Class Kit Vending Machine Conceptual Design

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I. Introduction

Around fifty devices a day are needed by students each year for their ECE (Electrical and Computer Engineering) courses. The main emphasis of this capstone project is the design and implementation of a vending machine that can loan out devices to students while keeping track of which students have taken the devices. A student can enter their information into the machine, and it will keep track of who has borrowed each device(s). Students will be able to view and choose which gadget to remove with the help of an LED (Light Emitting Diode) equipped drawer system. The purpose of this step in the design process is to complete the following: detail what subsystems must be in place in order for the vending machine to run, how these subsystems will interact with each other, and finally, what constraints each subsystem will have imposed on it and how each constraint can be tested. The following is a numbered list of specifications that are then discussed in the later paragraphs.

1. The machine shall be 2 to 4 feet in height.
2. The machine shall use encrypted ethernet for data transfer

3. A Microcomputer/PC shall be used to manage the data and allow proper function

4. The devices shall be uniquely identifiable

5. The machine shall use a card reader to obtain identification

6. The machine shall have nonvolatile memory to store the programs and data

7. The machine shall have LED (light emitting diode) indicators

8. Locks shall be installed to prevent device theft

9. The machine shall allow auto-download of data given a USB drive

10. The machine shall have a motorized center in order to rotate which device should be taken.

The machine will be no taller than the average window height, which is around 2 to 4 feet, and no smaller than 2 feet in height. This allows for easy portability from the office to the student lounge at Brown Hall and vice versa. The machine will use ethernet to send data to our customers and be encrypted to avoid others from accessing the students' information as well.

A Microcomputer (PC) will be used to manage the data acquisition system and allow the proper function of the machine. An SQL (structured query language) database will be programmed into the Microcomputer to hold the student ID (identification) number, name, email, course, and which board has been rented, as required by the customer. The boxes the devices are held inside must be uniquely identifiable according to the department, so each box must be scanned into the database before a device is taken. This is to prevent the theft of a device by any student and allows the customer to know which is taken. For the same reason, the machine shall have a card reader to ID every student. This way no student can fake the number, even if other information was incorrect.

For the entire machine to function after a reset and to remember information for the customer, the machine is required to have a form of nonvolatile memory such as MicroSD or an actual separate drive. The machine must have a series of LED indicators so the student knows which drawer and compartment to access when retrieving the board. Solenoid Locks shall be installed into the drawers and compartments so no single person can easily break through to the devices when the machine is unsupervised. The current plan is for a drawer and compartment to hold for several minutes to allow enough time for a worker to notice the attempt.

The following subsections provide detail on each of the previous requirements and how each shall be completed according to the customer.

II. Background

A question that may arise from the conceptual design is: why use a PLC and a Microcomputer in the vending machine? One reason that a PLC is being considered is due to a PLC is cycle-based. When discussing execution schemes, there are two that can be used: event-driven execution and cycle-based execution. In an event-driven scheme, like a microcomputer, "a run-to-completion step is executed each time an event is raised," while in a cycle-based scheme, like a PLC, "a run-to-completion step is executed periodically in regular time intervals," [1]. The reason this needs to be addressed and specified is to show how a PLC can be useful in our design. Being event-driven, a microcomputer will wait to scan until input is sent to it. On the other hand, a PLC will constantly check all inputs and sensors on a certain time cycle. It's important to have a cycle-based execution for the hardware components, such as locks and component sensors, because they are the main security measure against stealing the devices. There is a chance that if this scanning is done by the microcomputer, it could execute at the end of a long command, such as a "for" loop. If this is the case, the hardware scanning could happen minutes after the request was sent. Whereas if a PLC was used, the hardware could be monitored every scan cycle, for example, every 200ms. This makes PLCs more reliable in relation to securing the devices and monitoring hardware.

To secure the connection between the ECE office and the Vending Machine, there will be an encrypted Ethernet line. The form of encryption being used is called Symmetric cryptography [2]. This type of encryption allows both points of connection, Point A (The ECE Office) and Point B (The Vending Machine), to both encrypt and decrypt the information. This provides greater security than a simple Asymmetric system since both sides need a key to access the information.

To access information of the students who rented out the devices, a need for a database arises. For the database, a standard language is needed for accessing and manipulating the database. The chosen language for accessing the database is SQL [3]. SQL will be used to insert, retrieve and update information of the students who rented out devices.

III. Ethical Considerations

A scenario that must be considered is the stealing of a device from the vending machine. Given the chance that the faculty in the ECE office may step out of the office for a few minutes, there is a chance that someone could attempt to break into the vending machine to steal the devices within. To help prevent this, the vending machine will have locks on both the drawers and the lids of each device. There will also be a sensor system in place to detect if a box is in its compartment. While this will be mainly used for the SQL database, it can be given the purpose of detecting if a device is removed without approval.

A consideration that must be taken into account when designing this vending machine is the potential to take away jobs from ECE faculty. However, given why the machine is being designed and implemented, i.e. automating part of the process of checking out devices, the jobs of the ECE faculty will not be negatively affected. The ECE office faculty will have their jobs simplified by not having to keep track of paperwork, rather they will have a spreadsheet with student information and checked-out boards.

In addition, there will be a USB storage connection to transfer data to and from the device. This provides even greater security for the student data, that being physical security. This device will also require a form of encryption, in the case of misplacement or theft. The choice form of encryption would be one that can run directly off the USB drive, such as 'Rohos Mini Drive' or 'VeraCrypt' [4]. These types of programs use passwords, key files, and user varication to defend from capering. This would avoid the need for additional programs or applications to be installed on office devices.

IV. Block Diagram

A. Constraints

The following is the list of constraints that will be imposed on our subsystems:

i) Microcomputer System

(1) The microcomputer must contain a database that is programmed with SQL and another language such as C++ or Java.

ii) PLC

(1) The PLC must interface with the locks and LEDs.

(2) The PLC must control the step voltage of the motors.

(3) The PLC must communicate with the microcomputer.

(4) The PLC must know the device occupancy of each drawer.

(5) The PLC must have a timer system.

iii) Communication

(1) The machine must have a USB port to auto-transfer information between itself and the drive.

(2) The machine must receive a CSV file from the faculty computer.

(3) The Ethernet connection used to send the CSV file must have a form of encryption to secure student information.

(4) The machine must have a barcode scanner to send the board number to the microcomputer.

(5) The machine must use a card reader to read information off of an Eagle Card and use it as a unique ID.

(6) The machine must have a user interface involving a touchscreen to enter certain student information (such as name and email).

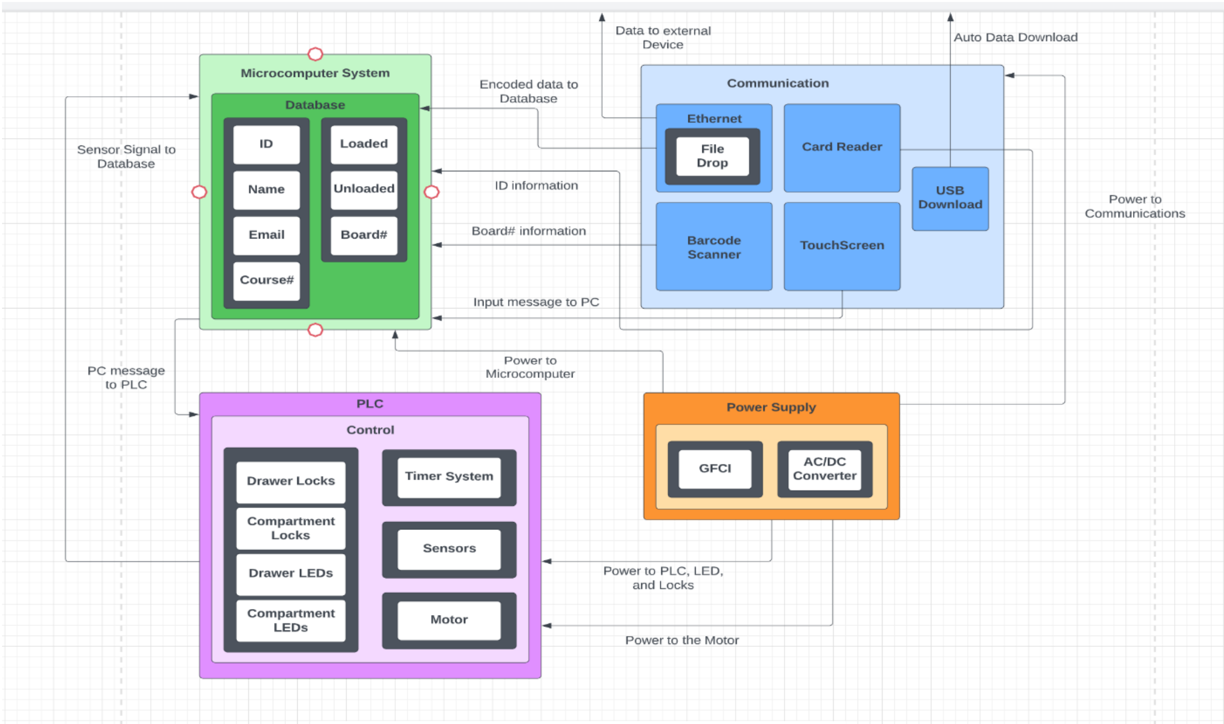

Figure 1. Block Diagram

iv) Power System

(1) As per the standard NEC 422.51, the power system must have a ground fault current interrupter (GFCI) to protect against the current surge.

(2) The power system must have an AC/DC converter to send power to the voltage-sensitive components.

(3) The power system must have an emergency stop control.

B. Microcomputer System

The microcomputer system should be able to meet the following criteria: It should have enough storage to hold device information, student information, and programming. It should also have connectivity ports such as a USB (Universal Serial Bus) and an Ethernet port.

The Microcomputer will not only be used for keeping up with the Database but also be responsible for communication with other subsystem modules. It should comprehend input signals from the Card Reader, User Interface (UI), and barcode scanner. Also, it should communicate with PLC for carrying out the operation of vending devices.

The Microcomputer will be mainly used for the following functions:

1) SQL Database

a. Inventory

With the aid of a sensor in the PLC system, the database will be utilized to keep track of the inventory inside the machine and will be able to inform the client whether a device is loaded or unloaded. If the package is loaded, the system will verify that the barcode scanner has read it. The system will check to see if the box hasn't been scanned and if it is unloaded. The database's inventory area will then be used to store and record all of the data.

b. Student Information

The database will also be used to maintain a list of the students who have borrowed gadgets for classes, and it will be able to transmit the data to the customer over Ethernet and/or a USB drive. The identification will be entered into the database under the students' section using the card reader that is attached to the computer. A user interface will be used to input the student's name and email. From a list of courses the database has, a course portion will then be selected. The barcode of the chosen board will be read by the scanner once it has been selected, and the consumer will then be able to use it.

To validate whether the information has been correctly processed and stored in the database, a mock trial will be done by using a teammate's Eagle card and after that, the data will be downloaded to see whether the information stored in the database is accurate or not. This will help verify that constraint i(1) has been satisfied and specifications 3 and 6 have been met.

C. PLC

In order to give the vending machine's hardware reactive functionality, a PLC will be implemented along with its necessary sensors. The PLC will be able to message the microcomputer as well in order for constraint ii(3) to be satisfied.

1. *Control System*

a) Motor

The PLC will control the motor used for rotating the platform holding the devices. When a device is removed and the machine senses that the device is removed, the PLC will send a step voltage to the motor and the platform will rotate by a certain angle. This angle will be determined by seeing how many devices are on the platform and dividing 360 degrees by the number of devices.

Input: The PLC signal from a sensor indicating that a device has been removed, and a voltage from the power supply.

Output: A rotation angle to move the next device to the drawer door.

This motor system will follow constraint ii(2) and specification 10. It can be tested during design and implementation once the motor, platform, and sensors are implemented. Before these are put into the machine frame, a device can be placed in front of the sensor and removed right after. If the PLC is correctly connected to the motor and sensor, the motor should rotate by the predetermined angle.

b) Locks

The locking system will be solenoid coils energized by the PLC. The PLC will run the student's course number and board needed through comparison functions to find where it is equal to a board number that isn't checked out. Once it finds equality, the corresponding locks will become un-energized so the student can grab the board. The functionality will be tested by running a test line in the PLC to see if a lock's tag correctly updates.

Input: Powered by the vending machine, energized by the PLC.

Output: Locking and unlocking the drawers and compartments containing the devices.

This locking system will follow constraint ii(1) and specification 8.

To properly protect the stored units, the locks must be able to defend against forceful entry and external interference.

To verify the locks' strength, there will be stress tests that match or overcome possible forces that would challenge their integrity.

The locks must also stay locked and/or return to a locked state in the case of blackouts, removal of power cord, or any other forms of power loss. This can be tested by use of a multimeter, confirming the resistance of the lock is zero, meaning the solenoid is grounded and functioning properly.

There will also be a system that confirms the door of the compartment is shut and locked before continuing any other process, avoiding any unwanted incidences or inconveniences. This system will use capacitance to sense a small charge from the lock connecting to a corresponding conductive sheet, confirming the state of the lock. This can be tested by connecting a capacitance meter along with sending a small signal through a powered device to confirm it can be sensed.

c) Indicator

The vending machine will have an indication system to guide the student to the correct drawer and compartment. When the PLC finds the correct board needed by the student, it will run the board's tag through compare commands until it finds the corresponding indicator tags. Once the tags are found, they will be energized and un-energized on a timed system.

Input: Voltage from the machine, energized from PLC, set to flash at a certain interval with a timer system.

Output: Drawer and compartment indicators will flash to show where the device is located.

This system's effectiveness will primarily be tested by user interactions. Since the entire reasoning behind the system's inclusion is to direct user attention, this will have to be tested by users who are inexperienced and unaware of the LEDs' purpose.

i) LEDs

This indicator system will follow constraint ii(1) and specification 8. To assist the user in identifying the location of their required device, there will be LED indicators on each of the drawers. When the user completes the process of renting out a device, the LED will blink on the drawer that has been unlocked, as will the LED of the specified compartment. LEDs will return to standby after the item has been removed and the drawer has been shut.

d) Timer System

The PLC will run the timer system used in tandem with the lock and indication systems. This system will be used to hold the solenoid coils as unlocked for a reasonable duration in order for the student to grab their device (roughly 15-20 seconds).

Once the time has elapsed, the coils will become energized and will lock once the drawer and compartment are closed. The timer system will also set the period of flashing for the indication system. Once the time for the coils has elapsed, the indicators will also stop flashing.

Input: Total duration from PLC, tag update from PLC.

Output: Solenoid coils will be unlocked for a given duration. During this duration, the indicators will flash to show where the device is located.

This timer system will follow constraint ii(5) by allowing the solenoid coils to be unlocked and the LEDs to flash for a given duration. This will be tested during the implementation phase by manually updating a lock or LED tag in the PLC. There will also be a timer, such as a TON (Timer ON) or RTO (Retentive Timer), linked to the tag. A TON timer checks if the tag has been on for a given amount of time, whereas a RTO keeps track of how long tag has been active over the course of it being active and inactive [5]. If the tag is updated and the PLC is correctly linked to the lock or LED, the lock should receive power or the LED should flash as long as the TON or RTO is active.

e) Sensors

To determine if the compartments of the vending machine need to be restocked, the PLC must know which compartments are empty or full. Sensors can be used to communicate the occupancy status of each compartment to the PLC. If there are no sensors, then the machine would not know which compartment is stocked with a device or not.

There are hundreds of sensor options to deliberate between; the sensor we choose must be able to fit in the designed compartment, not require to be recalibrated after implementation, and must be within the limit of our budget. Ideally, the sensor will send a one-bit binary signal back to the PLC for simplicity in communication and ladder logic code. In regard to this, photoelectric sensors are more advantageous than weight or distance sensors because they don't send back a multi-bit signal.

The sensor we choose must be connected electrically to the control system to communicate feedback with the PLC. The sensor must also have power delivered to it; This can be delivered by the power supply.

The implemented sensors satisfy constraint ii (4) by communicating to the PLC which compartments have a device in them and which ones do not. In order to test the sensors, a device will be placed between the send and receive ends. The signal will then be examined to make sure the sensor is detecting the "obstruction" properly.

Input: Power from the system

Output: Bit signal to the PLC system

D. Power Supply

For all of the mending machine's main systems to execute their tasks, they must be powered electrically. We plan on using a wall outlet as our power source; we will connect a power cord with a ground-fault circuit interrupter, GFCI, to the power supply that is nested in our vending machine. This will supply power to the PLC, microcomputer, barcode scanner, card reader, solenoid locks, sensors, and LEDs. Most of these systems will all need varying direct current voltage levels which require an AC/DC converter.

a) AC/DC Converter

All of the systems that compose our vending machine require a lower DC voltage than the 120 V AC wall outlet supplies--the PLC will probably be the only system that is powered with 120 V AC. The AC/DC converter will step down the 120 V and convert the AC power to DC power. From there the voltage will be amplified by Op-Amp circuits each corresponding to the voltage level required by each system. This system satisfies constraint iv (2) and will be verified through simulation and measurement using a DMM (Digital Multimeter) and Oscilloscope.

Input: Power from the mains outlet

Output: Lower-level DC voltage

b) *Power Protection*

To physically guard our systems against current there will need to be several different circuit protection components to the point of redundancy. If the GFCI senses any leaks in the electric current it will immediately trip and shut off the power protecting the power supply of the vending machine—this satisfies constraint iv (1) that was created due to engineering standard NEC 422.51 [6]. There will also be a circuit breaker before the power supply and fuses after the power supply to protect each sub-system. With these multiple layers of protective measures, all of the systems will be safe from damage caused by possible over currents. To satisfy constraint iv (3) the power cord that connects the vending machine to the wall outlet will be accessible to unplug—acting as an emergency stop control. In order to test the GFCI, there are cheap testing devices online that can be purchased to verify that it is functioning.

E. Communication

1. USB (Universal Serial Bus) Port

The vending machine will have a USB port as a form of communication between itself and the faculty computer. The device that will be used is a USB drive that will be able to auto-download the appropriate data from the Microcomputer.

Constraint iii (1) and specification 9 will be satisfied after the device has been tested. Constraint iii(1) was created due to broader implications. In order for the machine to positively affect the office workers, the team is adding the auto-download function in case there is no nearby computer that can communicate with the machine. To test the device, a drive will be inserted and then removed after a short amount of time. The data will then be read from the drive by a separate device to verify the drive contains the correct data.

Input: Data from the machine

Output: Data from Drive into the same or different machine

2. *Ethernet*

The ethernet cord shall be used to send and receive data to and from the customer. If the customer wants to see the database and who has taken items, they can request the file and it will be transmitted. The file will likely be a CSV from Excel that will feed from and to the database. The ethernet cable can be directly connected to the microcomputer and user PC using an ethernet connector, and with the right steps of static IP configuration, one can start transferring data from the microcomputer. The implemented Ethernet connection allows for constraints iii(2) and iii(3) to be satisfied, along with specification 2. Constraint iii(3) comes from the team's ethical consideration. There is no single specific standard applying to the data held, but the team believes that it needs to be protected regardless of the lack of a standard. In order to verify correct operation, the Microcomputer and a PC will be connected by ethernet, and data will be read and sent. Then the team will analyze the data to ensure it has been properly transmitted.

Input: Encoded message to the database

Output: Message signal to the connected device

3. *Barcode Scanner*

To register the individual devices to the machine and properly keep track of the current owner of the device, a barcode scanner will be installed. When loading the devices, the user will first have to scan their barcode, registering them to the indicated compartment. This will tie the device's ID to the compartment's location. The next board cannot be loaded until the previous one has been registered and locked. This will allow the database to then tie the rented device to the student, allowing us to keep track of its possession.

This motor system will follow constraint iii(4) and specification 4. The scanner allows for a simple way to record the ID# of the device which is stored and sent to the Microcomputer to be filed and organized.

Since this hardware's sole use is to record data, the testing process is mostly digital. The barcode scanner can be tested by keeping a note of what can and cannot be read. Through the process of trial and error by continuous testing, the validity of the device can be verified.

Input: ID of the device.

Output: Registering the location of said device.

4. *Card Reader*

The card reader shall receive a signal from an ID card issued to the student by the college. When the signal is received, the device will send the data to the database through the microcomputer. The Reader will have an indicator light for a correctly scanned card to notify the student that he/she is good to proceed. The card reader will satisfy constraint iv(5) and specification 5 once it is fully functioning. In order to verify correct operation, an Eagle card will be scanned and the data sent from the scanner will be checked to ensure the ID is read.

Input: Information from Eagle Card

Output: Create Data and send a signal to the microcomputer

5. *UI (User Interface)*

The user interface will be connected to the microcomputer and will allow the user to input their name, email, and which class(s) he or she needs a device for. The information is also relayed through the PLC system.

a. *LCD (Liquid Crystal Display)*

A User Interface (UI) is necessary for the student to select the necessary board since it can be used to collect information from the student, such as their name and email address, and when the information has been verified, the UI can be used to select the needed board from the given set of choices available. For the interface, it would most likely be a touch screen LCD if not a display for the user to input the information required. One of the constraints that we must follow is that it should be compatible with the microcomputer system we would end up using. For the system to work the following functions of the user interface should be read: a) should be able to recognize the depression of any key/screen and should be able to identify it and send it to the microcomputer. b) should be able to display coming off from different systems or subsystems or from the interface itself. Each time the operator accesses a menu function, the user interface module will send a notification to the main system i.e., Microcomputer. The relevant system will be informed by the microcomputer in response, and that system will then establish a direct connection with the user interface (UI). When the operator selects a menu function, the user interface module will communicate with the microcomputer, which will then alert the appropriate systems so that the function can be performed.

The system will be analytically validated by inputting student information and by selecting a board from the given set of choices and will be checked to see if the system was able to grab user information and send it to the database or not. The system would also be checked to see whether each message from the different pertaining systems is displayed properly or not. For example, if any information was not valid then the microcomputer should be able to communicate to the UI to display an error message and should ask the user to enter the information again. The UI will allow constraint iii(6) to be satisfied after the appropriate testing is verified.

Input: Message Signal to Microcomputer System

Output: Microcomputer signaling to PLC or UI itself.

V. Timeline

The attached Gantt chart displays the task to be completed over the course of the project. Each phase contains the label of the tasks, the time allocated, persons assigned, and dependencies of other task. Phase 1 is comprised of the design process. Phase 2 is the subsystem design phase. As a team we are to design the power system. And each team member is to complete a subsystem. Phase 3, pre-construction, is the time between approval and holiday break. This will be used as the prep time before our official construction phase, completing the work needed to be completed before working on the final product. Phase 4, the construction phase, is when most of the work will be done and is separated into 3 sub sections: Programming, Integration, and Physical Build. The programming will be primarily handled by Dillon Williams and Nidhay Patel, while the integration will be overseen by Austin Sigg, Ryan Reed, and Michel Turpeau. The final construction phase will be a collaboration between the ECE team and ME team. Phase 5, finalization, will primarily be testing and adjustments, ending with the delivery of the final product.

(The chart is attached on page 7)

VI. References

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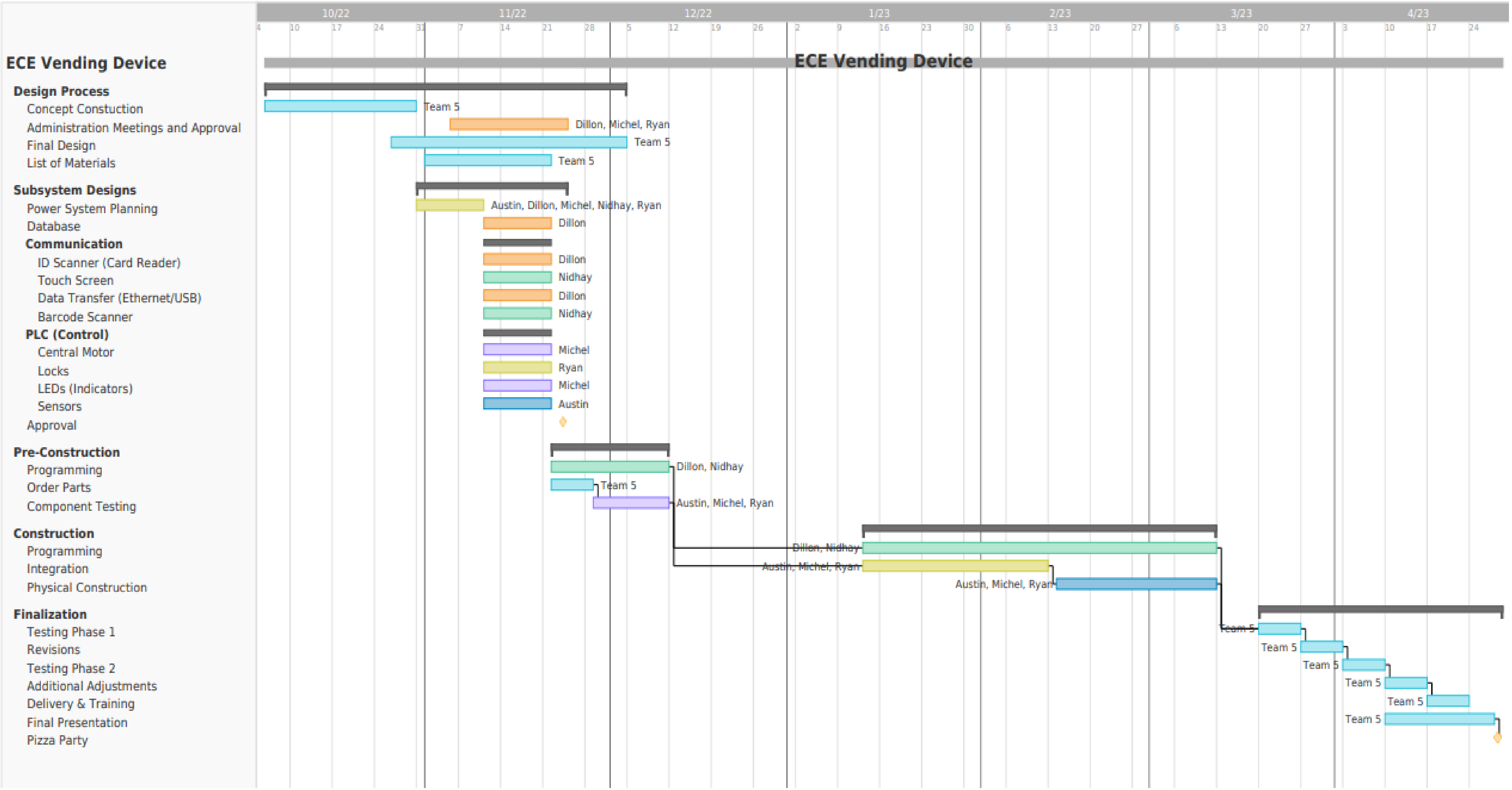

Figure 2. Gantt Chart