2. a. Provide the boost converter with 11V and 13V DC and verify the capability to output 16V within tolerance under a load of 1A. 3. a. Connect one of each voltage regulators to an electronic load and verify that the regulator can sustain a 0.5A output at the 3.3V, 5V, and 16V for at least 24 hours.

2.2.3 Power/Data Connections

We need to have connectors between sets of lockers that can survive 10 mating cycles, with locking connections to ensure that they will not come apart with regular use. Because the lockers are modular, we need to have a system where the power connections are not permanent and are relatively protected.

Requirements	Verification
1. Connectors must survive 10 mating cycles. 2. The connectors must be rated for the full current draw for any individual system (for their respective signals).	1. The connectors are cycled 10 times then all following tests are performed a. The connectors must stay connected once plugged in in the specified manner under no physical load b. The connectors must maintain enough conductivity to allow the

	system to function as intended (eg. CAN line noise increases but still works, this test passes) c. Ensure that one, randomly chosen, locker can function 2. a. Allow each pin to sink the maximum signal current specified by our protocol documentation for 5 minutes ensuring continuity.

2.3 User Interface

2.3.1 Keypad

This will be for the standard user input, to control which locker the user wishes to open. This will communicate with the microcontroller, which will then process the data. The keypad will be a purchased matrix style keypad with at least 12 keys or touch locations. It is connected to the main microcontroller as seen in Figure 15 through Transistor-Transistor Logic (TTL) logic.

Requirements	Verification
1. Key pad must have at least 12 keys with distinct output	1. a. Physically count the keys to ensure at least 12 are easily found b. Connect the microcontroller to the computer c. Ensure that each column and row register as independent through the GPIO by clicking on keys from each row and column and making sure that a logic level high appears in this system d. Ensure that there are at least 12 distinct combinations of rows and columns by pressing all of the keys and having a different combination of row and column appear for each one, thus being able to distinguish between each of the 12 keys

2.3.2 Digital Display

The Digital Display will act as a visual interface between the user and the main system controller. The screen will display prompts and information to the user in order to ensure self-explanatory and easy operation of the locker system, as well as button inputs from the keypad. The display needs to be at least 16x2 characters (or 80x16 pixels).

The LCD we have chosen, the NHD-C0216CiZ-FSW-FBW-3V3 [11], requires 3V instead of 3.3V. For that reason, there will be a separate Low Drop Out (LDO) linear regulator that will supply power to this. This unit is expected to draw 25mA and there is a .3V difference, so the total power dissipated over this is 7.5mW [eq.5]

$$P = I * V = .3V * 25mA = 7.5mW \qquad \text{eq.5}$$

The linear regulator for this system will be on the same board because the power dissipation is low enough that heat is not going to be an issue for the board, and because it is not a switching regulator so noise will not be an issue.

Requirements	**Verification**
1. Digital Display needs to be at least 80x16 pixels	1. a. Make/find a font that is 8x16 pixels b. Connect LCD to the microcontroller c. Using the microcontroller, write 32 characters to the screen, in two rows of 16, and make sure this is readable from a 1ft distance

2.3.3 Microcontrollers

The microcontroller will control the locking/unlocking of the lockers, take input from the keypad, and display the status on the screen. We have chosen an NXP i.MX rt 1064 [12] and an STM32F446RET [9], both with custom PCB. The master microcontroller will be connected to the keypad and Digital Display, and will send information over CAN [5] to the microcontrollers in each locker or locker assembly that will control the locking and unlocking. The master microcontroller we will be designing for is the NXP rt 1064 because it has the necessary GPIO [12] to accommodate all of our other block requirements, such as data logging to an SD card, RFID reading, and an LCD screen, in addition to our stretch goals like ethernet support, USB support, and audio aid. The STM32 chip was chosen for the slave boards because it is easier to design and program and it is cheaper. The slave board will be connected to each locker system

Requirements	Verification
1. Microcontrollers need to be programmable	1. a. Connect the microcontroller JTAG ports to the LPC Link programmer b. Write and download a program that flashes an LED to the microcontroller c. Verify that the LED flashes to ensure that the program is downloaded correctly

2.3.4 Data Collection

Data needs to be collected and logged so the OpenLab can have a record of who checks out equipment. Every interaction with the lockers will be logged into flash storage, so the lab monitors can access the logs in the case that equipment is missing or broken.

Requirements	Verification
1. Flash storage needs to be able to written to and read 2. Needs retain data in case of power loss	1. a. Using the microcontroller, write several checkout/check-in messages to the flash memory b. Again using the microcontroller, read the messages written and verify they are correct 2. a. After performing the above procedures, unplug the microcontroller and flash memory from all power sources, and then plug them back in b. Read the flash memory with the microcontroller and verify the messages written earlier were retained

2.3.5 User Identity Authentication

A user identity authentication system will be attached to the main console of the lockers to identify the user and log the information about who is checking out the equipment. This will need to have at least fifteen unique users at any time, because that is the number of lab monitors that are staffed at any one time.

Requirements	Verification
1. Can accurately identify the user out of a minimum of fifteen users, without mistakes.	1. a. Add 15 users to the system b. Connect RFID system to the computer c. Try all of their i-cards in a random order and print their data to the screen d. Ensure that each time an i-card is scanned, the data is correct

2.4 Hardware Subsystems

2.4.1 Modular Lockers

A goal of this project is to be able to scale to any number of lockers in the system, so in order to do that, having modular lockers that are independent of each other is important. Each locker needs to be its own separate unit, with enough electronics to function on its own. Therefore, each locker will have its own microcontroller that can connect to the master CAN bus [5], and therefore be able to send and receive data from the master microcontroller.

Requirements	Verification
1. Can be connected to the system in any order one locker at a time on first boot install and communicate without any custom MCU code (eg setting an address in mcu code so they connect in only one order). 2. Can support more than 1 locker system connected at a time	1. a. Shuffle 2 or more locker control boards with factory code, plug them one at a time in and test that configuration works successfully. (control boards may be unplugged before the next is programmed) 2. a. This should be evident after the first test but in the case that we have the funds to produce more

	than 2 locker control boards hook up more now and test that multiple function

2.4.2 Magnetic Locker Opening

When a locker is open we need a way for the user to be able to open the door. The locker will either have a handle and/or a spring/magnetic system to pop the door open when the solenoid is triggered.

Requirements	Verification
1. Can push open a locker door at least 1 inch past the solenoid lock bolt.	1. a. With the locker shut and latched, send a command to the locker control board to open the locker. b. Let the locker door swing open unobstructed. c. Measure clearance of the locker door past the solenoid lock bolt and ensure it is greater than 1 inch.

2.4.3 Solenoid Locks

As a security measure, the lockers need to remain locked if the power is off.Solenoid locks are a great way to accomplish this because when they receive current they will open, and otherwise remain in the locked position. When a signal is sent over CAN to open the locker, it will unlock for 2.5 seconds and then lock again. Each lock will draw a maximum of 12 W from the 12V rail, and only one lock will be actuated at a time. Therefore as we scale or develop for new configurations, there is no risk of exceeding the current limit of the AC-DC converter [10] due to simultaneous locker openings.

Requirements	Verification
1. Solenoid lock can remain retracted for a minimum of 2.5 seconds. 2. Solenoid lock draws less than 12W of power when retracting.	1. a. Apply 12V DC to the solenoid lock utilizing a power supply, and maintain power for 5 seconds ensuring that the bolt remains retracted for the duration of the 5 seconds. 2.

	a. Apply 12V DC to the solenoid lock utilizing a power supply, and ensure that the power output of the power supply is lower than 12W.

2.4.4 Scale and Weight Measurement

Each locker will have a beam-type load cell [13] that will be used to measure the weight of the equipment inside the locker. The data from the load cell will be interpreted by the locker's microcontroller to determine a weight, and compare it to the expected weight of that specific locker. The load cell will have to support a weight of at least 2kg and be accurate within 100 grams.

Requirements	**Verification**
1. The load cell must support greater than 2kg. 2. The load cell must be accurate within 100 grams.	1. a. Apply a load of 2.5kg to the load cell. b. Verify that the load cell shows no signs of structural damage. c. Verify that the mv/V relationship of the load cell is still accurate using a power supply and digital multimeter. 2. a. Apply known loads of 0.1kg, 1kg, and 2kg to the load cell. b. Verify the weight measurements are accurate to within 100 grams of the utilized load.

2.4.5 Locker Door Detection

Each locker will have a momentary switch on it, similar to an endstop detection switch. It will be simple closure detection: if the switch is closed, the circuit is complete, and the signal sent to the microcontroller will flag that the door is closed. This will be a component in determining if the check out/in is complete. If an individual goes to return a piece of equipment, but does not close the locker door, then the check out/in will be flagged as incomplete.

Requirements	Verification
1. The momentary switch must actuate when the locker door is fully shut.	1. a. Test the continuity of the momentary switch when the locker door is open and closed. b. Ensure that the switch only has continuity when the door is fully shut and locked.

2.4.6 ADC (Analog to Digital Converter)

The analog to digital converter will be responsible for taking analog voltage readings from the load cells and sending their values digitally to the microcontroller. The load cells will output a differential voltage of 0-5mV, and therefore an ADC with programmable gain will be required to make meaningful measurements. Additionally, the ADC should have a resolution of at least 12 bits and at least 8 channels to allow for the reading of 8 lockers on each Locker Control Board.

The ADC found that fits these parameters is the ADS131M08 [14] by Texas Instruments. The ADC meets or fulfills all requirements with programmable gain, 24 bit resolution, and 8 differential channels[14].

Requirements	Verification
1. The ADC must be able to communicate with the microcontroller. 2. The ADC must be able to make measurements with 10% accuracy from 0V to 5mV. 3. The ADC must be able to apply programmable gain to the measurement.	1. a. Apply a known voltage to the differential input of one of the ADC channels. b. Have the microcontroller request the voltage measurement from the ADC. c. Verify the returned voltage measurement. 2. a. Apply voltages ranging from 0 to 5mV to one channel of the ADC. b. Read voltage measurement from the microcontroller. c. Verify the measured voltage is within 10% of the applied voltage. 3. a. Apply a known voltage to the differential input of one of the

	ADC channels. b. Program the ADC to apply a gain to its measurement. c. Read the voltage measurement from the microcontroller and verify the gain was applied.

2.4.7 Solenoid Drivers

The solenoid drivers are responsible for actuating the solenoid locks. The drivers will utilize an N-channel MOSFET for low-side driving of the solenoid lock, and a low side gate driver to interface between the microcontroller and the MOSFET. A flyback diode will be used to ensure the inductance flyback does not damage the MOSFET.

The MOSFET should have a voltage V_{ds} rating of 2x12V=24V and a current I_d rating of 2x1A=2A giving a safety factor of 2 in order to ensure durability of the circuit.

The MOSFET chosen is the IRLZ44N [15], which exceeds our V_{ds} and I_d ratings and is readily available as a lab resource. If our design were to go into mass production, the TO-220 package would allow for a cheaper alternative to be used.

The gate driver chosen is the IRS44273L [16], which is a low side gate driver that can sink/source 1.5A, accepts a 3.3V capable TTL input, and is rated for up to 20V.

Requirements	**Verification**
1. The driver can actuate the solenoid lock utilizing a 3.3V signal. 2. The driver is capable of driving the solenoid lock for at least 2.5 seconds.	1. a. Connect a solenoid lock to the driver circuitry b. Apply 3.3V to the gate driver input pin and verify the lock retracts. c. Remove the 3.3V from the gate driver input pin and verify the lock extends. 2. a. Connect a solenoid lock to the driver circuitry b. Apply 3.3V to the gate driver input pin for 5 seconds and verify the lock retracts for the duration of the 5 seconds.

2.5 Risk Analysis

The greatest risk to the project is the implementation of the CAN network [7]. Due to the requirement of "modularity" this requires that all of the locker modules be flashed with the same firmware but be able to be plugged into an existing system and work and be identifiable from all the other lockers.

One option is to daisy chain CAN networks allowing each locker to have a master on one side and a slave on the next. This is similar to how the popular WS2812 LEDs work [17]. The issue with this is that all the data that is going to any locker has to pass through each locker on its path. This increases latency, hardware implementation complexity, and software complexity due to needing universal routing code.

Another option is a single CAN bus with each new device reporting as the lowest priority device This allows it to be configured on first install but makes it difficult to allow multiple new installations at the same time due to arbitration issues.

The last method is to have all the devices use the same priorities for messages and start the message with the device ID allowing it to arbitrate and identify itself with its device ID from NXP which are all guaranteed unique (similar to a MAC address). This option wastes a significant amount of data in communications, lowering the data rate and increasing overhead.

The reason this is the largest risk is because every method we know of has serious issues and we need to develop a method that does not have these weaknesses. We have ideas of how to design for most of the other subsystems in this project, but for the CAN system, we have to make some design decisions that will seriously affect both the hardware and the software of the system.

2.6 Schematics

2.6.1 Locker Control Board

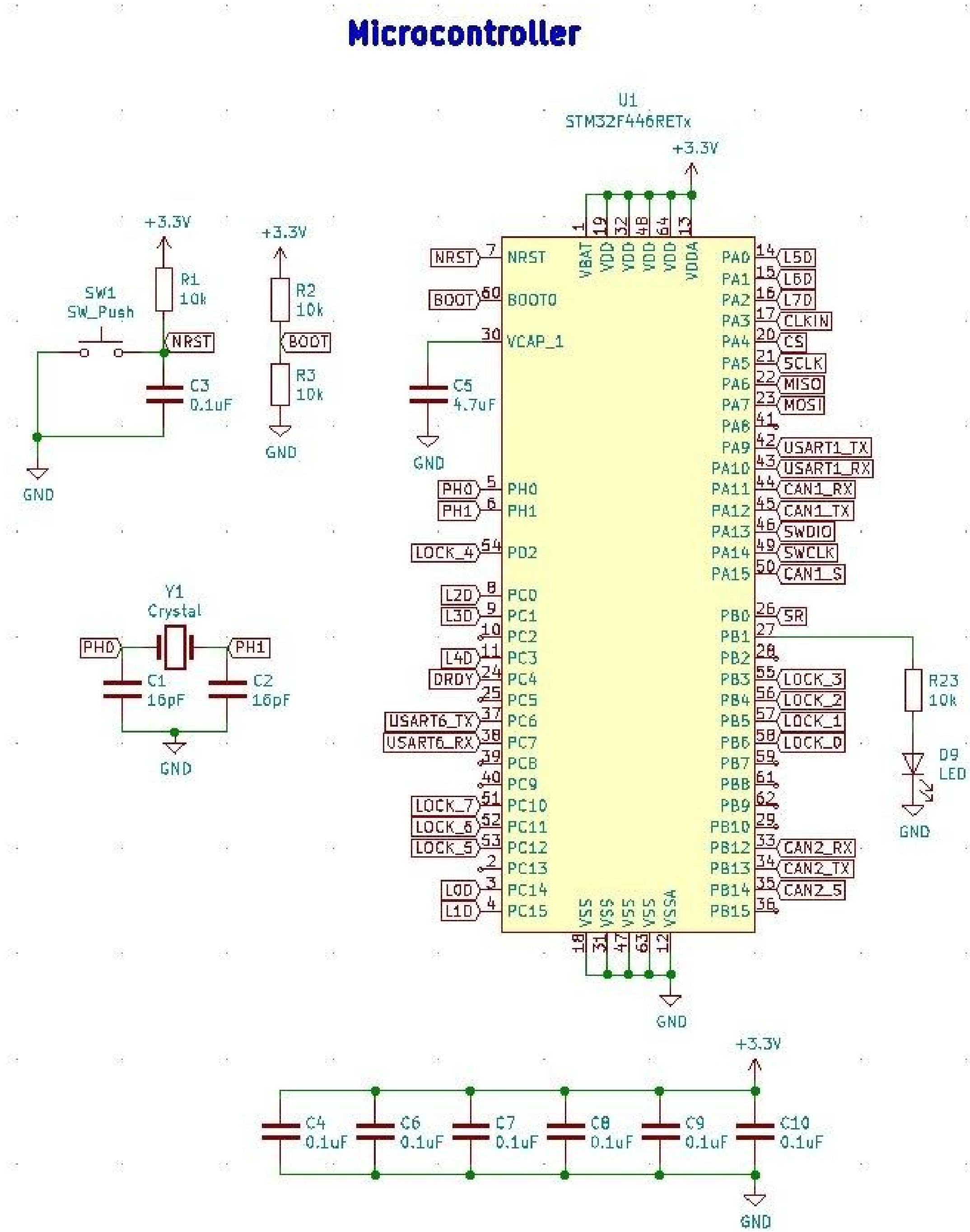

Figure 6. The STM32F446RETx microcontroller [11] will receive CAN messages from the user interface board and oversee the locker-control portions of kit check-ins and check-outs. Pictured here is the STM32 with its pinout, global labels, and peripherals necessary to the microcontroller.

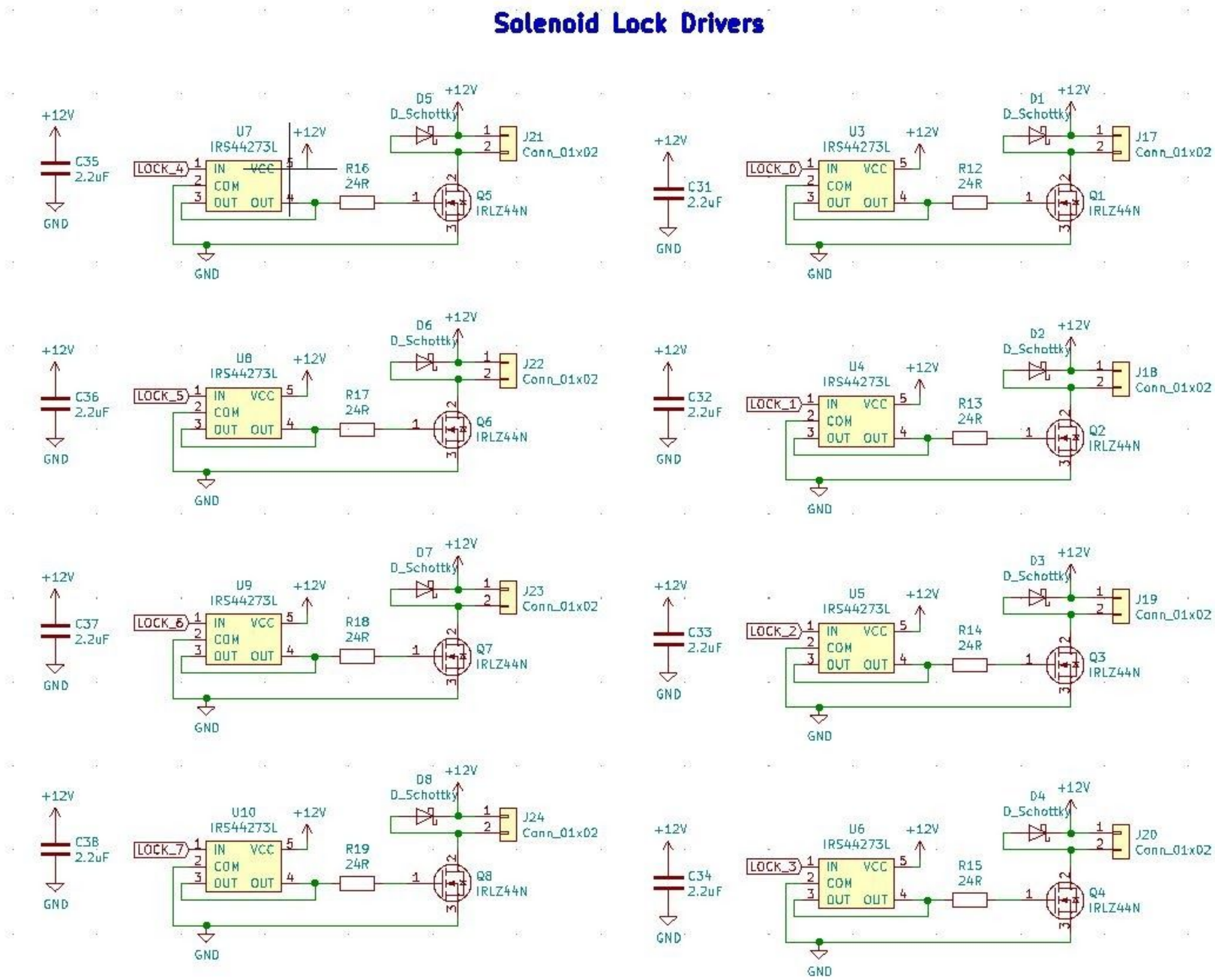

Figure 7. The Solenoid lock drivers consist of a low side driving circuit that allows for current to pass through the solenoid and thereby retracting the lock. The circuit consists of an N-channel MOSFET, a low-side gate driver, and a flyback diode to account for inductive flyback. The circuit is operated by TTL sent from the microcontroller where a logic high applied to the input pin of the gate driver turns on the MOSFET and thereby retracts the lock.

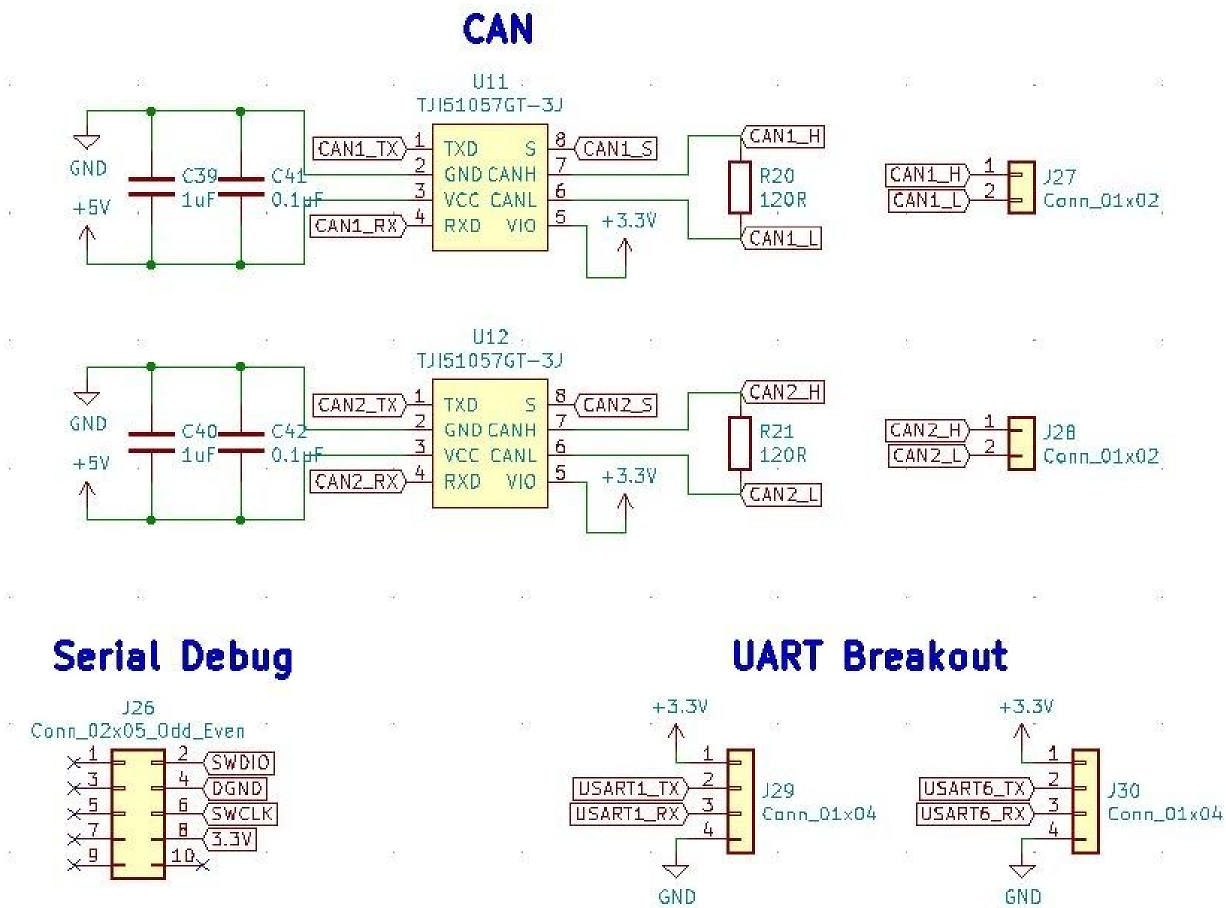

Figure 8. There are three major data buses on the locker control board: CAN [5], UART, and a Serial debugger connection based on JTAG [18]. The board supports connection to two CAN busses which the microcontroller interfaces with using the transceivers U11 and U12. The UART breakouts are a redundancy in case extra features are added to the locker system in the future. The serial debugging connection is used to program and debug the STM32 microcontroller.

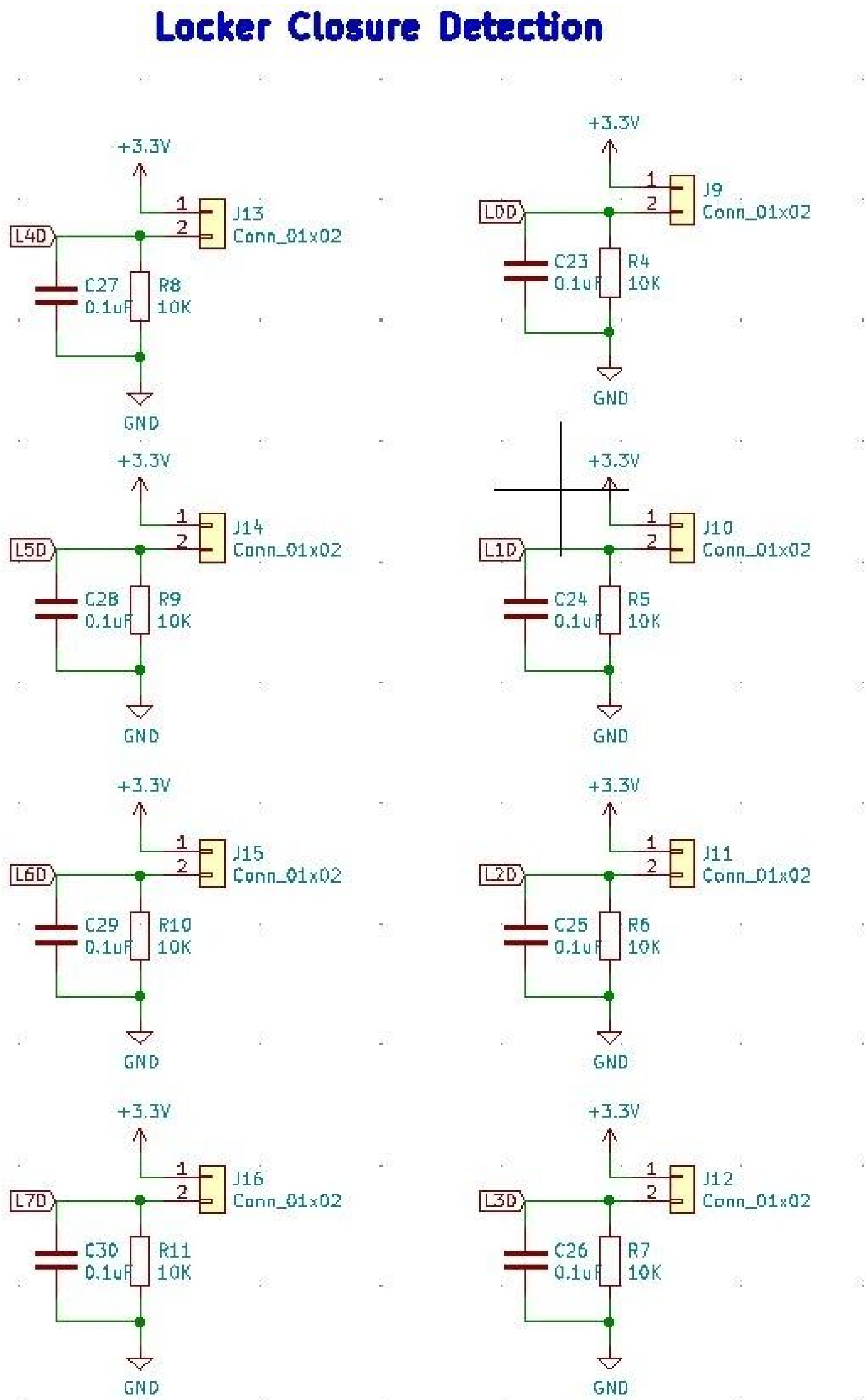

Figure 9. The locker closure detection circuit is based on the use of a momentary switch which applies a 3.3V signal to a GPIO pin of the microcontroller when the door is shut and pulls the pin to ground when the door is open. A 0.1uF capacitor provides hardware debouncing for the momentary switches.

2.6.2 User Interface Board

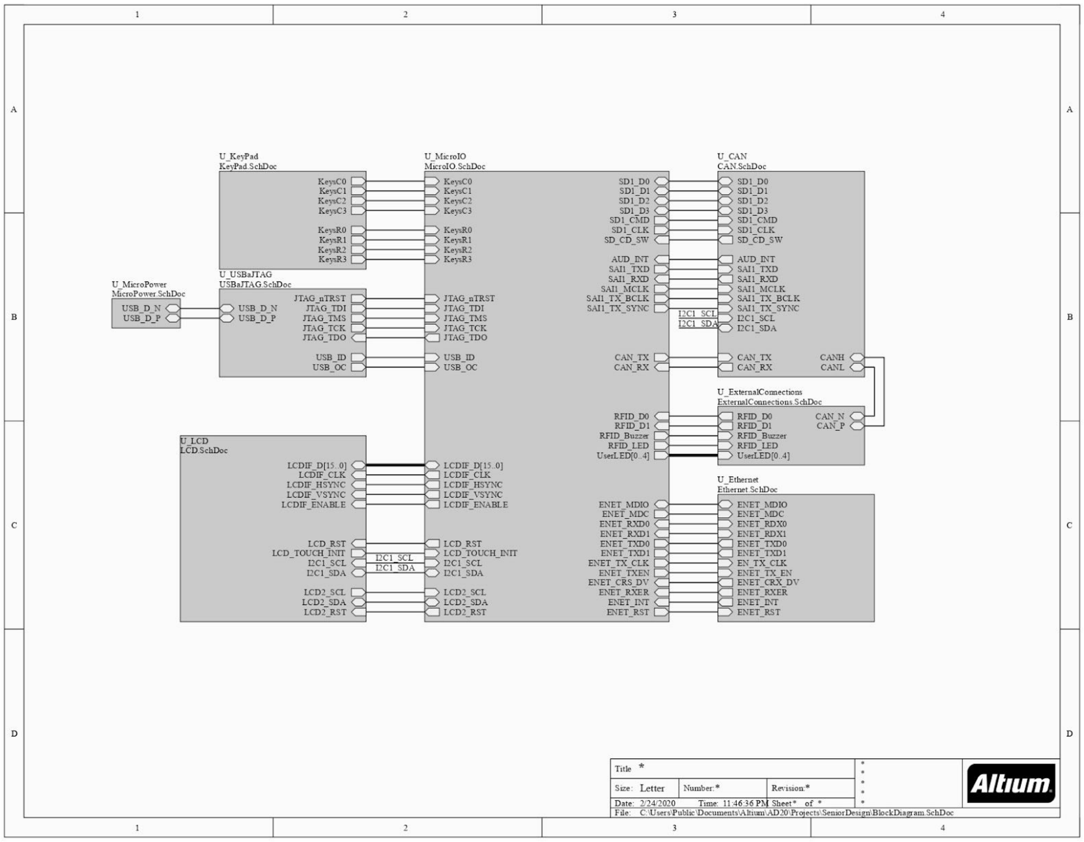

Figure 10. Visual diagram for the connection between sheets for Main User Interface PCB. Each of the following sheets of schematics are represented as a box, with only their off-sheet ports showing.

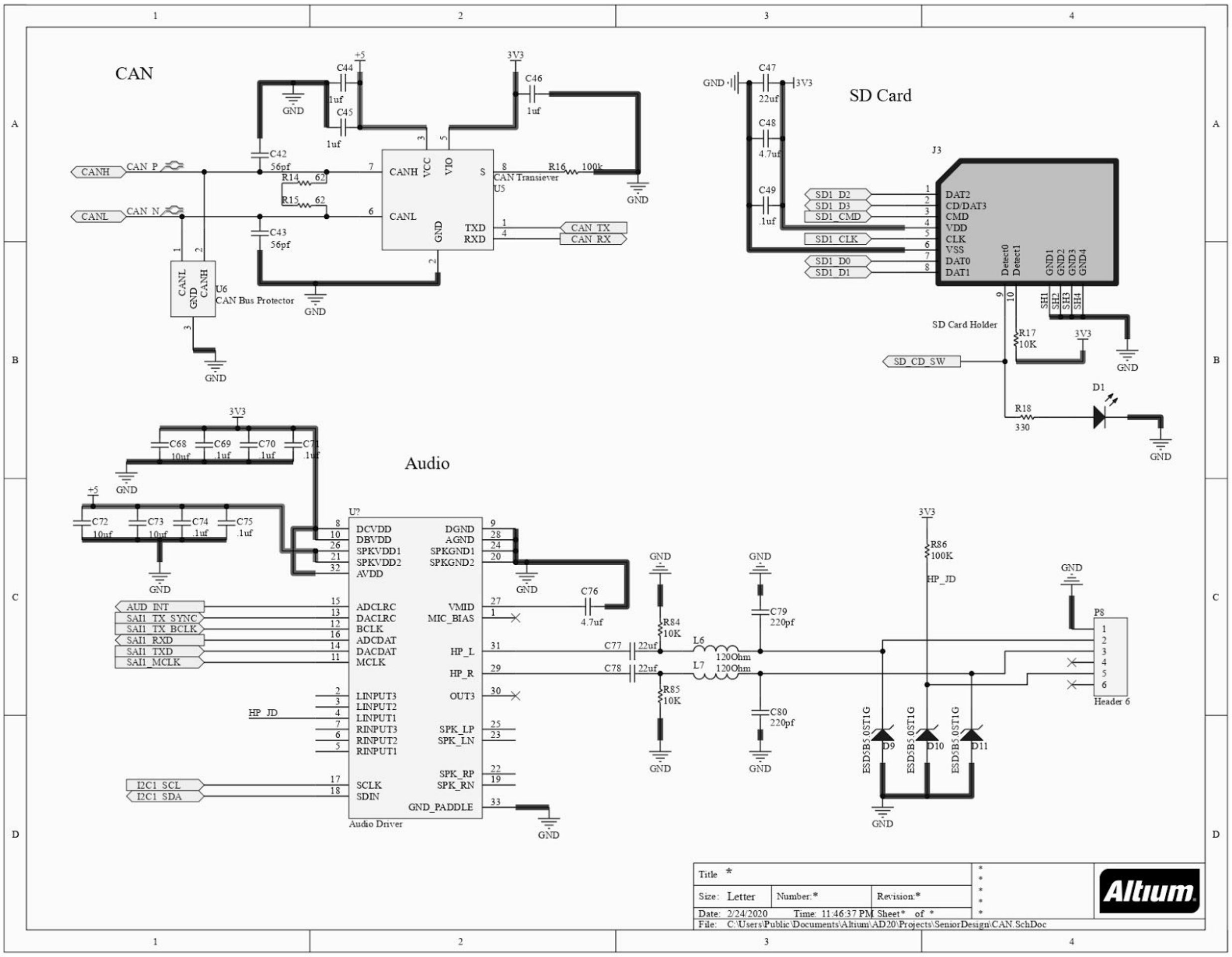

Figure 11. Circuit Schematics for the CAN bus, SD card, and audio driver on the main User Interface PCB. The audio driver seen here is a stretch goal, but included in this PCB in case there is enough time remaining to develop this system. The SD card holder is a standard microSD card, chosen for its small size. The CAN bus chip that has been chosen is the TJA1057GT/3J [19], and it has been chosen for its automotive rating and speed.

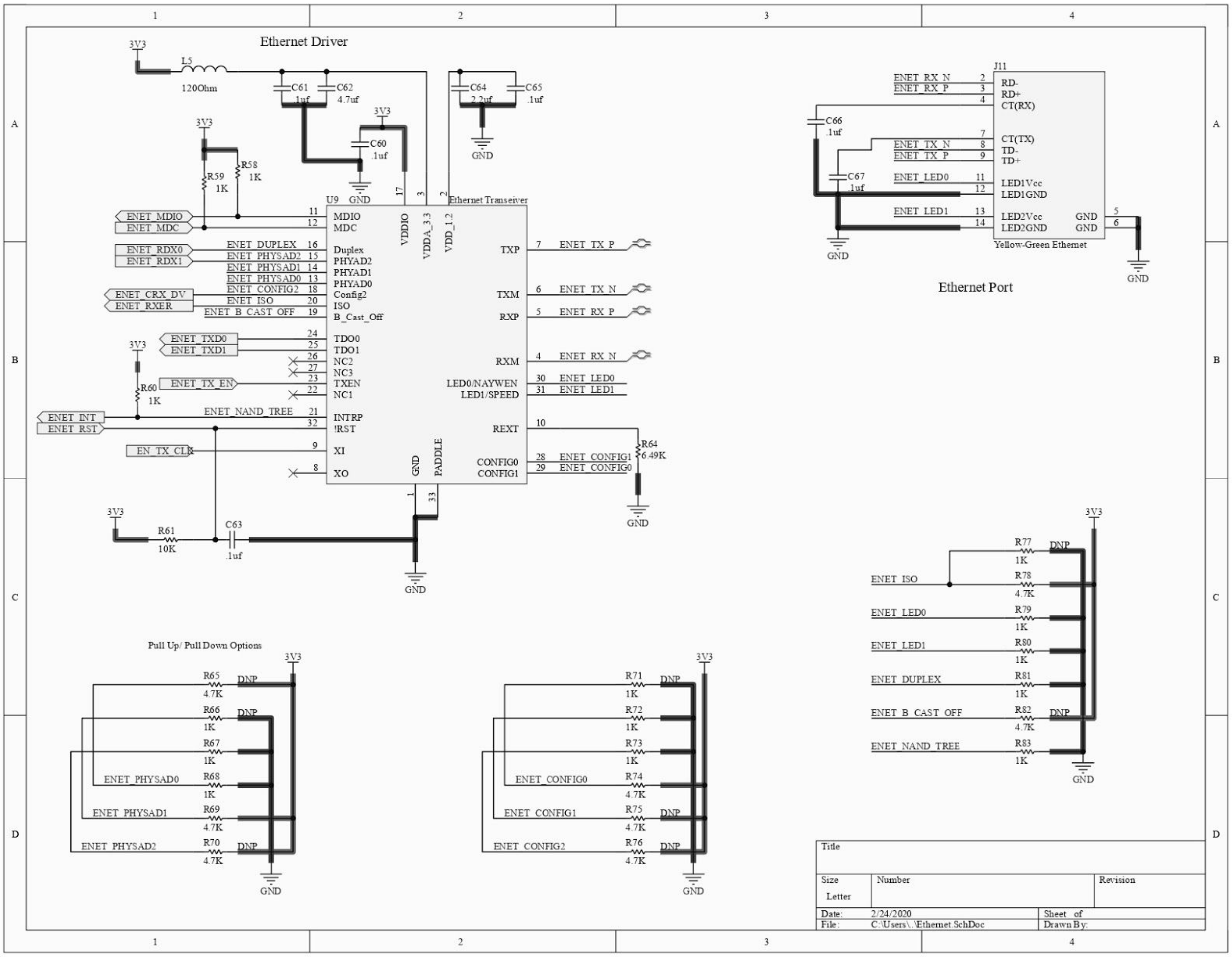

Figure 12. Ethernet schematics for the Main User Interface PCB. This includes the ethernet port, ethernet driver, and the different configurations that are configured through resistors. Ethernet is a stretch goal, so it will be put on the board and tested if time allows.

External Connections:

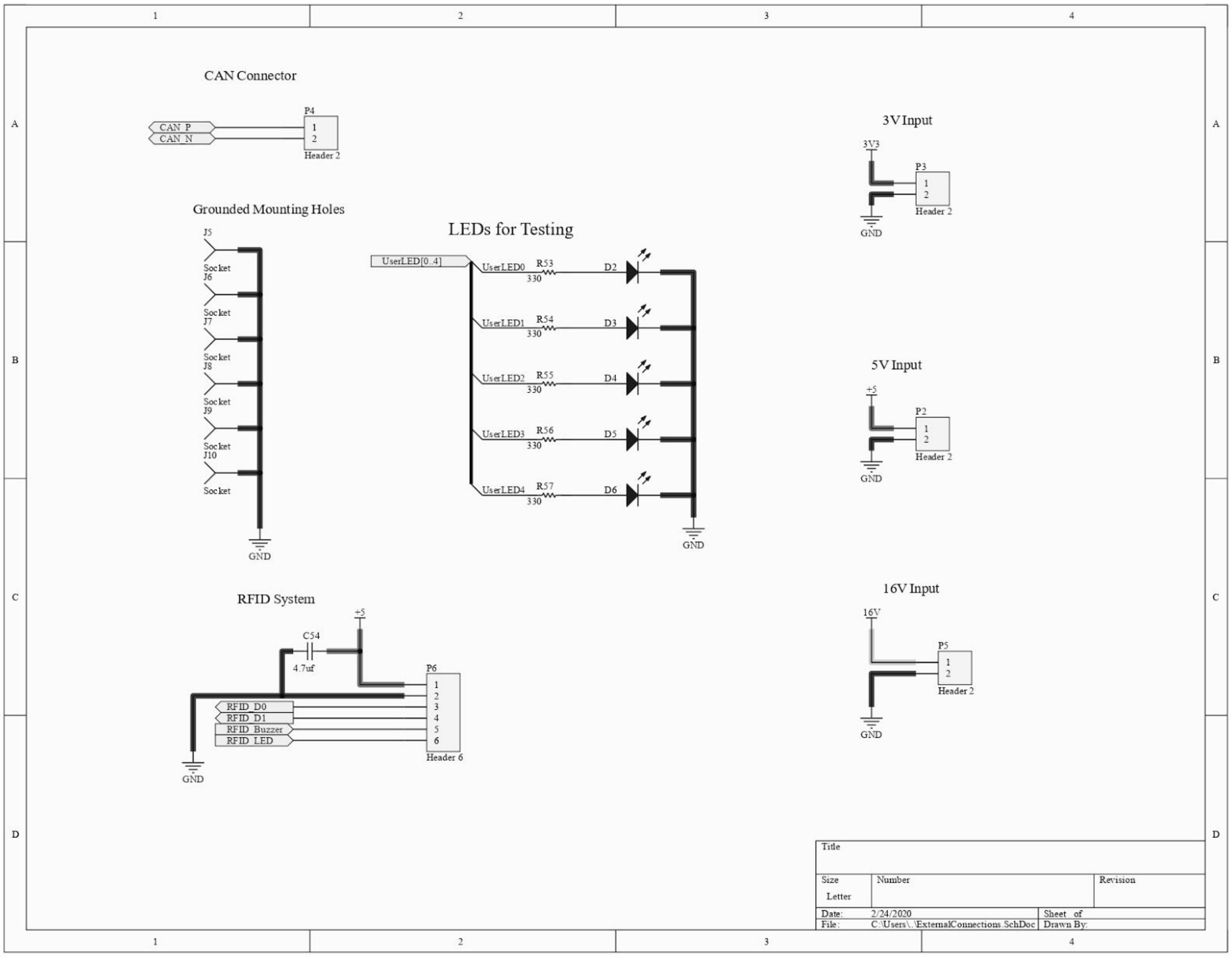

Figure 13. External Connection schematics for the main User Interface PCB. This includes connectors for the 3.3, 5, and 16V rails that are going to be generated on off board buck/boost converters, the CAN Connection, and for the PROX reader. Additionally, there are 5 LED's that we can use for testing or signaling if it is decided that that is needed in the future. Each of the power connectors use standard KK Connectors to ensure that the power connections are tight. For the RFID connection, there will be .1" female headers to solder the naked terminals given by the HID Prox Plus [1].

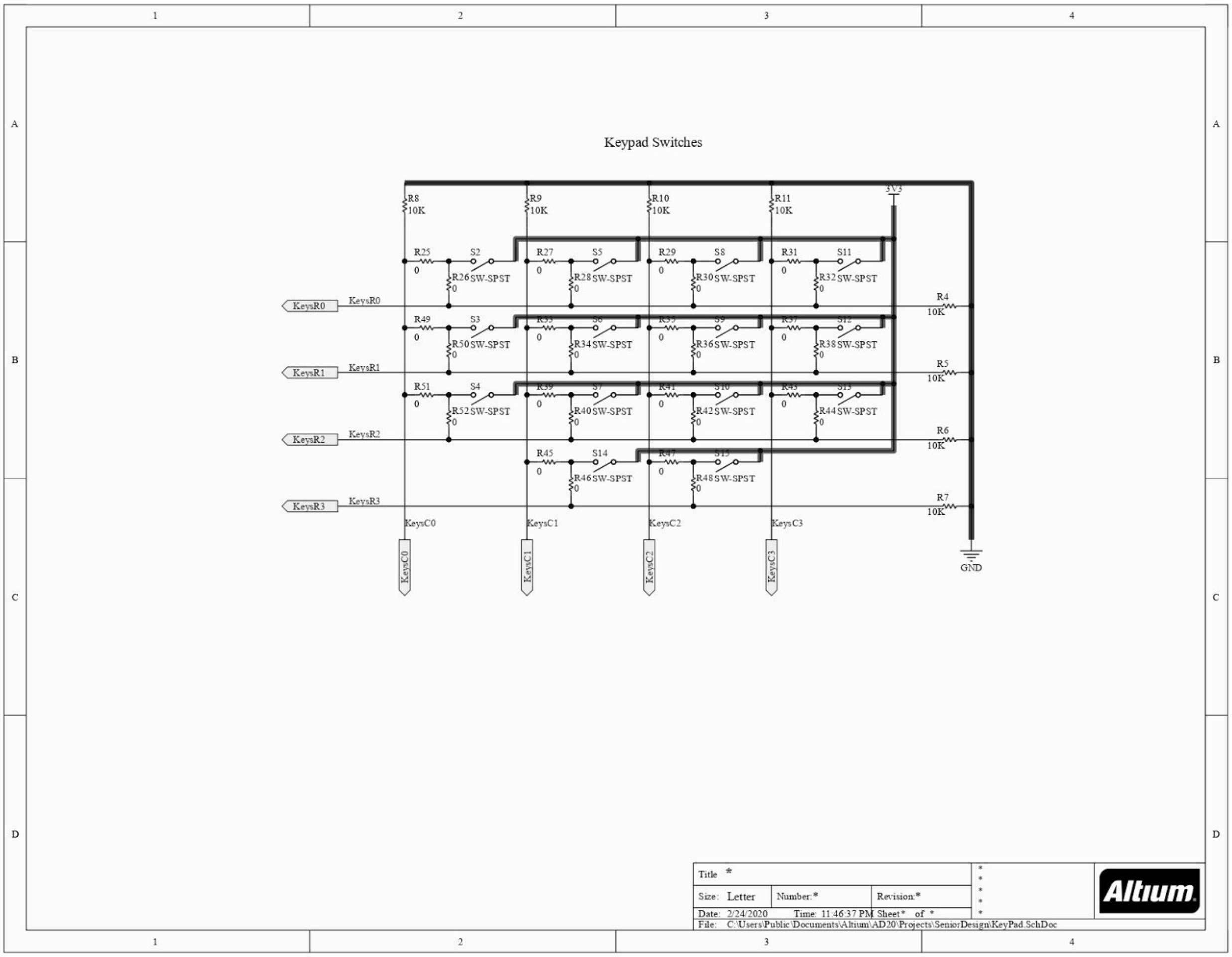

Figure 14. Keypad Schematic for the Main User Interface PCB. This is designed to have 14 switches: 0-9, backspace, enter, checkout, and check in, however, only 12 switches are required for our block requirement, the check out and check in buttons can be achieved without their own buttons. Standard cherry MX clear keys have been chosen for their durability and tactile feel.

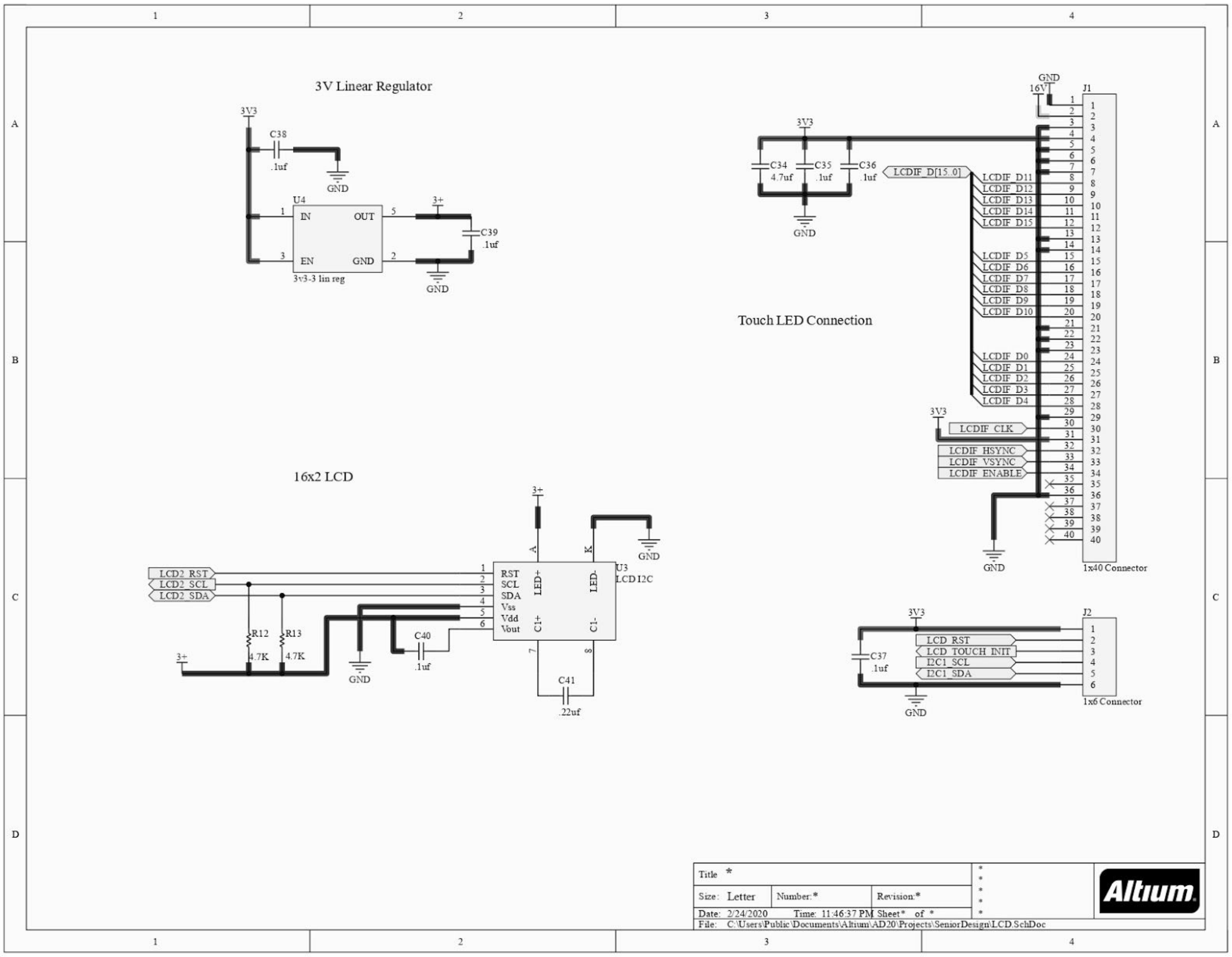

Figure 15. LCD Connector Schematics for the main User Interface PCB. This has two connectors, one for a standard 16x2 character LCD screen with backlight, and another for a touch interface. The touch interface is a stretch goal, but included in this PCB in anticipation. A 3V linear regulator is required to get from 3.3V to 3V as the 16x2 LCD requires 3V instead of 3.3V. The smaller LCD communicated to the main microcontroller through SPI.

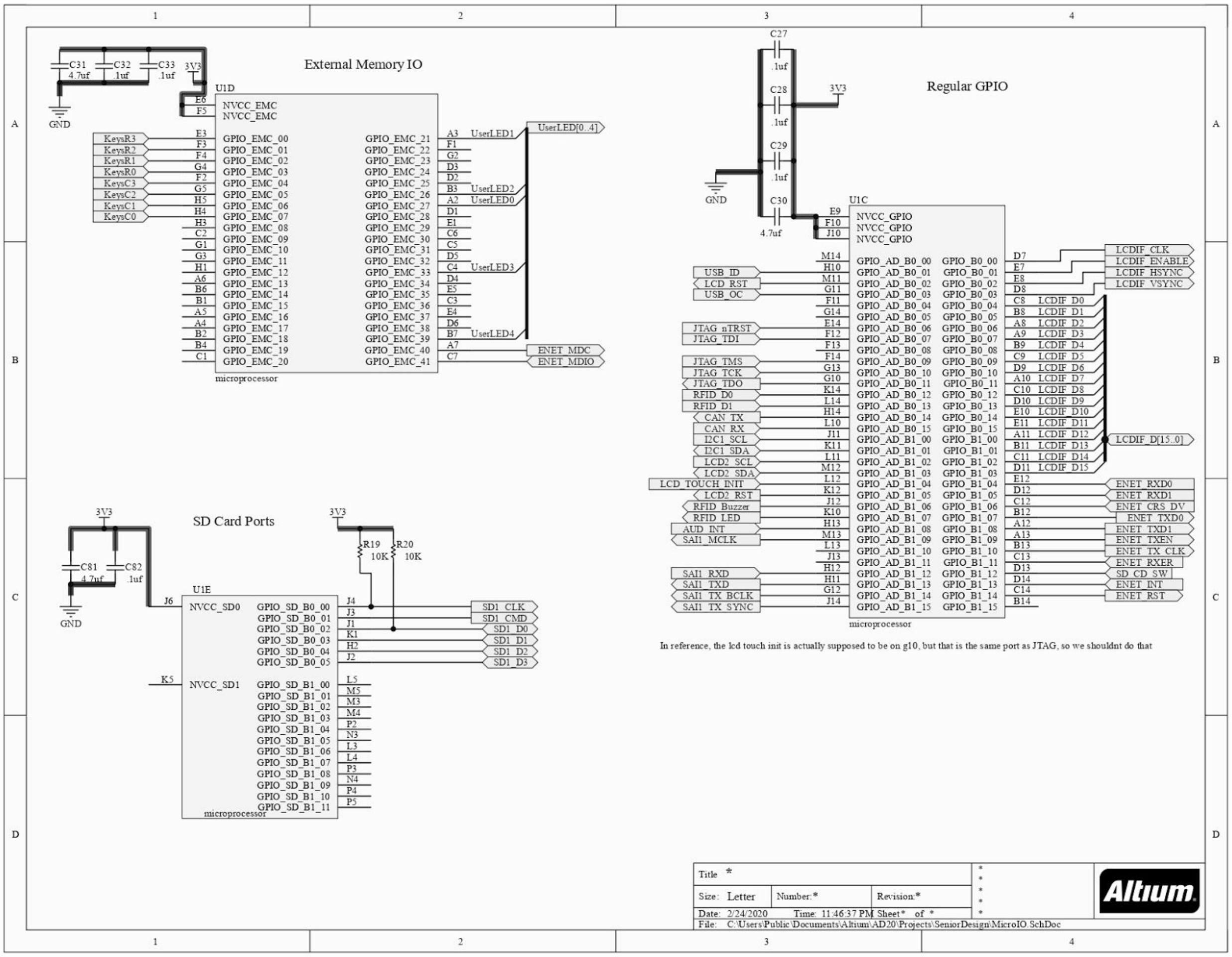

Figure 16. Main Microcontroller GPIO. Because the chosen microcontroller for the Main User Interface PCB has 196 pins, it does not fit on one sheet nicely, so this is only the GPIO Portions. All of the GPIO has offsheet connectors to the other schematics in order to keep the design clean. This microcontroller was chosen specifically for the especially high number of GPIO compared to the STM32 that is used elsewhere in this project.

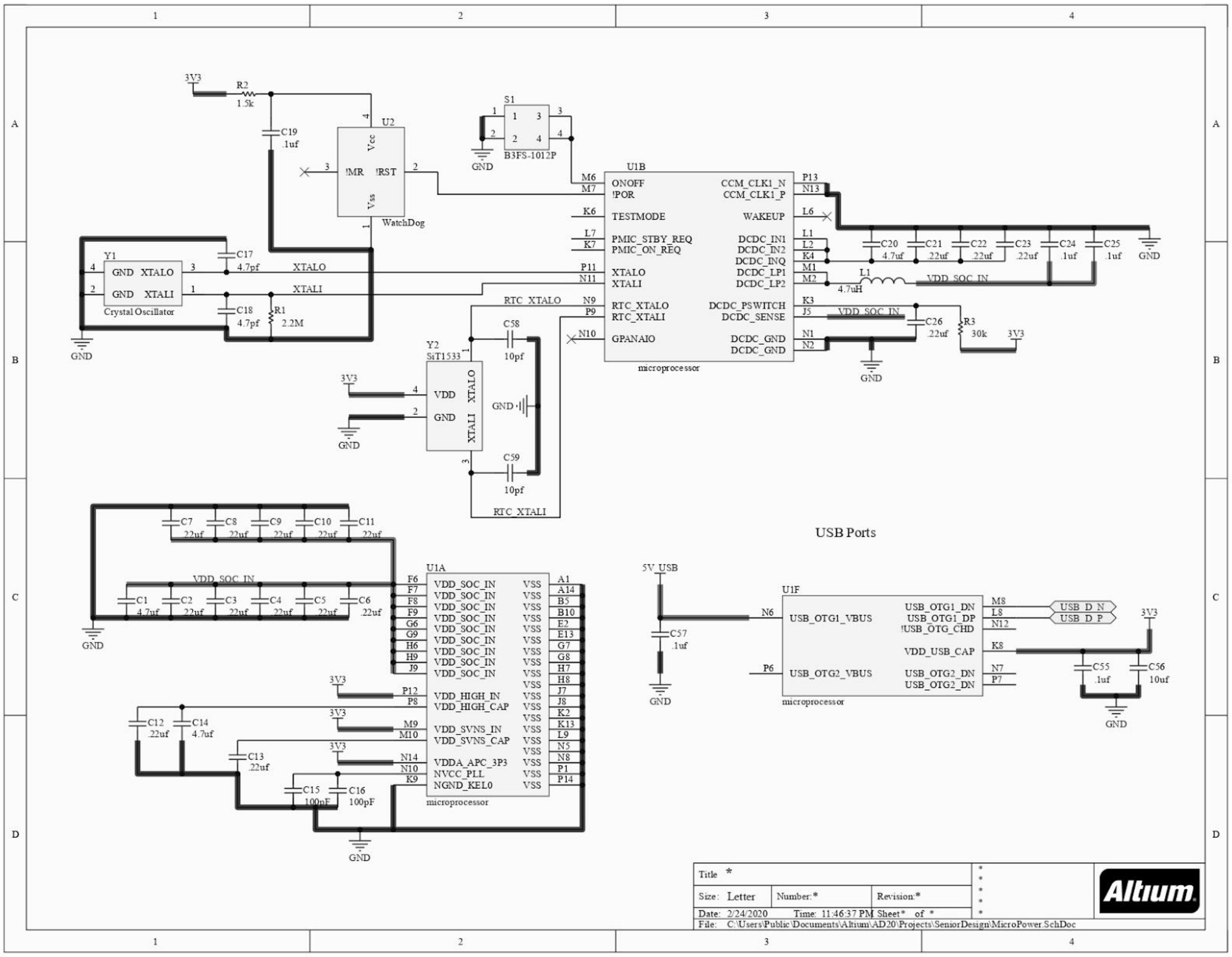

Figure 17. Main Microcontroller Power. This has all of the non-GPIO ports for the microcontroller on the main User Interface PCB. It includes the crystals, on/off button, watchdog, and decoupling capacitors.

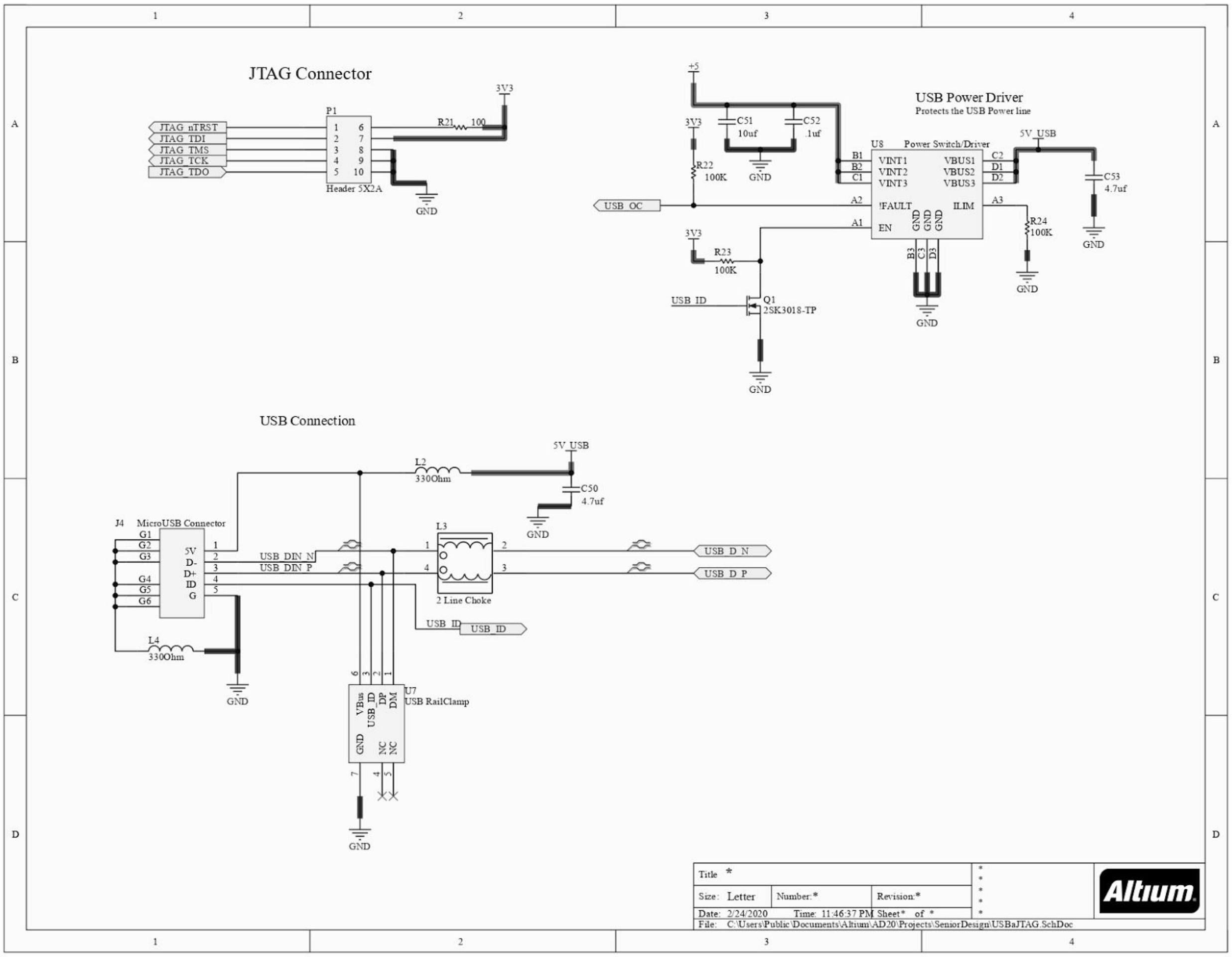

Figure 18. JTAG and USB connectors for the Main User Interface Boards. JTAG [18] is necessary to program the microcontroller, and USB could be helpful in the future for data collection but is not specifically required for this project. For the USB Connector, there is also a Power Driver to ensure that the USB power stays clean enough for the USB to use.

2.6.3 Boost Converter

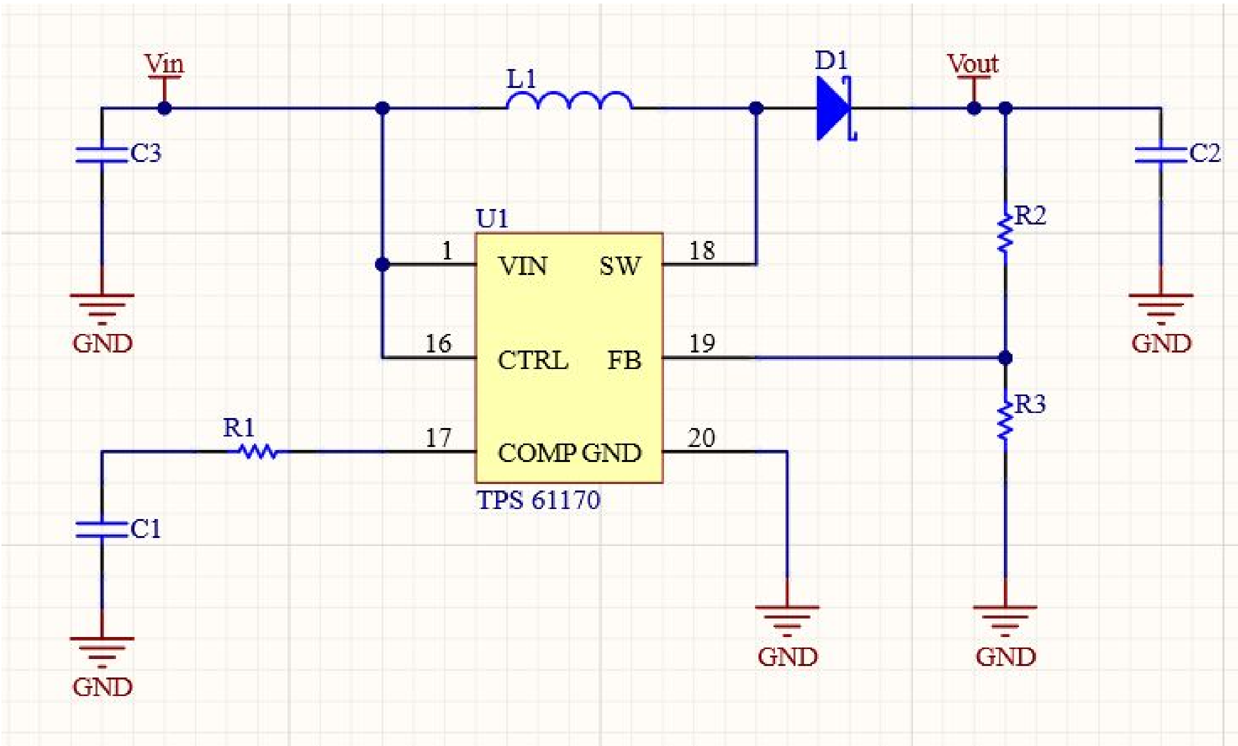

Figure 19. Boost converter. This is the schematic for the boost converter for the 16V rail. This circuit will be integrated into the voltage regulation board and be depopulated when not required.

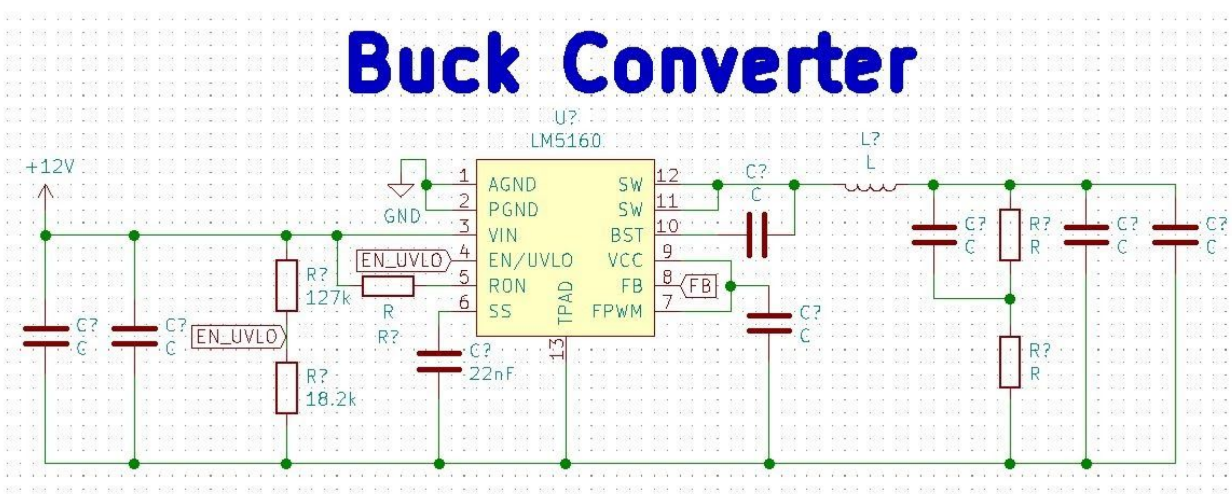

Figure 20. Buck Converter. This is the schematic for the buck converter for the 3.3V and 5V rails. The buck converters will both be integrated into the voltage regulation board.

2.7 PCB Design

2.7.1 Locker Control Board

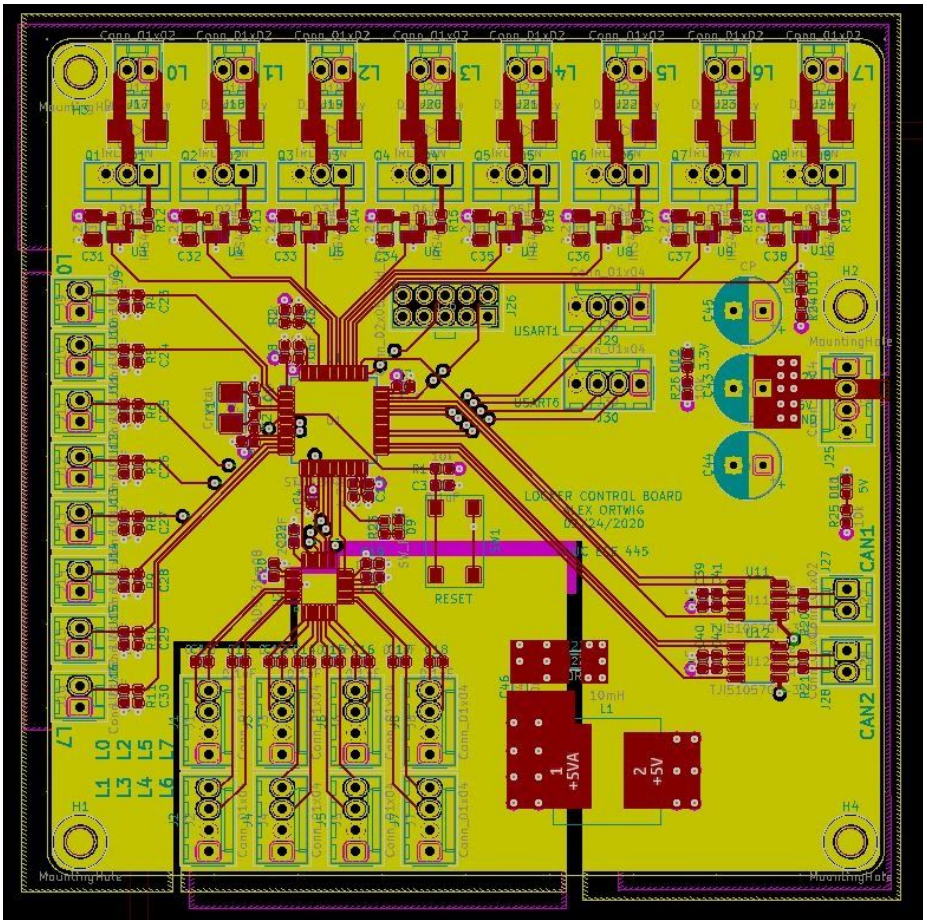

Figure 21. Locker control board layout. This board uses a 4 layer design due to the high density of components.

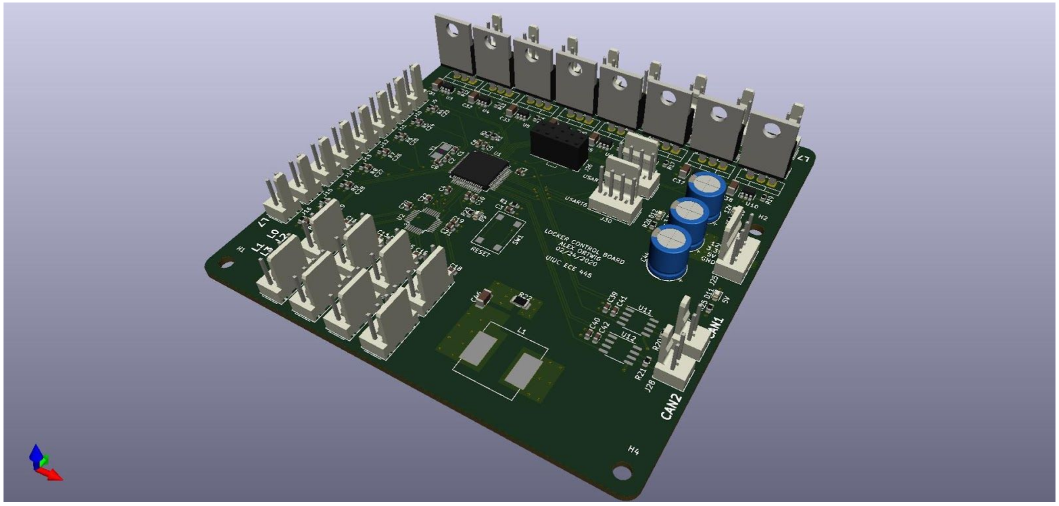

Figure 22. 3D model of the Locker Control Board, visualizing what it will look like after it has been manufactured and soldered.

2.7.2 Main User Interface Board

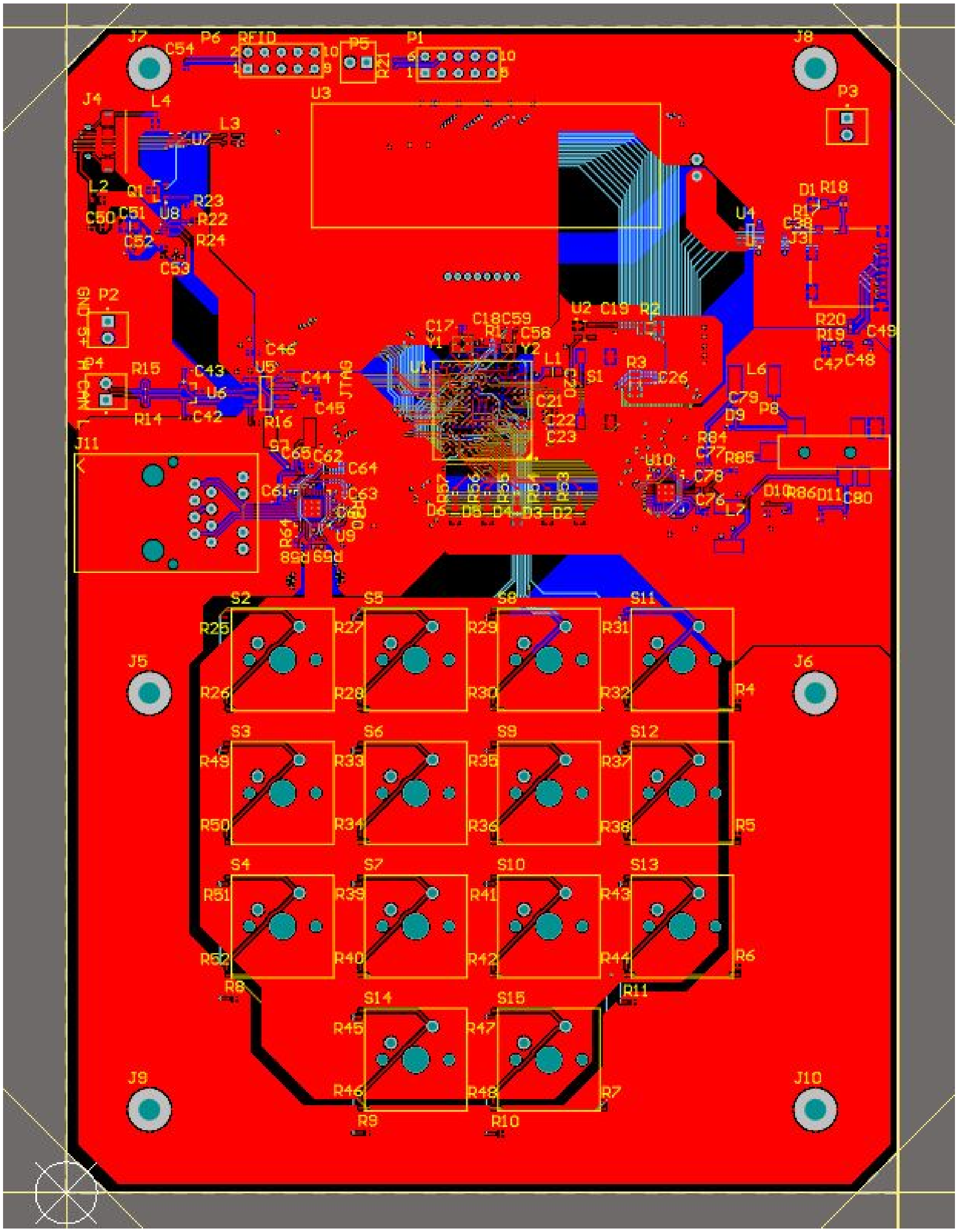

Figure 23. Layout of Main User Interface board. This board is 5”x7”, and contains the i.mx 1064 microcontroller, along with LCD, keypad, and CAN interface. This view is from the top layer, so many of the traces are hidden by the plane pours.

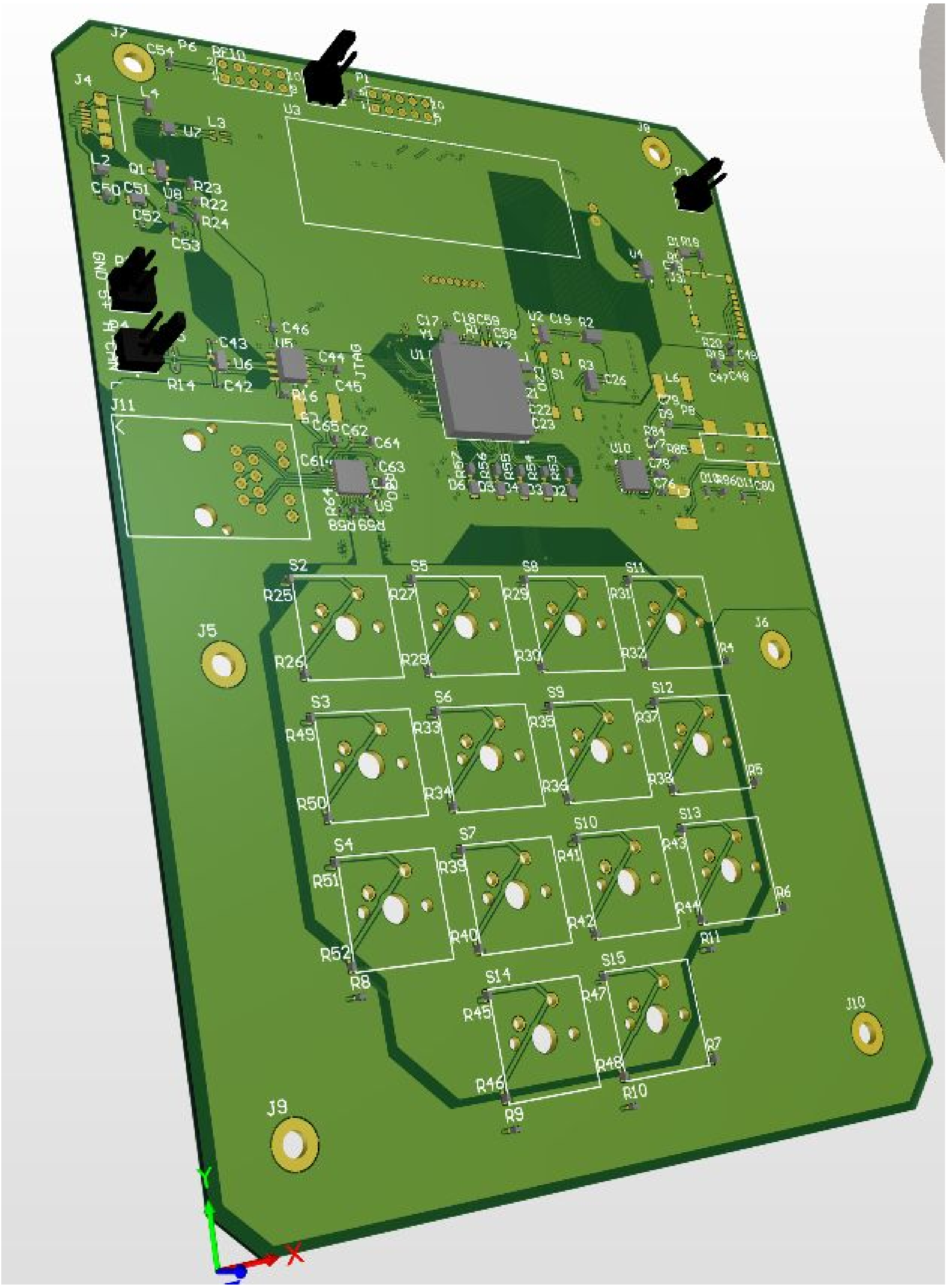

Figure 24. 3D model of the Main User Interface board. This makes it easy to visualize the layout of the keyboard and the LCD screen in comparison to each other.

2.8 Software

The software is divided into two major components, the display interface software which serves as the master of the system, and the locker control boards that control each set of lockers, that will all be slaved to the display interface board. Communication between the two systems will be done using the CAN protocol [5] to ensure resilient communication that can be expanded as more boards are added in.

2.8.1 Locker Control Board

The firmware on the locker control board (LCB) will support up to 8 lockers that each have a solenoid, operating on the signals it receives from the master over the CAN bus. The LCB relies on the master for being notified when to open/close, and will report the weight values back to the board, without verifying the item weight as that is handled by the master.

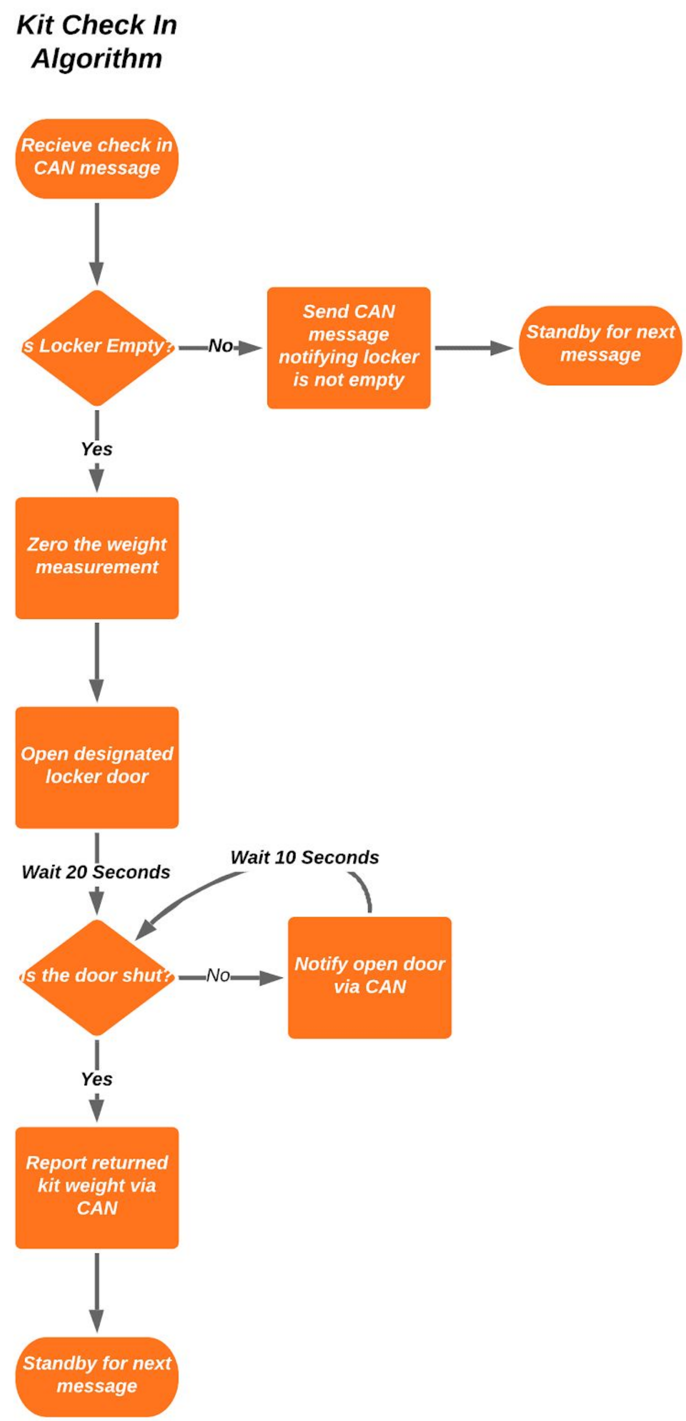

Figure 25. Equipment check in algorithm to be implemented on the slave boards

The kit check in algorithm (Fig 25) and the kit check out algorithm (Fig 26) depicted below are to be implemented on the locker slave boards. These boards will be constantly waiting for a CAN message. When a CAN message is received with the check in message, the board will take one of two actions, depending on if the locker is empty or not, which can be determined through a combination of data from the load cell and what the microcontroller believes to be in the locker. If the locker is not empty, then the board will send an error message over CAN to the main board, as a locker with something in it should not have another item added to it, and then return to standby mode to receive another message. If the locker is already empty, then the microcontroller will zero the load cell, open the door, and then wait for the kit to be returned and the door to close. For every 10 seconds the door is not closed, there will be a CAN message back to the main hub in order to signify that the kit is not checked back in yet, and log how long the total check in process takes.

Similarly, when a CAN message is received with a check out message, the locker will check to make sure there is something in the locker by checking the load cell and checking what should be in the locker based off of logs. If nothing in the locker is available, then the slave will send an CAN error message back to the master board. If the kit is available, the door will open, and it will wait until the door is closed, sending a message at 10 second intervals saying the door is open until the user has closed it.

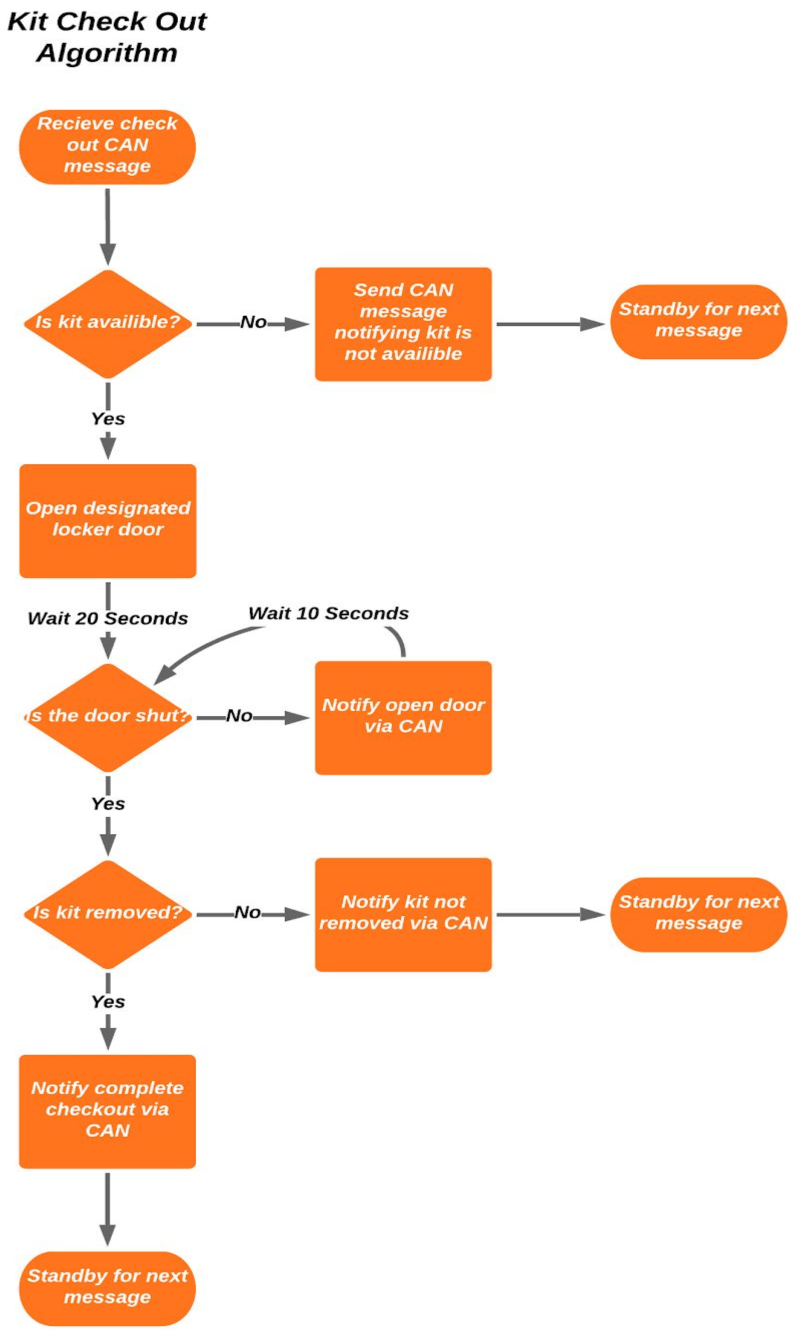

Figure 26. Equipment check out algorithm that will be implemented on the slave boards

2.8.2 User Display Interface

The user display interface system will serve as the master and there will only be one in the entire setup. This consists of the touch screen/keypad system as well as the data-logging. Once the user selects an item, the command to open will be sent to the appropriate locker control board over CAN [5], and the system will log the weight and new status. The entire algorithm can be seen in

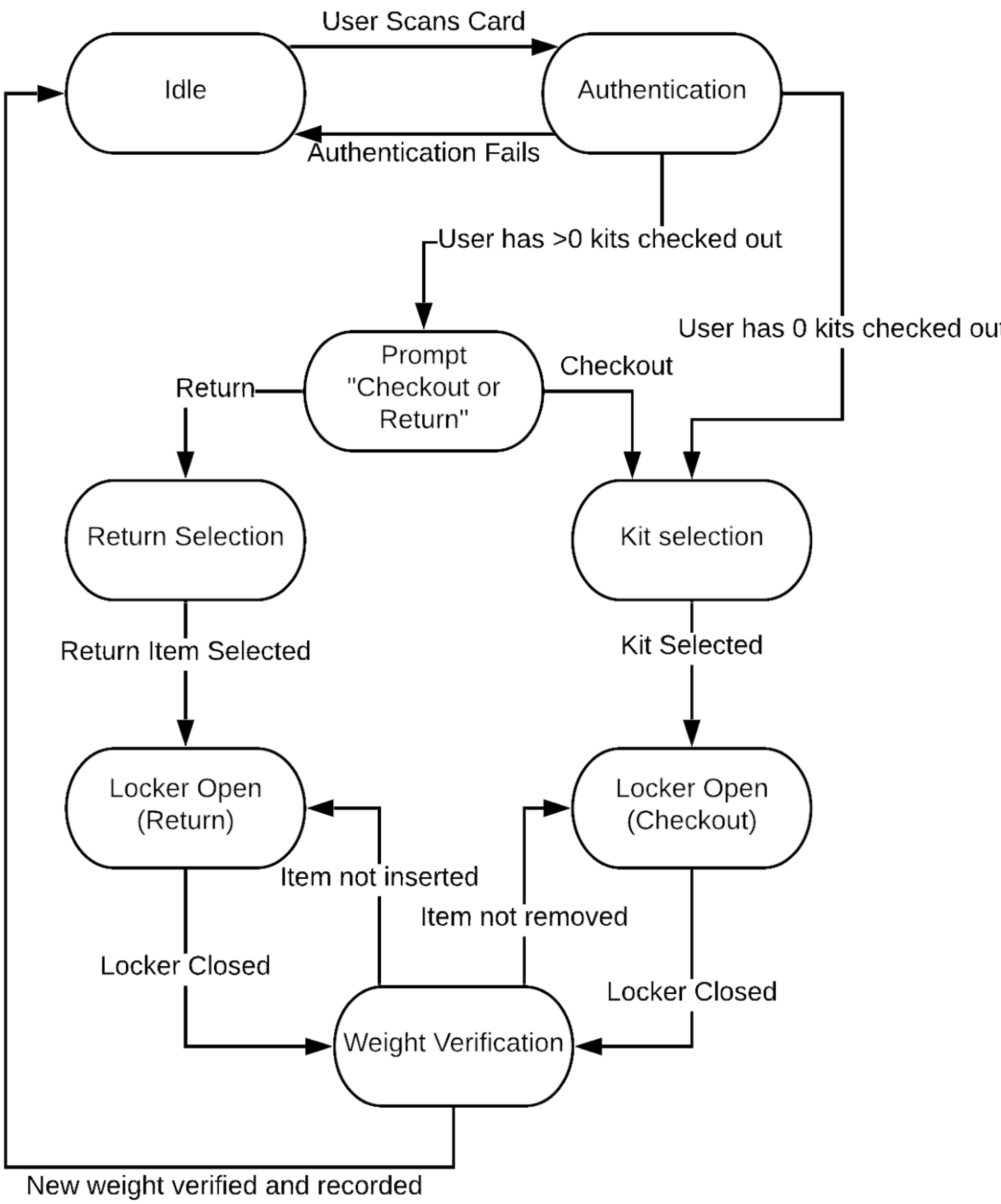

Figure 27. User Display Interface Algorithm. This will be the main logic behind the software on the Main User Interface board.

2.9 Tolerance Analysis

The most important area of concern for tolerance analysis in our design is going to be the accuracy of the measurements of our load cells. The load cells will output a differential voltage ranging from 0V to 5mV based on the load applied to the cell. Our requirements are to accurately read a load within +/- 100g using a 2.5kg load cell. 100g/2.5kg yields required measurement accuracy of 4%.

The ADC our design utilizes is a 24bit ADC with a 1.2V internal reference. The resolution of the ADC is therefore $1.2/(2^{24})$ or 71.5nV.

The load cells used in our design have a conversion of 1mV/V such that at rated load the differential voltage of the load cell will read 1mV per 1V applied and the change in differential voltage per gram of load applied can be calculated using [eq.6]. Since our load cells are rated at 2.5kg, the change in differential voltage per gram will be 2uV. To achieve our accuracy of +/-100g our ADC readings would need to have a minimum resolution of 200uV. Since the resolution of our ADC is 71.5nV, we will be able to meet the tolerance requirements for the load cell measurements.

$$\frac{1mV * V\ applied}{Rated\ load\ in\ grams} \qquad \text{eq.6}$$

3 Costs

The costs for the engineers for this system is \$50 an hour, for approximately 10 hours a week for this semester. This should be also multiplied by 2.5 for the cost of overhead. This comes to \$80,000 [eq.7] in total as a cost of labor.

$$4 * \frac{\$50}{hr} * \frac{10\ hrs}{wk} * 16\ wks * 2.5 = \$80,000 \qquad \text{eq.7}$$

Many miscellaneous parts are needed to complete this project that do not go on any of the PCBs and do not fit under labor costs. This is shown in the table below, which accounts for things such as lockers and other physical parts.

Item	**Price**
Grey lockers	\$175.00
Blue locker	\$82.00
USB to JTAG connector (LPC-LINK 2)	\$23.53
Power connectors for lockers	\$15.98
Signal connectors for lockers	\$17.98
Wire	\$21.99
Acrylic sheet locker window	\$29.98
Total	\$366.46

The approximate costs for the Main User Interface PCB is $76.81, as displayed in the following table. Because a minimum of five boards will be ordered, and in case one of the boards does not work, more parts than are needed will be ordered. In the case of resistors and capacitors, there is often a price break at 10, 50, or 100 components, so it makes more sense to order significantly more components than needed in order to pay this cheaper price. However, these are the costs for one board (with the component costs for one board), even though more parts will be ordered. Additionally, many of these parts are for stretch goals that hardware is going to be designed for, but not necessarily tested.

Designator	Quantity	Price	Total
4.7uf Cap	13	0.0549	0.7137
.22uf Cap	17	0.0168	0.2856
100pf Cap	2	0.0056	0.0112
4.7pf Cap	2	0.0074	0.0148
.1uf Cap	31	0.0074	0.2294
56pf Cap	2	0.016	0.032
1uf Cap	2	0.026	0.052
22uf Cap	3	0.194	0.582
10uf Cap	5	0.117	0.585
10pf	2	0.017	0.034
2.2uf	1	0.081	0.081
220pf	2	0.026	0.052
LED	6	0.201	1.206
Circuit Protection Diode	3	0.2	0.6
40Pin FPC Connector	1	1.08	1.08
6Pin FPC Connector	1	0.44	0.44
MicroSD Card Connector	1	2.02	2.02
Mini USB Connector	1	0.78	0.78
Ethernet Connector	1	5.21	5.21
4.7uH Inductor	1	0.129	0.129

330 Ohm Inductor	2	0.079	0.158
Dual Line Choke Inductor	1	1.06	1.06
120Ohm Inductor	3	1.73	5.19
2x5 KK Connector	1	0.308	0.308
2 KK Connector	4	0.16	0.64
6 KK Connector	1	0.403	0.403
Audio Barrel Connector	1	1.17	1.17
Mosfet	1	0.34	0.34
2.2M Res	1	0.027	0.027
1.5K Res	1	0.0064	0.0064
30k Res	1	0.44	0.44
10k Res	14	0.0064	0.0896
4.7k Res	10	0.0053	0.053
62 Res	2	0.053	0.106
100k Res	5	0.0064	0.032
330 Res	6	0.07	0.42
100 Res	1	0.0064	0.0064
0 Res	28	0.0032	0.0896
1k Res	14	0.0064	0.0896
6.49k	1	0.053	0.053
Push Button	1	0.71	0.71
MX Switches	14	0.8	11.2
Microcontroller	1	13.06	13.06
Watchdog	1	0.97	0.97
LCD	1	11.95	11.95
3V Linear Regulator	1	0.48	0.48

CAN Transceiver	1	1.43	1.43
CAN Bus Protector	1	0.43	0.43
USB Rail Clamp	1	0.88	0.88
USB Power Driver	1	1.14	1.14
Ethernet Transceiver	1	1.37	1.37
Audio Driver	1	5.57	5.57
24MHz Crystal	1	1.61	1.61
32.768KHz Crystal	1	1.19	1.19
		Total Price:	76.8093

The exact costs for the Locker Control Board is $52.70

Manufacturer Part Number	Quantity	Unit Price	Extended Price
CL10C160JB8NNNC	2	0.1	$0.20
CL10B104JB8NNNC	26	0.048	$1.24
885012206073	1	0.1	$0.10
CL10B105KA8NNNC	4	0.1	$0.40
CL10A475MA8NQNC	1	0.35	$0.35
CL31B225KAHNNNE	8	0.24	$1.92
CL31B106KAHNNNE	1	0.28	$0.28
ECA-1EM221	3	0.31	$0.93
STPS2L40U	8	0.41	$3.28
150060VS75000	4	0.14	$0.56
22232041	11	0.267	$2.93
22232021	18	0.161	$2.89
SFH11-PBPC-D05-ST-BK	1	0.66	$0.66
SRR1208-103KL	1	1.13	$1.13
IRLZ44NPBF	8	1.02	$8.16
ESR03EZPJ101	8	0.1	$0.80
RNCP0603FTD10K0	15	0.067	$1.00
RMCF0603JT120R	2	0.1	$0.20
RMCF1206ZT0R00	1	0.1	$0.10
B3FS-1012P	1	0.71	$0.71
STM32F446RET6	1	7.28	$7.28
ADS131M08IPBS	1	7.92	$7.92
IRS44273LTRPBF	8	0.86	$6.88

TJA1057GTJ	2	0.94	$1.88
ECS-5032MV-320-BN-TR	1	0.9	$0.90

The approximate costs for the power distribution boards are $16.00 per board, and we need at least two power distribution boards for this project, so the cost for this system is $32.

In total, the price of the system is $80,527.97.

Item	**Price**
Labor Costs	$80,000
Mechanical Parts	$366.46
Main User Interface Board	$76.81
Locker Control Board	$52.70
Power Distribution Board	$32
Total	$80,527.97

4 Schedule

This schedule is split into two parts to improve readability, as we have four members in our group.

Week	**Abby**	**Alex**
2/24	Complete main user interface board design and layout	Complete the locker control board design and layout
3/2	Order components for main user interface board	Complete the voltage regulation PCB. Order components for the locker control board and voltage regulator board.
3/9	Assemble the main user interface board. Start on data collection software	Assemble the locker control board. Test and verify the lock driving circuitry. Test and verify the locker closure detection.
3/16	Start LCD and keypad testing	Assemble the voltage regulation

		boards. Begin programming the locker control board.
3/23	Finish LCD and keypad testing	Test and verify the voltage regulation boards.
3/30	Test RFID with software from Aditya	Begin testing the ADC and load cells.
4/6	Begin testing the CAN interface	Finish testing the ADC and load cells. Begin programming/testing the CAN interface.
4/13	Data collection testing	Continue programming/testing the CAN interface.
4/20	Full system testing	Finish programming the locker control board.
4/27	Full system testing and preparing for final demo	Full system testing, and Final Demo
5/4	Finish writing final paper	Finish writing the final paper

Week	**Aditya**	**David**
2/24	Design software state diagrams	Order and assemble lockers
3/2	Start RFID Software	Research and design power connectors for lockers
3/9	Finish RFID Software	Manufacture power connectors between lockers and acrylic locker fronts
3/16	Start data collection software	Assemble locker peripherals including solenoid locks and load cells
3/23	Finish data collection software	Start the CAN interface
3/30	Test RFID Software with hardware	Finish the CAN interface
4/6	Begin testing CAN Interface	Begin testing CAN Interface

4/13	Test data collection software with hardware	Test data collection software with hardware
4/20	Mock Demo, finish up loose ends for demonstration	Mock Demo, finish up loose ends for demonstration
4/27	Demonstration, start on final paper, system testing	Demonstration, start on final paper, system testing
5/4	Finish final paper	Finish final paper

5 Ethics and Safety

We intend to follow the IEEE Code of Ethics 7.8.1-3 and 7.8.5-9 [20]. Some of the Code of Ethics is not applicable due to the nature and methods of our project. In the case of any violations of this code we will take them seriously, especially in the case of injury of a group member or other entity. Due to our project having a physical construction component, we will emphasize the safety of the end consumer when operating our device according to the Code of Ethics 7.8.1 [20].

One concern that follows with the code of ethics currently present in the OpenLab is the potential for an abuse of the trust given to lab users to maintain the integrity of the equipment. There is the potential for certain lab kits, such as boxes of cables or tool kits, to be returned with missing or added materials, and a goal for this project is to track when such events occur in order to improve the security and availability of the OpenLab's resources.

There are cameras in the OpenLab that are currently used to track serious theft, but it would be ideal not to use any external systems to prevent theft from the locker system. This system will work in conjunction with the security cameras and lab monitors in the case of a suspected misplacement of lab supplies so there is no chance of an accidental flagging of an innocent student which would violate injuring the reputation of others [20].

In addition to the ethical concerns, it is expected that this system be plugged into the main AC power at all times. Therefore, it is necessary to isolate the power system from the mechanical system. If there are any faults in the power system, the user needs to stay safe. For this reason we will be using an off the shelf power supply listed either by UL [5] or ETL [21].

Another potential concern is ensuring that we are always following UIUC lab safety rules [22]. This would entail ensuring that no potentially hazardous materials are stored in the lockers, or if they need to be stored, all regulations surrounding their storage are followed. Additionally, everyone involved should be aware of the procedures surrounding the materials. We do not expect this to be a major concern as the OpenLab does not typically store or loan out hazardous or otherwise restricted materials, and requires laboratory safety training before students are allowed inside, but it is something to keep in mind. We will have to comply with lab regulations regarding Electrical Safety, ensuring we externally use flexible cords with 3-wire design whenever possible.

The last concern that was voiced was the fact that this could replace the lab monitors in the lab. Part of the lab's draw is the human factor of having someone always present to watch over the lab and ensure safety as well as to instruct users. This project will not eliminate the positions of the lab monitors, but free them to perform other tasks. This system will actually not allow checkouts for certain tools until there are lab monitors present. We have the lab monitors run laser cuts and there are plenty of things that need to be done around the lab to improve the lab itself. All this system would do would be to allow the lab monitors to perform fewer menial tasks during their shifts.

6 References

[1] “HID Proximity” *HID*
https://www.hidglobal.com/products/cards-and-credentials/hid-proximity
[2] “Automated Smart Locker System.” *Meridian Kiosks*,
www.meridiankiosks.com/solutions/automated-smart-locker-system/.
[3] “Equipment Management” *Assa Abloy*
https://www.traka.com/en-us/site/traka-usa/usa-applications/asset-management/
[4] “Locker Systems” *Kiosk Information Systems*
https://kiosk.com/market-solutions/locker-systems/
[5] “ISO 11898-1:2015 Road vehicles — Controller area network (CAN) — Part 1: Data link layer and physical signalling” *ISO*
https://www.iso.org/standard/63648.html
[6] “Uline Three Tier Lockers - 1 Wide, Unassembled, 12" Wide, 18" Deep, Gray” *ULINE*
https://www.uline.com/Product/Detail/H-7585GR/
[7] “Power Supply Test and Certification” *UL*
https://www.ul.com/offerings/power-supply-test-and-certification
[8] “LM5160, LM5160A Wide Input 65-V, 2-A Synchronous Buck / Fly-Buck™ DC/DC Converter” *Texas Instruments*
https://www.ti.com/lit/ds/symlink/lm5160.pdf
[9] “Arm® Cortex®-M4 32-bit MCU+FPU” *STMicroelectronics*
https://www.st.com/resource/en/datasheet/stm32f446mc.pdf
[10] “TPS61170 1.2-A High-Voltage Boost Converter“ *Texas Instruments*
https://www.ti.com/lit/ds/symlink/tps61170.pdf
[11] “COG (Chip-on-Glass) Liquid Crystal Display Module” *NewHaven Display*
http://www.newhavendisplay.com/specs/NHD-C0216CiZ-FSW-FBW-3V3.pdf
[12] “NXP i.MX rt 1064” *NXP*
https://www.nxp.com/docs/en/data-sheet/IMXRT1064CEC.pdf
[13] “3133 - Micro Load Cell (0-5kg) - CZL635” *RobotShop*
https://www.robotshop.com/media/files/pdf/datasheet-3133.pdf
[14] “ADS131M08 8-Channel, Simultaneously-Sampling, 24-Bit, Delta-Sigma ADC” *Texas Instruments*
https://www.ti.com/lit/ds/symlink/ads131m08.pdf
[15] “IRLZ44N HEXFET® Power MOSFET” *IRF*
http://www.irf.com/product-info/datasheets/data/irlz44n.pdf
[16] “IRS44273LPBF Single Low-Side Driver IC” *Infineon*
https://www.infineon.com/dgdl/Infineon-IRS44273L-DS-v01_00-EN.pdf?fileId=5546d46269e1c019016a4e9c18ca0cff
[17] “WS2812 Intelligent Control LED” *Worldsemi*
https://cdn-shop.adafruit.com/datasheets/WS2812.pdf
[18] “1149.1-2013 - IEEE Standard for Test Access Port and Boundary-Scan Architecture” *IEEE*
https://standards.ieee.org/standard/1149_1-2013.html
[19] “TJA1057 High-speed CAN transceiver” *NXP*

https://www.nxp.com/docs/en/data-sheet/TJA1057.pdf
[20] "IEEE Code of Ethics," *IEEE*. [Online]. Available:
https://www.ieee.org/about/corporate/governance/p7-8.html.
[21] "ETL Listed Mark" *intertek*
https://www.intertek.com/marks/etl/
[22] "Laboratory Safety Guide" *University of Illinois at Urbana - Champaign*
https://old.drs.illinois.edu/site-documents/LaboratorySafetyGuide.pdf