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Automated Storage & Retrieval System
(AS/RS)

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ABSTRACT

The purpose of this project was to improve upon the initial design of the Automated Storage and Retrieval System (AS/RS) demonstrator previously constructed and conceptualized by Joseph Faith and Greg Clevidence. Larger scale systems that this one model replicates are integral in the manufacturing industry for product management and eliminate significant portions of time in processes. The demonstrator is a table-top device focused on robustness, safety features, and offers a realistic depiction of similar systems used in the field. This system is meant to teach future students at the University of Southern Indiana about this aspect of manufacturing, which is the core objective of this project. The demonstrator features single and dual operation commands, with emergency stops with a side maintenance door to mimic the real-world safety features. The system also features a CLICK+ PLC, which is more representative of the teaching environment in the SCADA classroom and one of the integral ways that students will ultimately learn about automated storage and retrieval systems.

AUTOMATED STORAGE & RETRIEVAL SYSTEM

1. INTRODUCTION

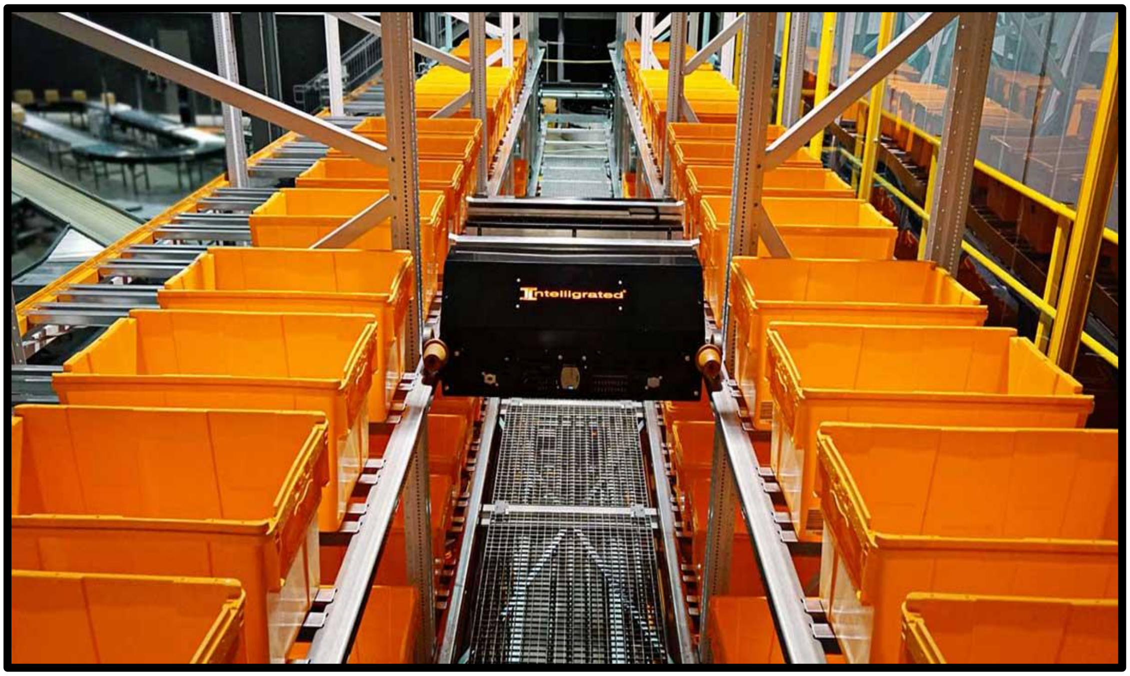


Figure 1: Factory Example of an AS/RS System [1]

Automation in the manufacturing industry has revolutionized the speed manufacturers can push out products to storefronts and customers. Automated Storage & Retrieval Systems are machines and systems that move in a confined three-dimensional space aimed at minimizing the space needed to store items. The goal of these machines is straightforward: retrieve an item from a bin or location, give the item to the user of the machine, and if desired store another item in a location. Retrieving an item alone is called a ‘single operation’ while the process of retrieving and storing an item is called ‘dual operation’. The AS/RS in Figure 1 is denoted as a single operation system, for example. Before the development of these types of embedded systems, however, factories were a bustling and often much more dangerous place. Freight would always be moving around, and space for that freight would dwindle as more was made.

“Warehouses were wide-open, and storage was spread out, which didn’t make good use of the space. As demand picked up, warehouses had to handle greater quantities of goods. The way inventory was stored didn’t lend itself to the process of demand-oriented flow and picking” [1]

The need for compartmentalization was growing rapidly as the flow of goods was being disrupted greatly by the limited space these warehouses could provide. It could not only be a safety concern, but also hinder the transportation of these goods to customers and out of the factory workers' way.

Thus, enter in the Automated Storage and Retrieval System (AS/RS). Automated Storage & Retrieval Systems have been around since the 1950s. These devices have offered compatibility and simple storage for a myriad of different devices and tools. In the modern-day world, these systems have aided in the compartmentalization of freight and merchandise for many warehouses. These systems can be impressive, spanning sometimes from the size of a small shelf to the size of a whole building depending on functionality. Most require some form of actuation, usually along an X, Y, Z axis, however some have been known to simply function in the X and Y axes. Several types exist out in the real world, with vertical carousel AS/RS, linear AS/RS, and several more serving factories and manufacturing facilities for years to come. With numerous types of systems and different functionality depending on the factory and manufacturer, it's important then to be able to understand the AS/RS's often complex coding, actuation, and design. There is a need for understanding automation in the field of industrial factories for compartmentalization of tools and products due to expanding factories and overpopulation in the world.

Often, these systems are managed by technicians within the company, but this is learned from on-the-job training and experience beforehand. Most students who graduate from universities such as the University of Southern Indiana may not have a lot of experience or exposure to these systems. It is important then to be able to show these valuable systems that aid factories and manufacturing facilities to students so that they have some experience with them and give them an advantage in the field. By teaching students about these systems and how they work, as well as relating it to relevant classwork material, universities and institutions can further bridge the gap between the modern engineering field and the college. This is the need this project aims to satisfy.

2. BACKGROUND

The manufacturing industry has evolved substantially since the first industrial revolution. A substantial amount of this revolves around finding proper storage and space for items so that workplace accidents are avoided & space is used efficiently. The automated storage and retrieval system was thus created to handle this task. The very first automated storage and retrieval system was created and "…. went into operation in 1962, installed at a Bertelsmann book-club warehouse in Gütersloh, Germany." [3] The expanded storage allowed for several manufacturing plants to create additional space and allow for a much safer work environment. In the modern age, this technology is much more complex than its predecessor of 1962. With coding languages that are more complex and robust, these systems can be incredibly complicated in terms of hardware and software. That is why it is important to teach future generations about these systems. At the University of Southern Indiana, the automated storage and retrieval system demonstrator idea was conceptualized to be able to teach students about these fascinating and complicated systems.

2.1 Previous Solutions/Products

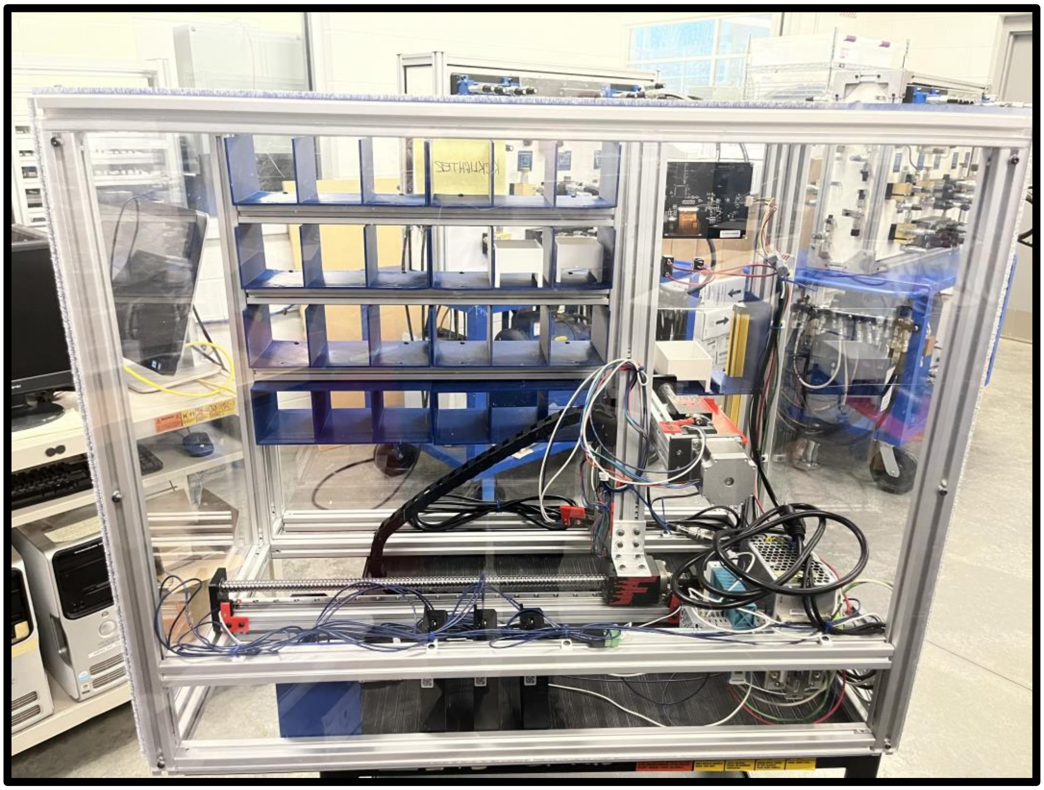


Figure 2: Old AS/RS Build from Spring 2023 Semester

Teaching future generations about these embedded systems requires that functioning demonstrators and simulations be made for those interested in learning about them. The AS/RS Demonstrator will do just that. Developed by Greg Clevidence and Joseph Faith, it consisted of an enclosed structure with three actuators controlling a small, printed plastic arm that would retrieve items from small boxes held in blue containers and is shown in Figure: 2. The machine featured single and dual operation commands, where it could retrieve and store an item in whichever place a user would like. As seen in Figure 2, which is the system itself, it featured an area where the user or customer of the system could choose their selection on the HMI or human machine interface. This would then send a signal to the Arduino, the brains of the machine, which would then send a signal to the three actuators to retrieve the items desired with the plastic arm. These actuators were controlled by three stepper drivers for each, which aided in controlling the pulses received by the actuators as well as a ten-amp power supply. These items formed the backbone of the system and summed up the large portion of the system's overall function. While the fabrication of the system was constructed, it lacked functionality and proper safety precautions that were relevant to the manufacturing engineering field. The wires were not properly managed, which allowed the actuators to run into the side of them. The left most portions of the storage section (the blue containers) were not able to be accessed with the picking arm. Some parts of the system were not functioning, while a few were broken and simply needed replacing. The problems in the machine will hinder any sort of learning experiences that students in SCADA could learn. These problems along with others stressed the need to create functionality and user friendliness as well as improvements to the overall system. That is what the second phase of this project plans to bring.

3. OBJECTIVE STATEMENT

This project aids in providing functionality, user friendliness, and overall quality of life improvements to the retrieval system. The intent is to create a functioning system that mimics real world applications of an AS/RS system for a classroom setting.

3.1 RELIABILITY & LONGEVITY:

The demonstrator must be a reliable and robust system to teach students in SCADA and others in manufacturing engineering study for many years to come. Because this product will be utilized by the university, maintenance must be made as straight forward as possible, and parts must be replaceable/ readily available for simple swaps of damaged or malfunctioning parts.

3.2 Functionality:

The demonstrator must perform as programmed and desired, with single and dual operation for retrieval and storage. All items within the system must work together and communicate properly. This functionality was not possible with the previous design but will be achieved by this machine.

3.3 Accurate Representation of Real-World Applications:

The demonstrator must mirror real world applications of this machine. The machine must also imitate manufacturing and factory automated storage and retrieval systems that are currently being used in the workforce. This includes safety features, up to date system technology, and comprehensive easy human machine interactions. This will provide a greater understanding of the machine's usage and advantages in the field of Manufacturing & Industrial Engineering.

4. REQUIREMENTS & CONSTRAINTS

In terms of the overall system, there were a few constraints that aided but also hindered several different decisions when creating the AS/RS. One of these constraints that was present within the system was the continuation of the project with materials from before. While renovating the whole system to include new parts, some parts seemed integral to keep, such as the actuators and the stepper drivers. These fundamental building blocks would be important to the overall integration with the newer system, but still could be limiting at times to work with. Another constraint was the relatability and classroom application of the machine. Originally, the machine was built with an Arduino Uno, but this system did not seem like a proper tool for teaching students about classes in manufacturing like SCADA where these machines were most prevalent. Thus, the machine would need to correlate with some of the technology utilized in that class and others for manufacturing engineers. Items like the programmable logic controller (PLC), and industrial level human machine interfaces (HMI)s had to be considered and taken into account. Other considerable constraints include the portability of the device, the amp draw (which was around 9.93 Amps) of several components already within the system (and those being added in), and the overall time frame that the deliverables must be completed. Because this was a university-funded project, there was no cost constraint within reason. More considerations are as follows:

4.1 University Applications

The system will be designed with the students on campus in mind, and the SCADA class in particular consideration. PLCs and HMIs are commonplace in the class, and so the bulk of the system's overall coding experience will be focused on that medium.

4.2 Safety and Precautions

The system will feature many different safety features commonly seen in the manufacturing engineering field. These systems are integral to not only safety, but the learning experience about common safety practices in factories and with automated storage and retrieval systems. This includes adding an emergency stop, door switch (which utilized a reed switch), light curtain, and on/off button on the HMI screen, which are commonplace components used in safety precautions.

4.3 Reliability

The system must be functional and work as intended. It should improve upon the original design to fulfill its functions, while also staying slightly faithful to the original creators' ambitions. The system must represent a real-world working system, but on a smaller and more demonstratable scale and be utilized as an instructional tool. The system must showcase longevity and robustness to be usable for multiple years to come. Some examples of improving the system's reliability include adding a rail on the top of the system to increase stability of actuators and replacing broken limit switches as well as fixing the system's actuation.

4.4 User Friendliness

The system should be simple to debug and include proper documentation of wiring as well as system functionality. In the system before, the wiring was convoluted, and very little information was given on the overall wiring of the system. User friendliness will also include the development of a new HMI interface for ease of access and simple debugging. The system will also be easy to reset and maintain, with new maintenance doors included on the side of the machine, components oriented for the ease of maintenance/troubleshooting and a new cart that the demonstrator will sit on.

5 PROJECT DESIGN

This will be a portable demonstration model for the classroom setting. This AS/RS demonstrator model will be powered by a 120vac outlet. The demonstrator is going to be constructed in a manner that will mimic real world applications. It will consist of a Click+ PLC, an Automation Direct HMI, a safety circuit system, and a full wire diagram with proper cable management. These are improvements that have been advised to be addressed by the former group and by Mr. Kicklighter, the client and teacher of the SCADA class.

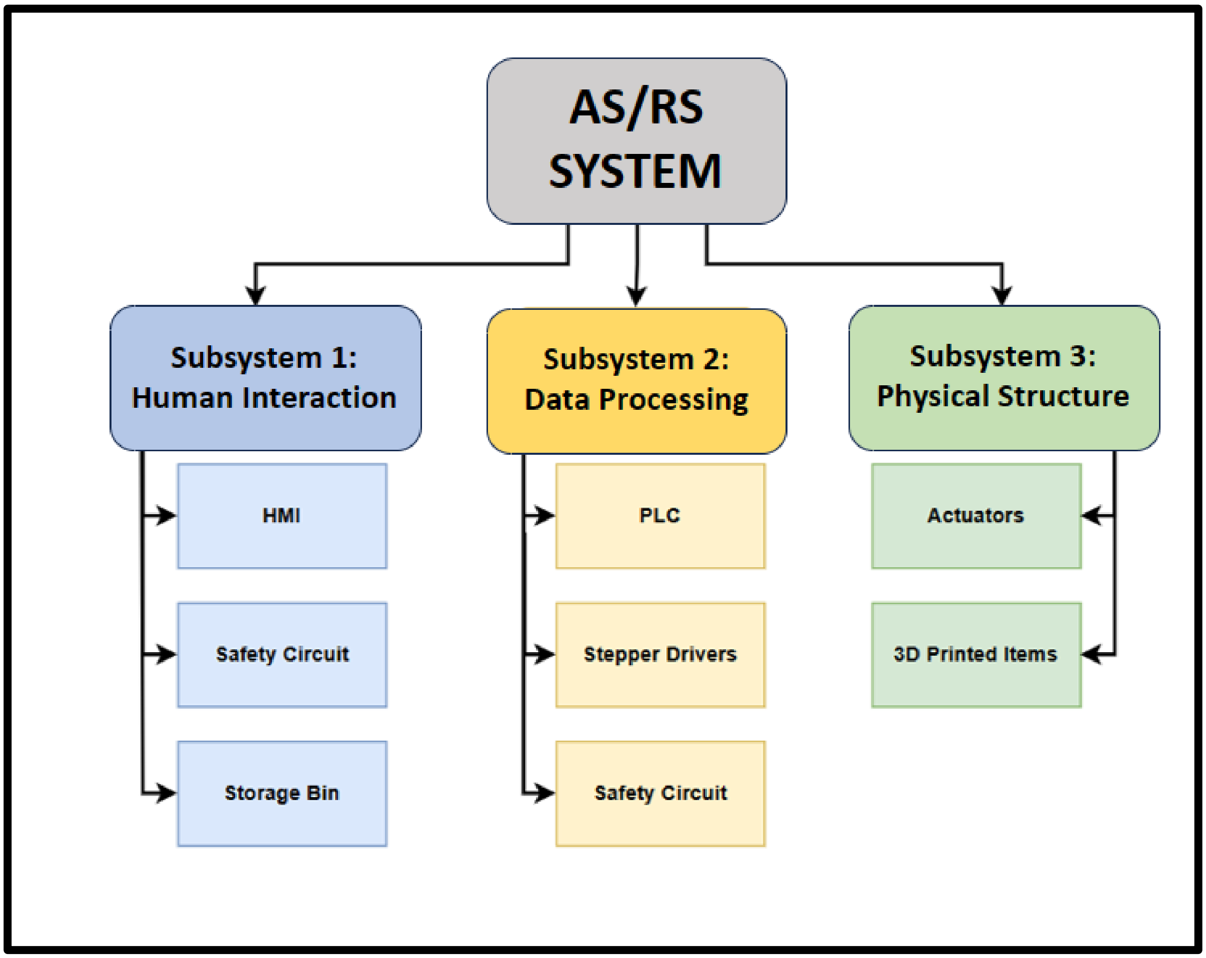


Figure 3: System Block Diagram

The Automated Storage & Retrieval System (AS/RS) project focuses on the functionality, safety, and longevity of the machine. The workload was split between the software functionality, the hardware functionality of the project and this can be shown in Figure: 3. The incoming power from the wall will be converted to a DC voltage to power the automation and control portion of the demonstrator. There will be an HMI that is used to interact with the user. This HMI will receive an input from the user of what they would like to receive. The demonstrator will check to see if there all safety features are active. If so, it will retrieve the desired part and deliver it to the user. A simplified model for this system is presented in Figure 3. There were three main considerations that the team focused on when creating this system:

There were a few major design choices when it came to the overall functionality of the system and the direction that our group wanted to take the project. While there was an emphasis on sticking with some of the equipment provided by the previous group, many things were required to be taken out due to design considerations listed above. The overall functionality of the system was imperative and one of the main focuses for the project. The first design choice that our group made was on the control of the system.

5.1 The Frame Of The Machine

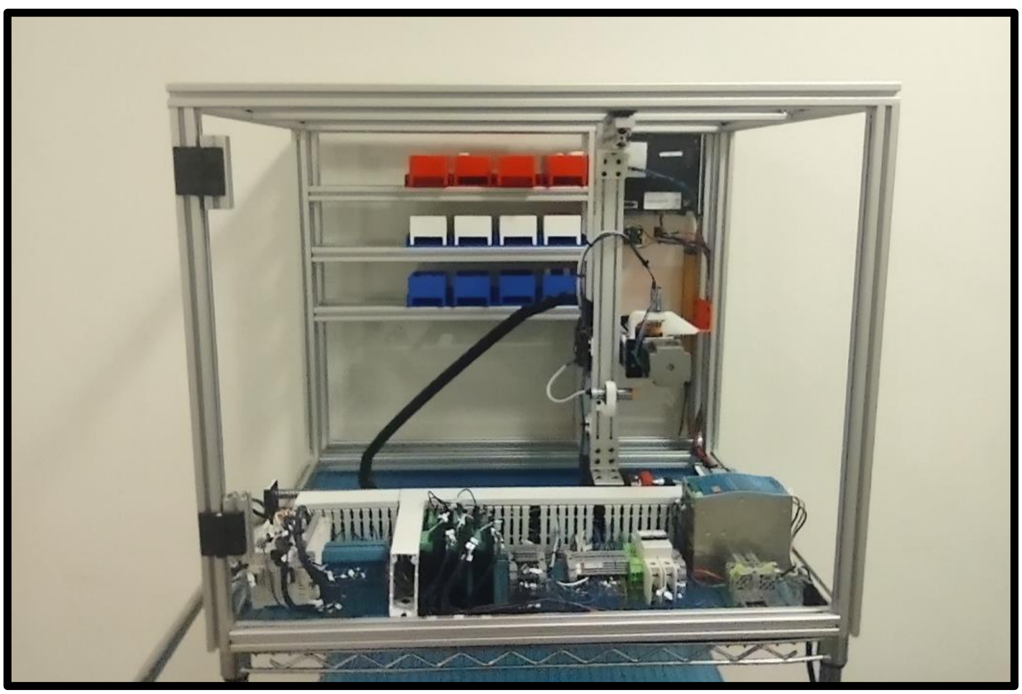


Figure 44: Back View of Machine

The frame of the automated storage and retrieval system demonstrator was originally constructed by the previous team, shown in Figure: 4. This frame was made of extruded aluminum bars, fastened with several 90-degree angle brackets. The dimensions of the box were: 25” (height) x 30” (width) x 24”(depth). There were a few issues with this design choice (the most prevalent being the issue with the actuators & spacing),so components were located side by side. Because of the cramped nature of the box, this design choice would cause potential damage to the wires and to those using the design. Our team’s solution for this issue was to extend the depth of the box out by 4 inches and utilize wireways to separate the components/wires/actuators. Extending the actuators outwards allowed for more room to allow the machine to move, and execute the code provided to it by the PLC. The large white plastic wireway (as seen in the figure above) provided not only a safe location for all wires (improving our wire management), but also allowed for a physical barrier between the component side of the backplate & the actuators. The wireway also allowed for even greater organizational potential, allowing for easier labeling of the wires and traceability of these wires.

5.2 THE PLC

Figure 5: Chosen PLC

One of the current problems with the system was with the Arduino Uno microcontroller. While the Arduino Uno is a cheap inexpensive way of programming, the code created for this project was slightly messy and convoluted in execution. It was previously used by those who had started the project as the brains of the system, but the coding became slightly impractical to go in and change due to the large amount of code that would be required to sift through. It also had no relevance to any class in the manufacturing engineering field for SCADA students, so this must be changed. Our decision that we have set in motion is the removal of the Arduino microcontroller to utilize a different system to control our AS/RS. Our solution to this problem is replacing the Arduino Microcontroller with a PLC (programmable logic controller). When it comes to solutions to this problem, three came to mind. These were:

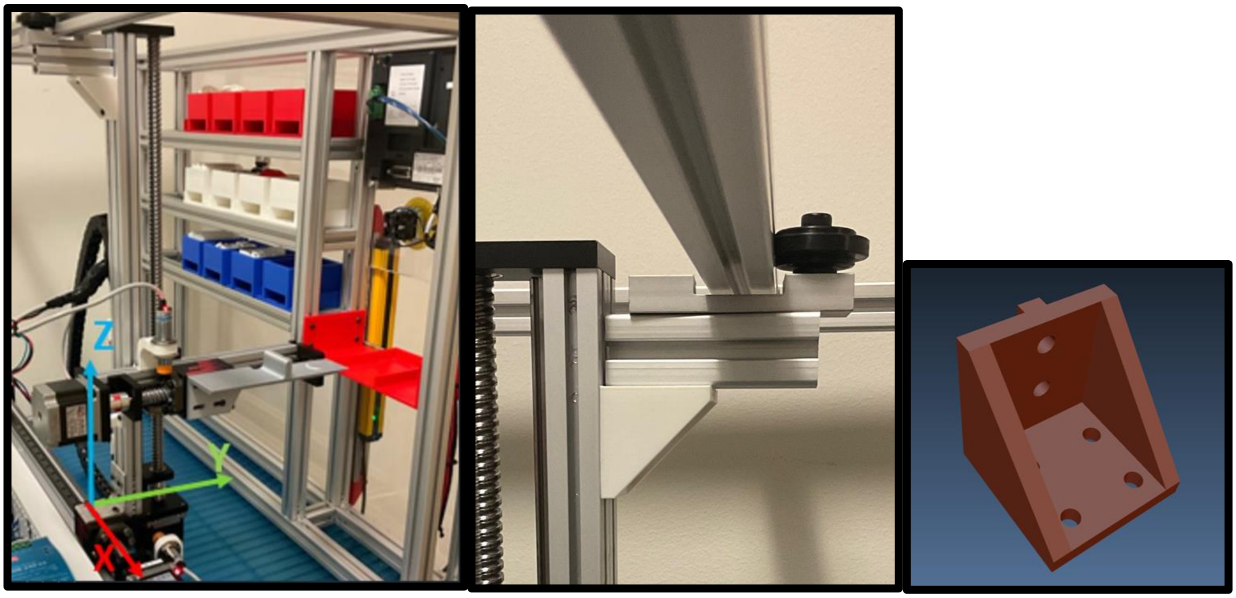
- Utilizing an Allan-Bradley PLC
- Utilizing a CLICK+ PLC
- Keeping the Arduino Uno microcontroller.

Constraints for this choice include that the system must communicate with the stepper driver motors. The system must be easily programmable and potentially removable if necessary. Finally, the system must represent SCADA classroom work as well as be representative in the field of Retrieval Systems. Out of all of the choices, there was an obvious answer for one of them. Automatically, the Arduino Microcontroller is removed. Its impractical amounts of code make coding it convoluted. It does not represent relevant work in SCADA. This then made the final choices come down to the Allan-Bradley or the CLICK+ PLCs. Ultimately, the main deciding factor with these aspects came down to user friendliness and availability of programming software. The CLICK+ PLC was thus chosen. The team is more familiar with working with the CLICK+ PLC, it was more cost efficient than the Allan-Bradley PLC, and it was also the most utilized PLC in the SCADA classroom. This PLC is shown in Figure: 5. This made the component the best to choose for this project.

5.3 HMI

Figure 6: C-More EA9 HMI [6]

After choosing the CLICK+ PLC over Arduino Uno, our team realized that a new HMI would be required. The connections between the CLICK+ PLC and the Nextion HMI, which was utilized before by the previous group, were not compatible and thus it needed to be exchanged. Some design considerations for this also include the communicability with CLICK+ PLC as well as the overall appearance of the HMI. The HMI also needed to be able to connect with any modules that would be included with the PLC, as there could be a chance later that a design change requires an extra module. The C-More EA9 T7-0L, shown in Figure: 6, was thus chosen. This HMI has a colored screen and is roughly 7 inches in width. The product can communicate with the PLC controller and is very similar to what is seen out in the industry. This HMI is programmable with a USB and an Ethernet connection, depending on what is desired it also features other commendable functions within it.



a b c

Figure 6: Actuation layout view (a) Guiderail with Roller (b) & 3D printed adapter(c)

5.4 Guide Rail

There were issues with the overall stability of the previous system's actuation arm. The system was top-heavy, and wobbly so any sort of accuracy or precision was not possible with the current set up. There were a few options when it came to rectifying this issue. A guide rail with roller was looked into as well as an updated 3D printed arm. Other options also included lighter actuators or potentially redesigning the containers for the boxes. What was finally chosen was a combination of solutions. A guide rail with a roller would be implemented and the 3D printed arm was updated. The containers for the boxes will be redesigned but no lighter actuators have been chosen to be implemented. The reason for this is due to the functionality of the overall actuators existing in the system: they work but require some simple stabilization. Another factor was cost efficiency and keeping true to the former design, as new actuators are quite expensive and can be problematic to install.

5.5 STORAGE/PICKING SYSTEM

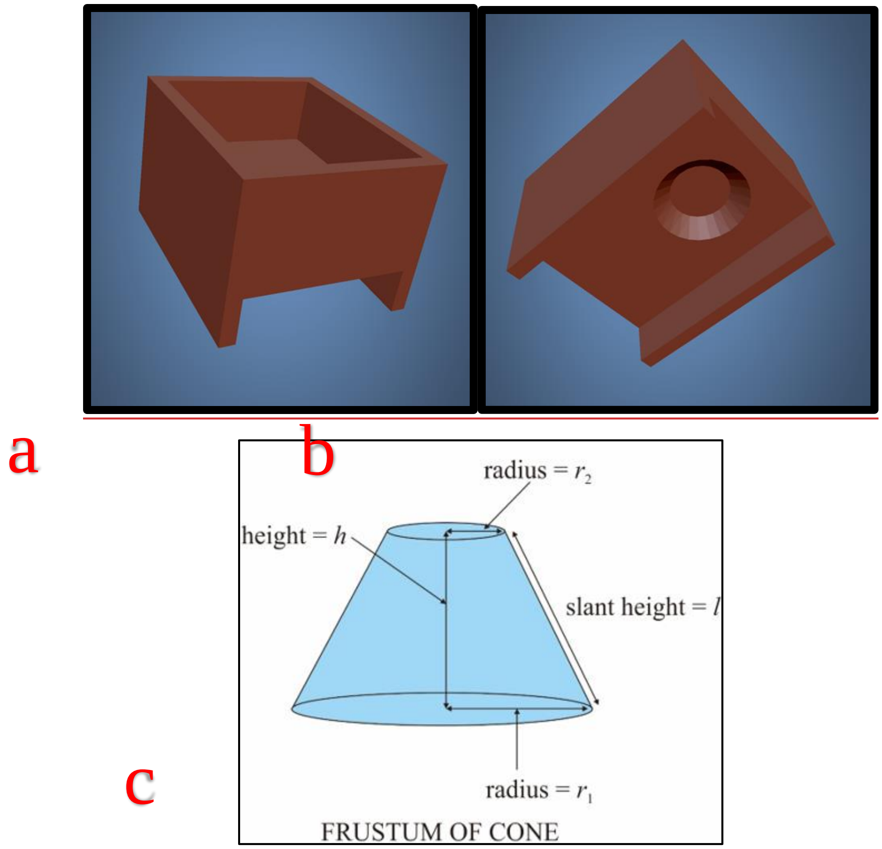


Figure 8: Bin Bottom View (a), Bin Top View (b) Frustum(c)[4]

5.5A. THE FRUSTUM

In the original bin design created by the group before, the bins of the system (which are retrieved in the system by the machine and stored) featured a small opening at both ends where the previous arm design could be placed into. Examples of this frustum design can be seen in Figure:8. This previous design, while functional, did come with the caveat of accuracy in the code when moving the actuators. Finally, the previous design also struggled with bin stability on the arm.

The way that our group fixed this issue was redesigning the bottom of the bins to have a conical frustum indent instead. This allowed for more leniency with actuation, and a way for bins to autocorrect their position on the picking arm when the arm executes the picking process. To improve the reputability of the bins position on the arm, a conical frustrum was used. The slant of the frustrum helps slide the bin into position with the arm. This design allows the bin to be misaligned with the arm by 0.25 inches. This distance is given by the difference between the top and both radii of the frustum.

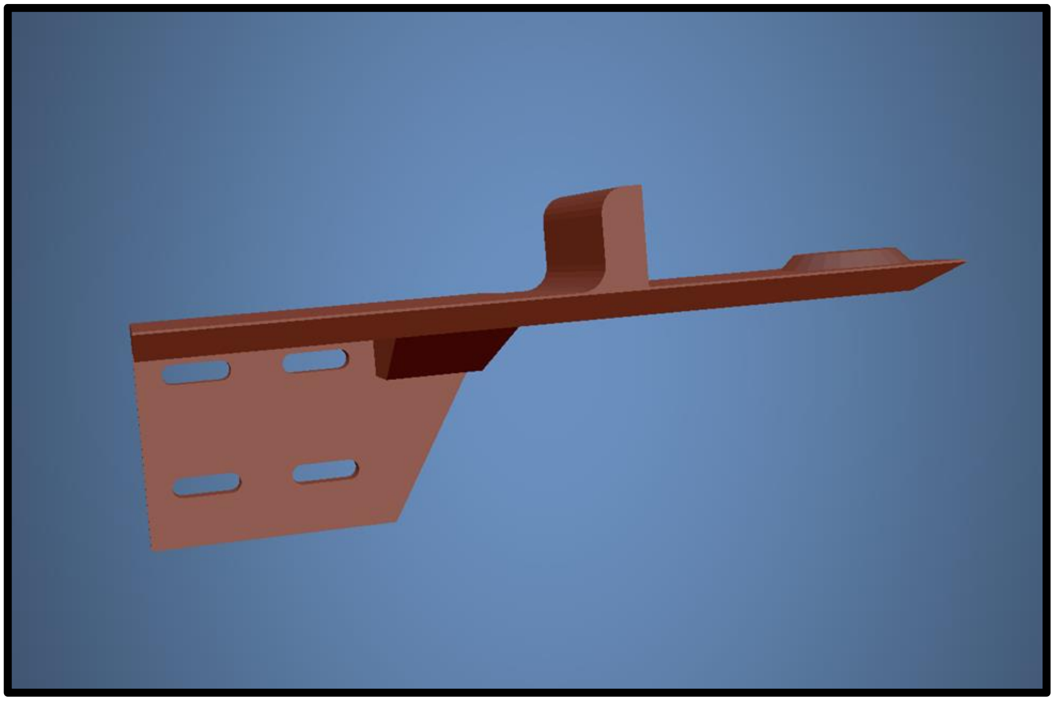


Figure 9: 3D Printed Arm with Frustum

5.5B. THE ARM DESIGN

The arm was made adjustable to help with misalignment issues. The previous arm bent over time, so the new arm was made thicker with added support to fix that issue. A frustum and retaining wall (as seen in the figure above) were also added for aid in aligning the bins properly on the arm. The front of the arm is chamfered to help in the event of a misalignment with the bin location. When the bin is lifted it will center itself on the arm because of the frustum and the back of the bin will align with the retaining wall. This wall is used to help keep the bin straight on the arm. This arm is shown in Figure: 9.

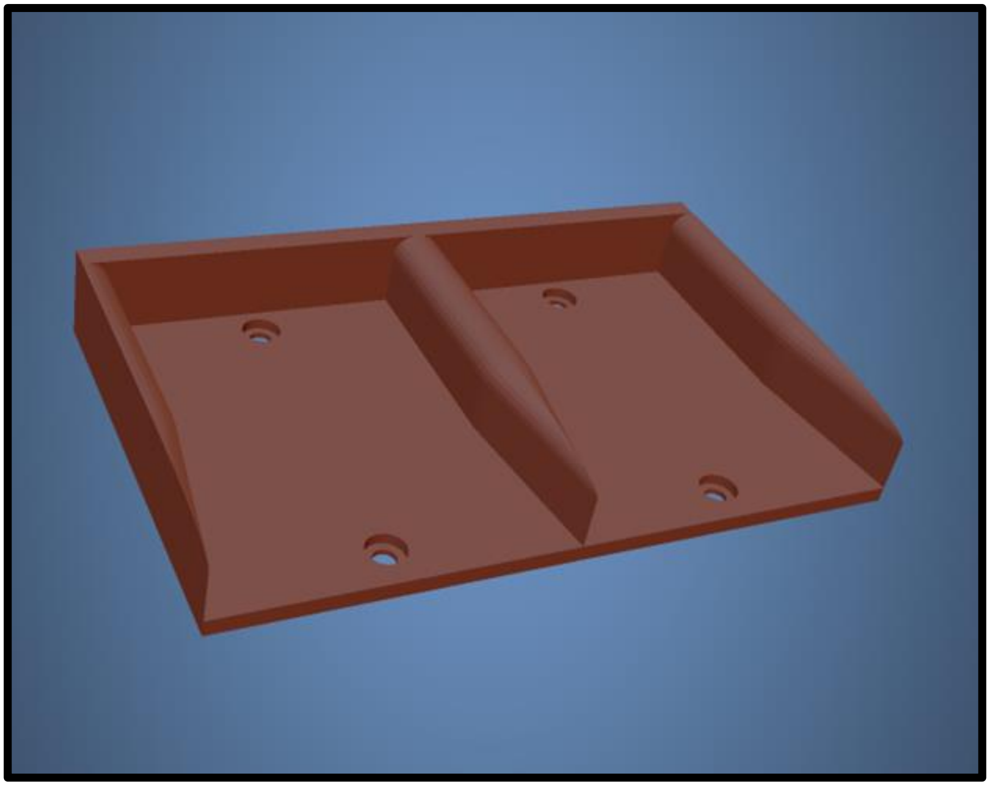


Figure 10: 3D Printed Storage Areas

5.5C. THE 3D STORAGE AREA

The storage area is designed to keep the bins in a repeatable bin picking location. The walls of the storage area, shown in Figure: 10, are used to keep the bin in a repeatable placing position. The entrance to the storage area is tampered to help align the bin into the proper side to side position while the stopping wall will help stop the bin at a consistent depth.

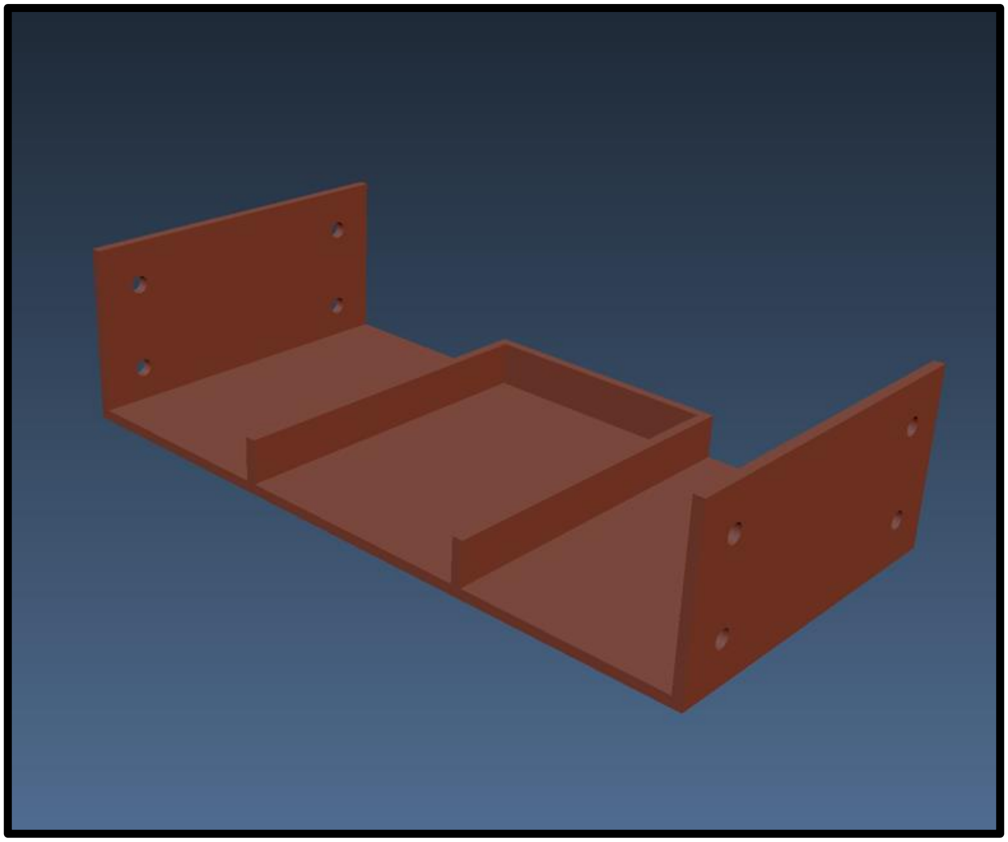


Figure 11: 3D Printed Staging Area

5.5D. THE STAGING AREA

The delivery area is the location where the bin will be retrieved from and placed onto by the user. When the bin is delivered it will stay on the arm and not physically touch the delivery area. This delivery area was 3D printed, and mimics the previous group's staging area, which was much larger and at a lower height. This staging area is shown in Figure: 11 The delivery area itself was made shorter, but mounted higher to align with the light curtain, which was mounted on the outside of the machine.

Figure 12: Emergency Stop Button

5.6 EMERGENCY STOP BUTTON (E-STOP)

One of the strengths of the new Automated Storage & Retrieval System (AS/RS) was its focus on safety & mimicry of modern industry safety systems. The emergency stop button is a typical safety circuit component that can be found in the manufacturing industry. This button is shown in Figure: 12. This button is a latching button, meaning that when pressed in, it must be physically turned in a different direction to unlock it. The emergency stop button was placed right next to the system's main power button and HMI and is easily accessible if the machine acts in an unpredictable manner or the possibility of injury to a user occurs.

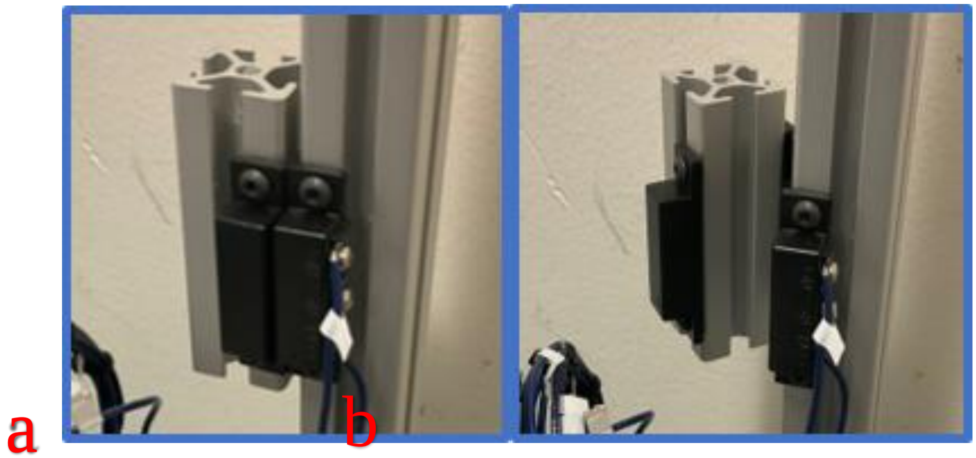


Figure 13: Reed Switch Open(a) & Closed(b)

5.7 DOOR LATCH

The safety door latch was another component created for the safety circuit. To properly perform maintenance on the automated storage & retrieval system, a back maintenance door was created for convenience of the system. These door latches are also typically seen in industrial facilities on a myriad of equipment. When the door latch is closed, the safety circuit is active, and the system then is operational unless something else is triggered. If the safety door is opened, the system stops, and maintenance can be performed on the interior sections of the machine. The door latch itself is a reed switch, shown in Figure: 13, which essentially opens the circuit when the maintenance door is open. After the door is open and the actuation process is stopped due to the door latch, then the user should put the PLC in stop mode, or the Circuit breakers should be shut off during maintenance.

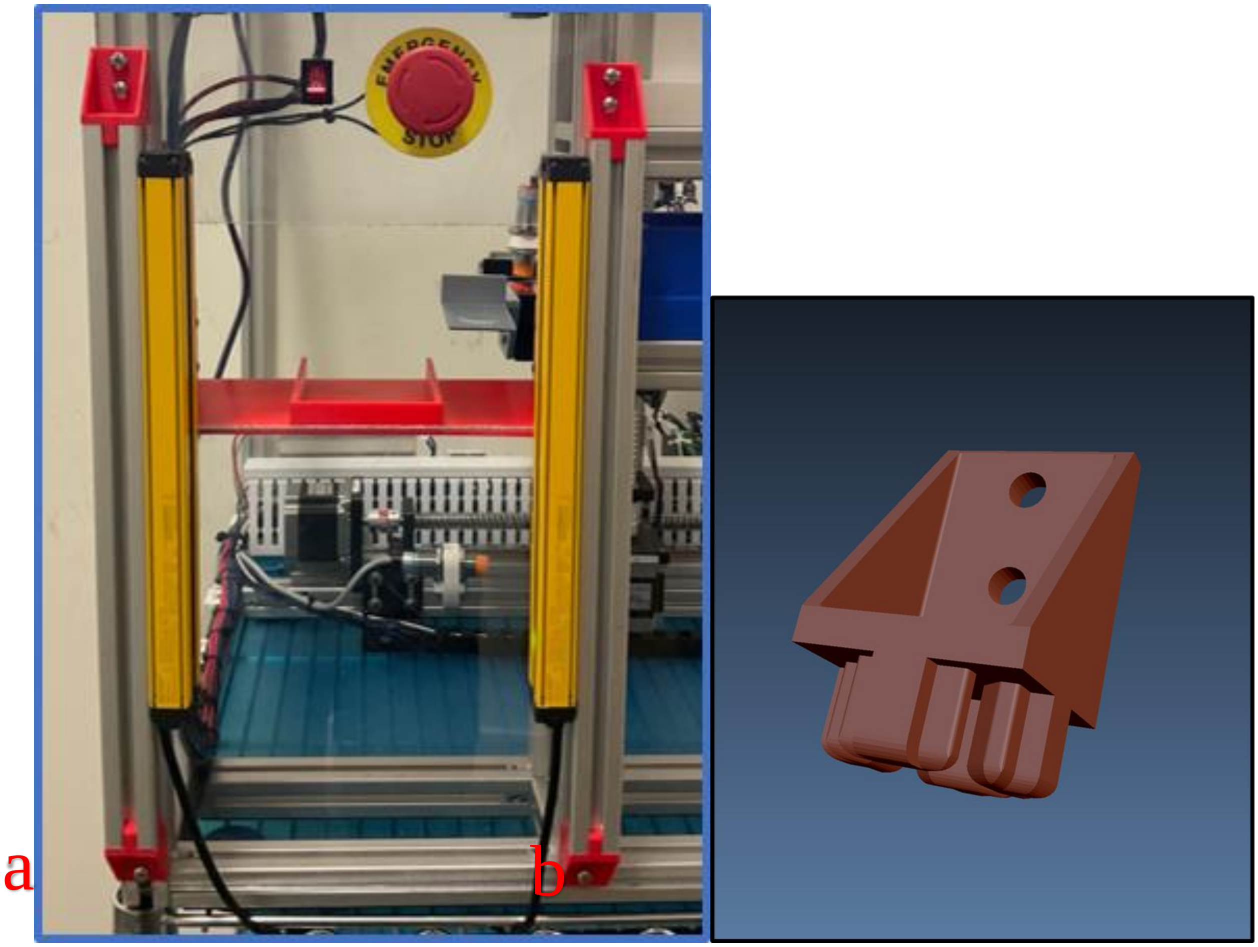


Figure 14: Light Curtain (a) & 3D Printed Bracket (b)

5.8 LIGHT CURTAIN

The original system solution did feature a light curtain, which is a set of opposing sensors that when their beam is obstructed will send out an electrical signal. The light curtain, however, was not set up outside of the delivery area. This light curtain and the mounting bracket are shown in Figure: 14. This posed a problem, as injury could happen to someone if they reached the delivery area while the machine was still in motion. To fix this issue, the light screen was moved outside of the delivery area with a set of extruded aluminum and 3D printed brackets as seen in the above figure to hold them in place. This allows for the proper installation of the light curtains where injury can be prevented.

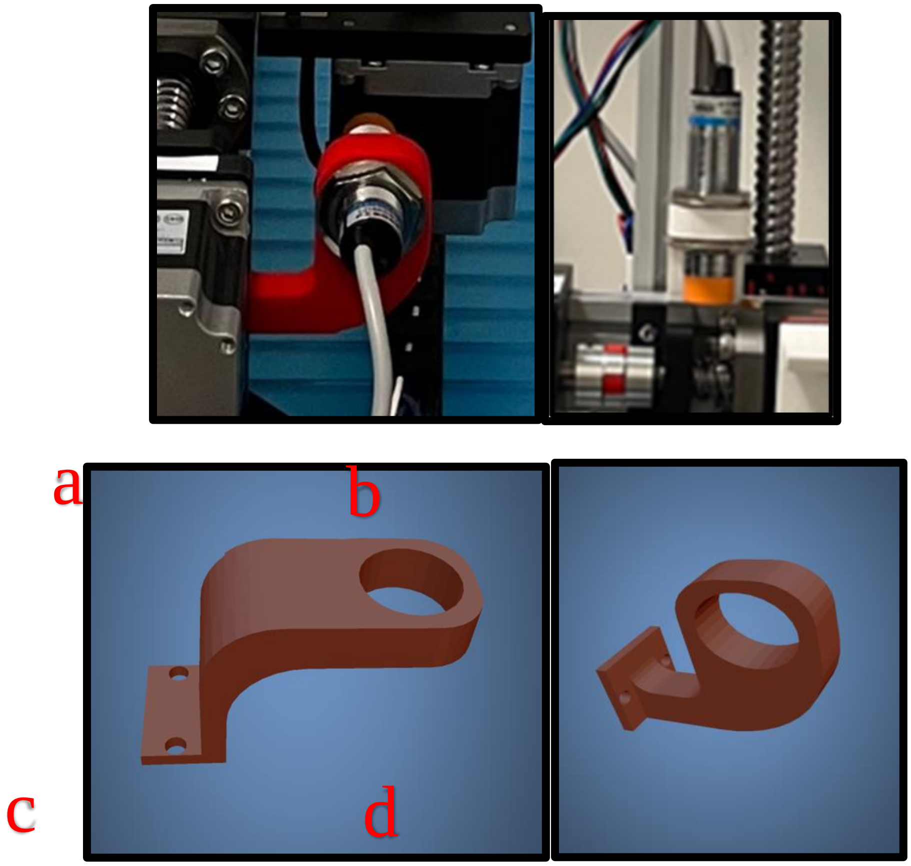


Figure 15: Proximity Sensors (a & b) & 3D Printed Proximity Switch Holders (c & d)

5.9 Proximity Switches/ Proximity Switch Holder

The proximity switches are used for the limit switches to protect the actuators. The previous solution to the AS/RS demonstrator used rocker limit switches. The issue with those switches was the travel of the button was shorter than the stopping distance of the actuators. When the actuation hits the rocker limit switch it would stop the power to the stepper driver but the momentum in the system would past the travel of the limit switch causing physical failures. To fix this issue of rocker limit switches breaking, proximity switches were used as the new limit switches. These proximity sensors and their mounting brackets are shown in Figure: 15. The proximity switches have a longer sensing distance than the old rocker switches. The proximity sensors use inductance to detect metal. With this sensing style it can be used as a contactless limit switch. With the 8mm distance, the actuators have plenty of time to stop before reaching the limit switch. The brackets designed to hold the limit switches are made for the proximity sensor to be adjustable to make setup and maintenance of the system easier. The figure above also shows the 3D printed proximity sensor holders, which were created to hold the proximity switches. These were mountable to the extruded aluminum and provided a simplistic way to change the machine's home position by adjusting their location on the extruded aluminum next to the actuators.

Figure 16: Fuyu 150MM Actuator [5]

5.10 FUYU 150 MM ACTUATOR

An issue with the earlier design was a lean created by the y axis actuator on the main vertical axis (Z axis). This caused a lot of issues regarding the stability of the picking process and allowed for wobble in the system to fluctuate the levelness of the picking arm. This also created a torque on the stepper driver motor of the x axis, which could be dangerous if further lean was produced. To combat this, two solutions were created. The first solution was a guide rail supported by a 3D printed bracket. The second solution was a new actuator to replace the 100mm actuator on the y axis. By utilizing a larger actuator of the same manufacturer, this actuator was able to provide more balance to the Z axis and levels out the main picking arm. This actuator is shown in Figure: 16.

6. PROGRAMMING

6.1 ORIGINAL SOLUTION

The previous group utilized an Arduino Uno to control the actuator's movement. The Arduino utilized C, with libraries of commands to control the speed, motion, and direction of the actuators. Programming with this language, however, can often be complicated and several pages of coding. The previous group was not able to implement functionality with this code in time.

6.2 NEW SOLUTION

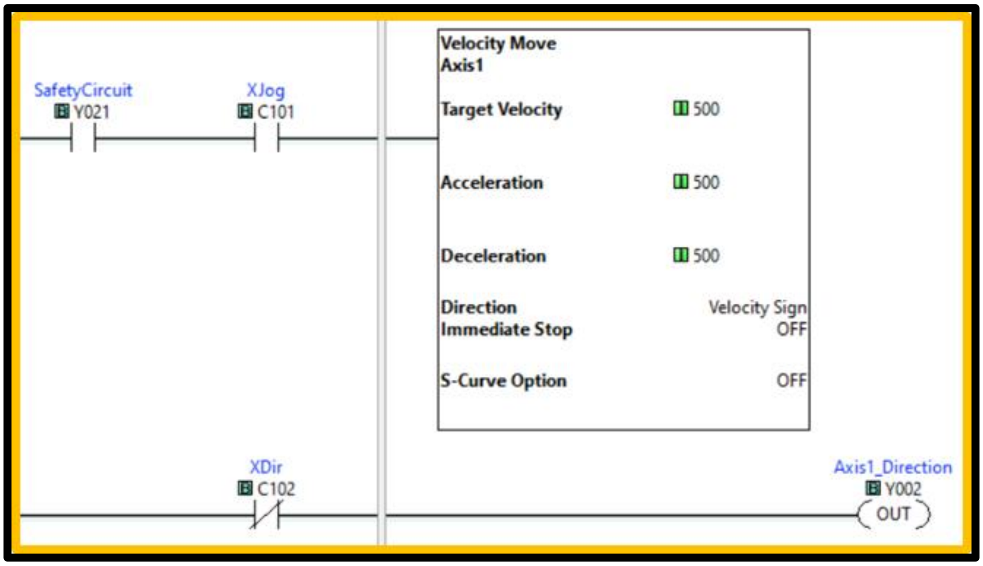


Figure 17: Example Code

The solution that our group created for the project was to utilize a new medium of coding with the Click + PLC (programmable logic controller). Programmable logic controllers are commonplace in the automation, manufacturing, and industrial fields. These PLCs utilize a type of coding language called Ladder Logic, which is shown in the above figure. Programming in Ladder Logic occurs on a rung basis, meaning that each row constitutes a 'rung' where internal bits, inputs, and outputs all feed into an output on the other side of the rung. This provided a much more visible experience with the code, and a simplistic look at the logic moving the actuation, which was one of the factors considered when choosing a new medium. Another reason that guided this decision was the prevalence in the field. Programmable logic, an example shown in Figure: 17, is commonly used in automation and is typically integrated into systems at factories across the world. Therefore, teaching students about these types of systems & this programming language was key. This choice of programming medium will help reaffirm ladder logic taught in classes like SCADA, Advanced Automation, and ultimately was the deciding factor in the team's pursuit of a new coding medium.

6.2A Initial Coding/Testing: Velocity Based

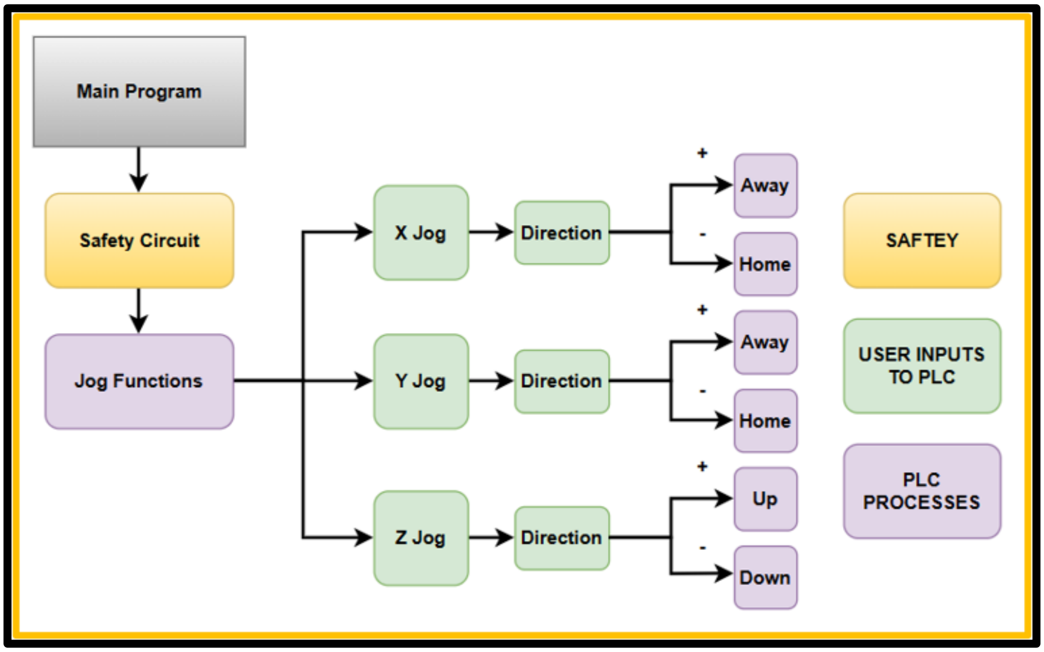


Figure 18: HMI Display (a) Flow Diagram of XJog Program(b)

To begin coding with the ladder logic programs in the Click PLC, we started with research and basic programs. The first program was to verify movement with the machine and ensure that it was possible. The first program created was called 'Jog Program' and utilized a function in the Click Programming software called the 'Velocity' function. This is a high-speed input/output that can be specified in the coding language. In terms of motion control, the High-Speed IO allowed for creation of three 'PTO Axis'. These include designating the limit switches, pulses, directions, and several other features. The flow diagram above shows the general logic behind the program. This diagram is shown in Figure: 18. So long as the safety circuit is functioning and not broken, the jog functions will be available. The three PTO Axis would then be available, where when one is pressed (for this example, Xjog), the actuator will move in that direction at a predetermined constant velocity. The directions were controlled by buttons on an HMI screen. Finally, the directions are denoted by a + or – button. The HMI screen is in the

Appendix: 2. The result was that actuation was possible, and therefore we could move on to position commands and more accurate movements with the actuators.

$$Measured\ Rate = 4063\frac{pulse}{inch}$$

$$Rated\ Acceleration = 500\frac{millimeter}{second^2}$$

$$Rated\ Max\ Speed = 40\frac{millimeter}{second} = 1.575\frac{inch}{second}$$

$$Pulse\ Rate\,\mathrm{Max} = 4063\frac{pulse}{inch} * 1.575\frac{inch}{second} = 6399\frac{pulse}{second}$$

Figure 19: All Relevant Equations Used

6.6B. Calculations For Moving Into Position Movements

Velocity movements were helpful in that they aided our group in characterizing our machine, and its stepper motors. In order to create an accurate bin picking program, our group needed to move from velocity movements to a specified position in the three-dimensional frame. This would not only offer a reliable position to pick the bins, but aid in the optimization later of the code/ actuator movements. Our group would need to figure out the amount of pulses per second our actuation was traveling and then the max speed. The first step was to determine the maximum number of pulses we could achieve into our stepper drivers and stepper motors. Our team began by constructing a small experiment where a constant velocity of 20000 pulses was sent into the stepper driver motors. The distance it traveled was then measured by a square propped against the wall of the x axis ball screw actuator. The average was 4062.99 pulses/inch with a standard deviation of 0.02992. The standard deviation is a value of how accurate our measurements were, and the average was in relation to the final number the group used. Because the standard deviation was low, the group was relatively confident that the measurements were accurate. This measured rate was then simplified down to 4063 pulses/inch. Once this was known, the maximum stepper motor speed was 500mm/s^{2}," which was a value found from all stepper driver datasheets.. From here, a rated maximum speed could be determined using dimensional analysis to find 40mm/s or 1.575 in/s. From here, a maximum pulse rate of 6399 pulses/s or around 6400 pulses/s was determined as the Maximum pulse rate. This would be the max value that our group could send into the stepper motors. To stay well within that range in testing, the group decided upon testing using a maximum amount of 1600 pulses/s. This would allow our group to move into position-based movement commands and code for more accurate/ repeatable movements. The calculations used are shown in Figure: 19.

6.6C. Bin Picking Program: Position Based

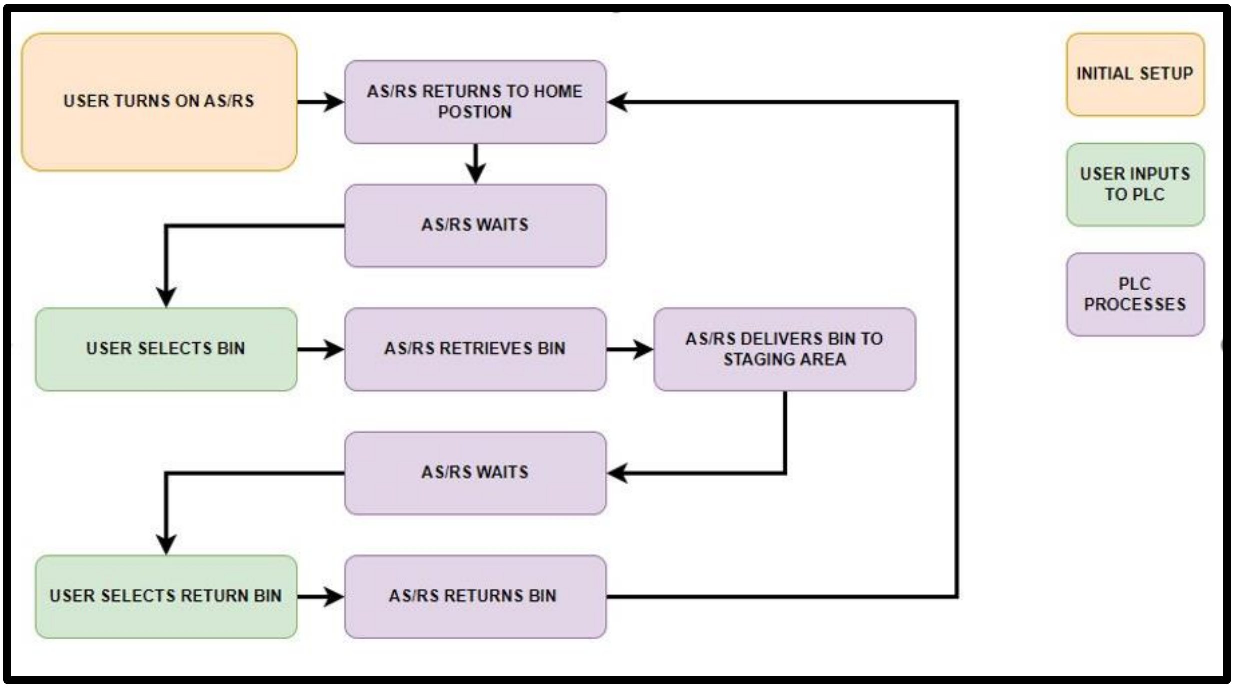


Figure 19: Flow Diagram for Bin Picking Program

Because the automated storage system has many different locations, movement must be accurate and timely with quick changes being able to be implemented. The flow chart in Figure: 19 shows the exact process of every single movement created for the picking and storing processes. Each box represents a Position Movement, except for the last box on each which is a complete bit. There was also a wait function in which the machine would wait on user input from the HMI or from other interactions. This is typical of automated systems which usually will do a function and then proceed with an idle function to wait. The code above was implemented and tested for functionality. It was proven to work, and both processes were successful. The flow diagram above shows how this could be implemented with subroutines. This final program can be found in Appendix: E and the addresses for these are located in Appendix: D.

6.6D. BIN PICKING HMI PROGRAM

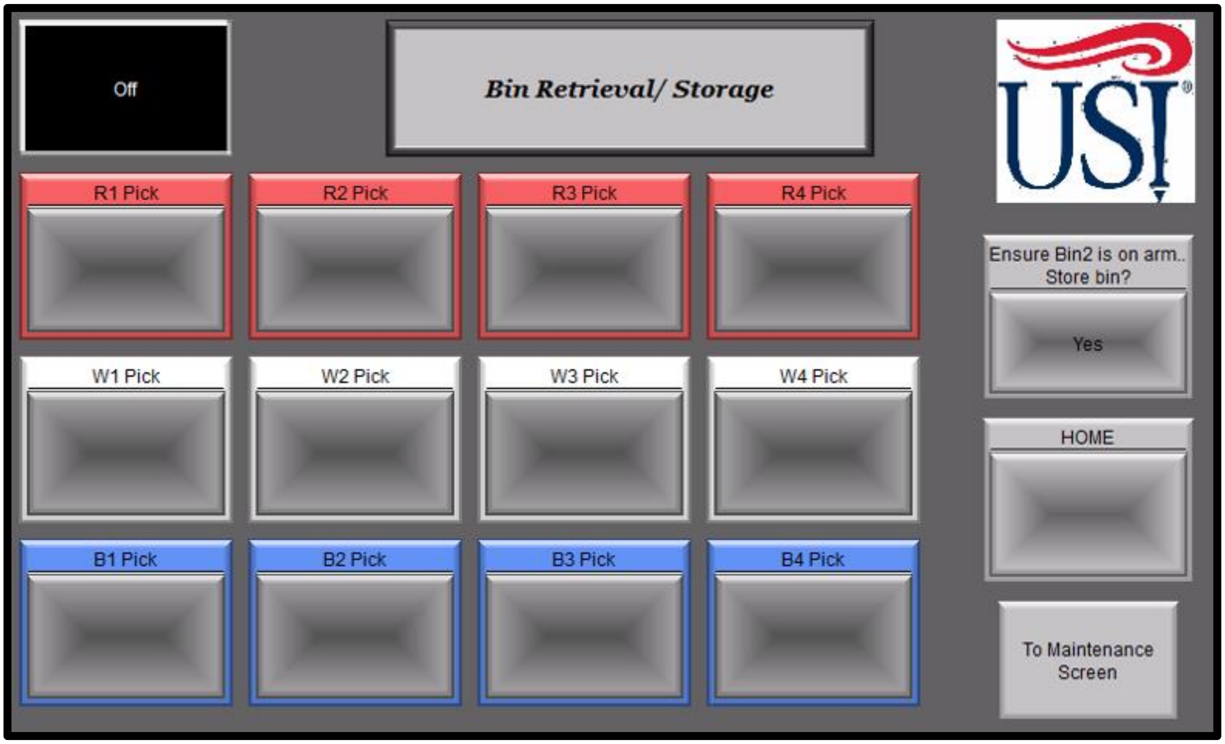


Figure 20: HMI Screen for Bin Retrieval/Storage Program

The layout of the HMI, as shown in Figure: 20, was chosen as the final version of the main screen for Bin Retrieval/Storage. This HMI screen mirrors the real-world representation of the machine's actual bin locations in color and format, making choosing which bin easier for users to see. A home button was placed on the HMI screen to help users home the machine before each picking/storing process. A maintenance screen is also accessible from this main screen, the maintenance screen being the Jog test screen that was developed in early testing. Finally, a button on the side appears just above the home button when users would like to return the bin after it has been delivered. This button will appear based on what users have chosen as their bin of choice.

7. CONNECTIONS BLOCK DIAGRAM

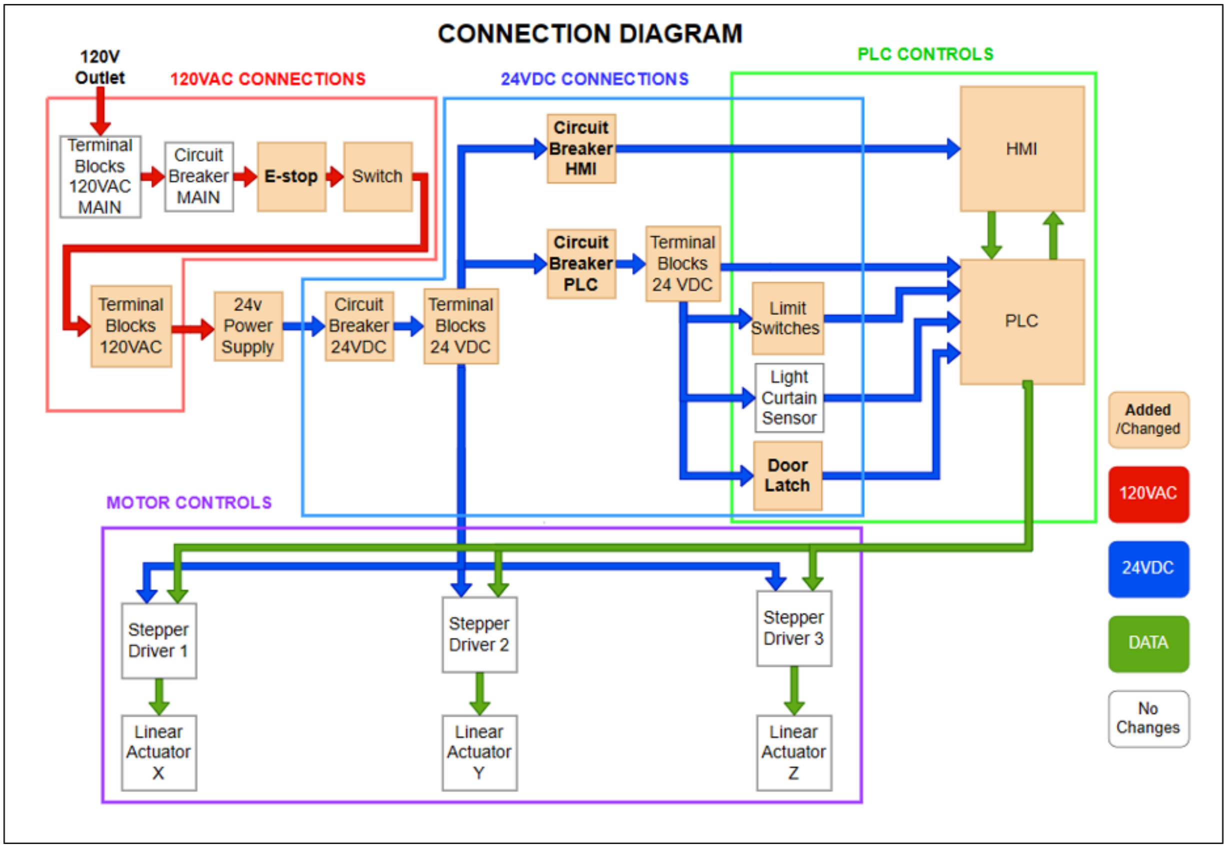


Figure 21: Final Connections Block Diagram

` The connections diagram shows a complete system of the electrical components. The 120 VAC is denoted by red, 24VDC is denoted by blue and the data is denoted by green. In this diagram, the changes from the current system from the old is highlighted by light orange boxes. If the change is a new addition it is denoted with bold text. The original system had a 5VDC system that powered the Arduino and controlled the stepper driver's controllers. This 5v portion was removed because it was no longer needed. The Click+ PLC uses 24VDC and the stepper driver controllers have a 24VDC option and did not need to be changed.

7.1 *ELECTRICAL LAYOUT*

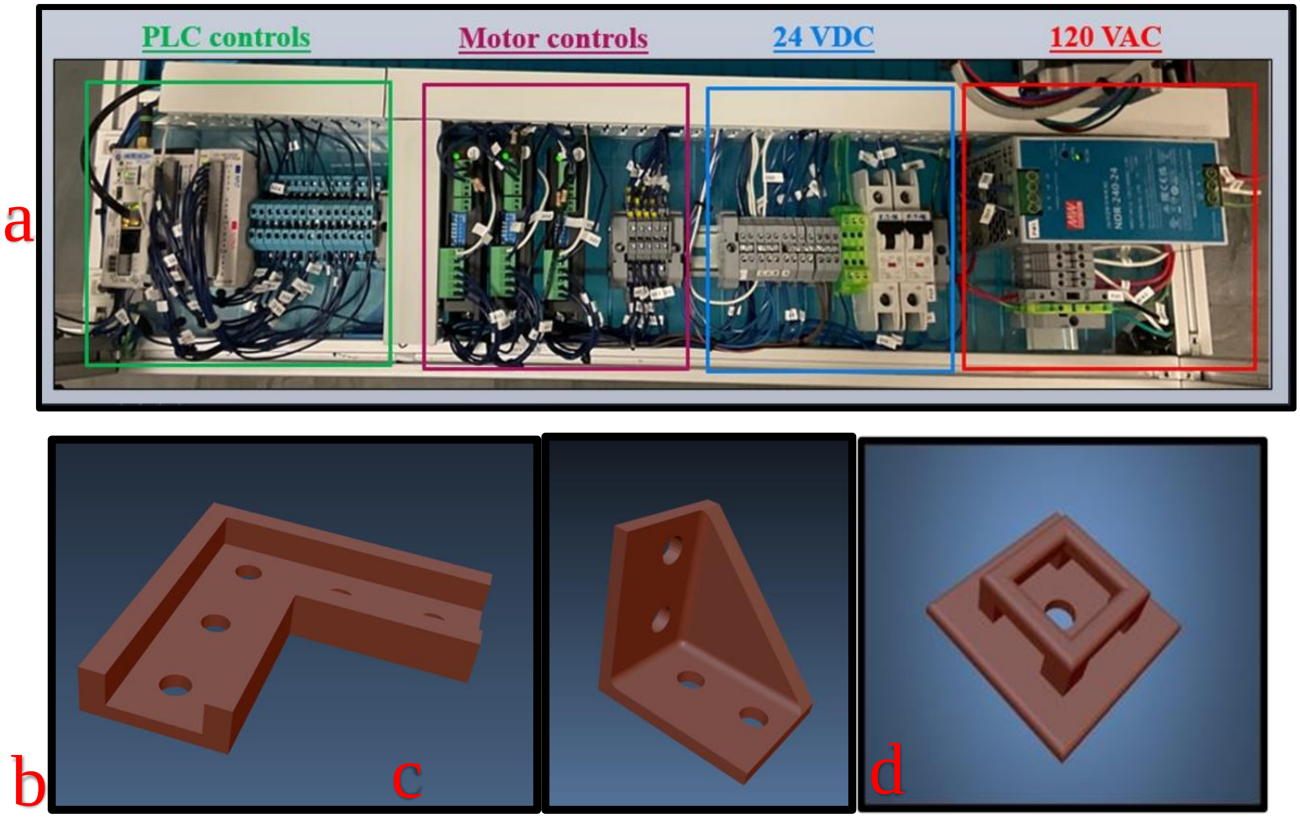


Figure 22: New Electrical Components (a) & 3D Printed Brackets (b & c & d)

The electrical layout for the system was changed in this iteration of the design. The previous team arranged the components along the back section of the box. This created an issue where easy accessibility to these components and wiring were not possible. Due to the wiring of the previous system as well, there were issues in determining what wire went where. The solution to this problem with the system became a backplate created with plexiglass and extruded aluminum. 3D printed brackets were designed by Jack Bulcher II to aid in holding the plexiglass and metal together. Figure 22 shows all of these components and the 3D printed materials. The goal of changing the electrical layout was to segregate each portion of the electrical components by the amount of voltage they required or other similar qualities. Shown above from right to left is the following:

- 120V Section: This included the main power supply, terminal blocks, and a set of circuit breakers that lead into the 25V section.

- 24V Section: This section included the terminal blocks for the majority of the connections, as well as circuit breakers that aid in lowering the voltage from the 120V section to the 24V section. This area ultimately acts as a transition to the Stepper Driver Section.
- Motor controls Section: This section included the Stepper Drivers, and 2.2kΩ resistors.
- PLC controls Section: This section included the PLC, PLC Input/Output Module, & communication terminal blocks.

8. RESULTS

The overall system was fabricated and built in its entirety. It features a multiple bin picking program, proper wire management, and documentation for students who would like to study the machine & its inner workings. The machine fully integrates the safety circuit into its functionality, allowing for users to safely operate the device without the risk of harm coming to them or the machine. Finally, the AS/RS demonstrator mimics the NEC (National Electrical Codes) and IEEE standards, which are common in most factory settings for similar systems.

The program currently can pick and return multiple bins. The remaining bins are not functionally available but do feature bits in the actual program that could be implemented into a working code. The system features numerous 3D printed items that aid the machine in the machine's processes, such as the arm, frustum, bin/bin indent, storage area, and delivery areas all working together in the execution of request. The frustum design does help with the alignment of the bins allowing them to be misaligned from the center of the bin in the picking plane. The picking arm held the bin during transportation with no issues involving misalignment during the picking and returning processes. The safety features did stop the machine correctly but with how the program was set up sometimes there were sometimes issues with the picking or returning program. Depending on its position in the program during the safety system being tripped sometime caused and error when it would skip an actuation movement. This could be due to an error in programming with how the safety system and the bin picking memory system are connected. If there was no safety system triggering incidences, the AS/RS demonstrator was able to run multiple iterations of the picking and returning process. Because the system could run multiple iterations of the picking and returning process, we know that the program would properly reset all necessary values within the program once completing each task.

9. BILL OF MATERIAL

Part Description	Price	Qty	Subtotal
1"x1"x22" Aluminum Extrusion	$5.34	4	**$21.36**
1"x1"x30" Aluminum Extrusion	$7.10	2	**$14.20**
1"x1"x28" Aluminum Extrusion	$6.66	6	**$39.96**
1"x1"x24" Aluminum Extrusion	$5.78	4	**$23.12**
1"x1"x23" Aluminum Extrusion	$5.56	5	**$27.80**
1"x1"x19" Aluminum Extrusion	$4.68	6	**$28.08**
1"x1"x3" Aluminum Extrusion	$1.16	8	**$9.28**
Black TPV tread Strip	$4.98	4	**$19.92**
M4 Tnuts (100 Pack)	$9.78	2	**$19.56**
12 mm M4 Screws (100 Pack)	$8.99	1	**$8.99**
10 mm M4 Screws (100 Pack)	$8.99	1	**$8.99**
3 Pin Red LED Power Switch	$7.99	1	**$7.99**
HB2-BS545 (E-Stop Button)	$19.00	1	**$19.00**
5Sets Magnetic Reed Switch (Designed prox switch)	$17.99	1	**$17.99**
Linear actuator assembly (100mm NEMA 23)	$150.00	1	**$150.00**
Linear actuator assembly (400mm NEMA 23)	$182.00	1	**$182.00**
Linear actuator assembly (500mm NEMA 23)	$195.00	1	**$195.00**
Stepper Motor Driver (DM542T)	$28.99	3	**$86.97**
Drag Chain	$10.69	1	**$10.69**
Light Curtain	$64.31	1	**$64.31**
HI-010 (Steel Black Powder-Coat Heavy-Duty Hinge Kit (SMALL))	$5.25	2	**$10.50**
2751 10 Series Dual Roller Wheel Bracket Assembly	$68.12	1	**$68.12**
Wire Computer Cart - 30 x 24 x 40"	$230.00	1	**$230.00**
Plastic Shelf Liner - 30 x 24"	$26.00	1	**$26.00**
Push Handle for 24" Wire Shelving - Chrome	$19.00	1	**$19.00**
C-More EA9-T7CL-R (HMI)	$668.00	1	**$668.00**
D0-MC-BAT (Lithium Metal Battery)	$3.00	1	**$3.00**
SE-ANT210 (STRIDE whip/straight 2.4 GHz WiFi antenna, IP65, connector mount)	$9.50	1	**$9.50**
Programming cable, USB A to microB-USB, 6ft cable length.	$5.25	1	**$5.25**
CLICK PLUS PLC, 24 VDC required, (1) option slots, WiFi LAN/Bluetooth, Ethernet, serial and microB-USB ports, microSD card slot, no on-board I/O.	$205.00	1	**$205.00**
CLICK PLUS discrete combo module, Input: 8-point, 24 VDC,sinking/sourcing, Output: 6-point, 5-27 VDC, sinking, 0.1A/point.	$58.00	1	**$58.00**
CLICK discrete combo module, Input: 8-point, 24 VDC, sinking/sourcing, Output: 8-point, 12-24 VDC, sourcing, 0.1A/point.	$82.00	1	**$82.00**
FAZ-B5-1-NA-L-SPEaton miniature circuit breaker, current-limiting, 5A, 240 VAC / 48 VDC, 1-pole, B curve, thermal	$20.00	2	**$40.00**
FAZ-B2-1-NA-L-SP Eaton miniature circuit breaker, current-limiting, 2A, 240 VAC / 48 VDC, 1-pole, B curve, thermal	$20.00	1	**$20.00**
4Pcs M12 Proximity Switch NPN 3-Wire Normally Open 3D Printer Inductive Proximity Sensor 8MM Detecting Distance	$21.99	2	**$43.98**
Inside Corner Brackets	$2.70	60	**$162.00**
25"x30"x.25" Polycarbonate (Front & Back)	$47.35	2	**$94.70**
24"x25"x.25" Polycarbonate (Sides)	$61.10	2	**$122.20**
24"x30"x.25" Polycarbonate (Top)	$32.40	1	**$32.40**
Total Cost			**$2,854.86**

Table 1: Bill of Materials

Table 1 above shows the new bill of materials. This includes the components used from the previous team's build in the new build as well as components bought for the new build. The total is $2854.86. Table 1 shows the Bill of Materials for this project. While this seems like a lot of money at face value, it's important to remember that automated storage and retrieval systems in the modern engineering world cost tens of thousands of dollars, sometimes even more. This lends credence to a cost-effective build.

10. SCHEDULE

Table 3 shows the anticipated timeline that the team created for the AS/RS project. This timeline includes the summer semester, where work could be done on the system. It is important to refresh the understanding of the CLICK+ PLC, so members of the team chose to take the summer and first few weeks of the fall semester to test out the PLC and its communications with the other components of the systems such as actuators and HMI, hence the actuation testing. Fabrication will also be included in the list as the machine needs to be extruded and new plexiglass needs to be applied to the outside of the system to enclose it. The maintenance door could be put in at this time as well. Actuation Testing will take roughly the summertime and 5 weeks of the fall semester to allow for ample time in checking the distances between box containers. The mounting of the devices should be relatively simple and will only consist of 2 weeks, as some internal parts will be moved around.

The HMI testing will be crucial to the overall functionality of the machine. This is the device that will bridge the gap between the machine and the human and allow for configuration of buttons as well the communication with the PLC. It is imperative that this must work. The Wiring Diagram portion should not take long, as this will simply document everything that has been connected during the time before and after the testing. Therefore, two weeks maximum was allotted to that section. Wiring will occur simultaneously so that the wiring diagram will be as accurate as possible. Programming the system, including the HMI and the PLC, will be the bulk of this project. It directly corresponds with the functionality of the machine so it will be included up until presentation day to ensure that all works well. The 3D printing of parts will be focused around a 3-week schedule as the process can be a bit slow depending on what is being printed. Functionality Testing will correspond directly with programming as the two are directly correlated so allotting enough time to it will allow proper execution of all testing that can be finished. Project Finalization includes any sort of small changes, cleanup of code/fabrications, and ensuring that the real-world presentation of the project looks presentable and orderly.

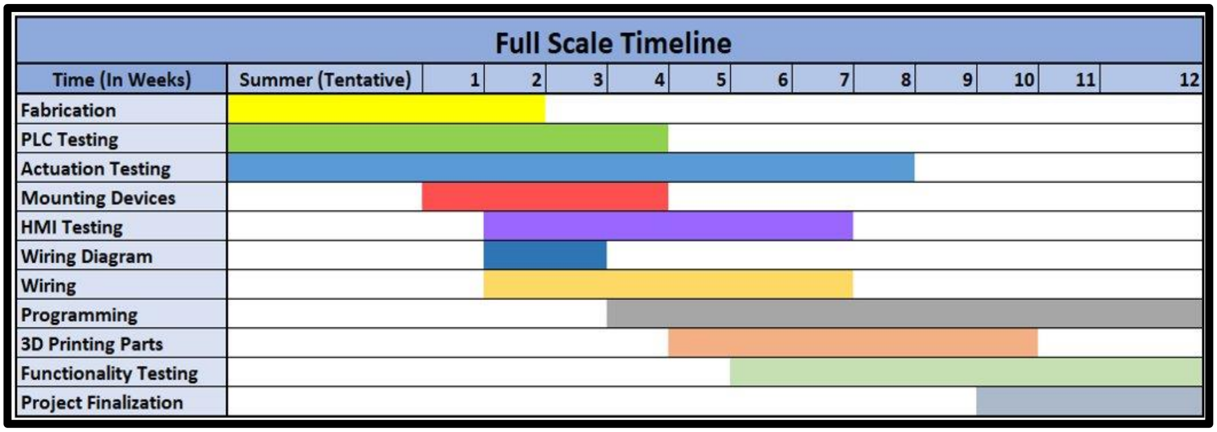


Table 2: Timeline

11.TEAMWORK BREAKDOWN

Table 2 showcases a Gant chart for the overarching view of the semester. The teamwork will be evenly distributed between the two team members, Jack and Chris. Some processes will have a larger amount of time dedicated to them due to the overall learning processes of those steps. Chris will focus on heavier emphasis on the PLC programming portion and HMI testing, while Jack will have more emphasis on the fabrication and wiring portions. However, these two portions will be evenly distributed between the two members and overlap may occur in duties depending on the adherence to the timeline. Documentation will be present for all work on the project.

12. FUTURE WORK

Future work for the AS/RS system will include finishing programming the pick and returning sequence for the rest of the bins, better optimization of subroutine coding as well as the potential to extend the main box containing the system. Aspects that could be included in the future as well is the implementation of bin catch for the storage area, overtravel switches, and a built-in monitor for coding the demonstrator. Extending the system’s box will allow for the potential of more storage locations. The subroutine coding will allow for ideal and organized coding that reflects the robust ladder logic coding techniques seen in the modern engineering field. The bin catch system would keep the bins in the storage area when the AS/RS demonstrator is physically being moved to another location. The overtravel switches, while not necessarily needed, do provide another safety measure to be implemented into the system. A built-in computer with a monitor could be mounted in the automated storage and retrieval system demonstrator to allow for monitoring of the code, and easy access to coding. This computer with a monitor would allow for more demonstrating capabilities such as being able to monitor the code in real time, program the machine without needing access to an external computer and give the opportunity for trouble shooting applications.

13. CONCLUSION

In conclusion, this project was an attempt to continue the previous group's ambitions to produce a functioning Automated Storage & Retrieval System Demonstrator. The project ultimately was considered a success in that functionality was achieved through the design choices of the group. The machine can pick up multiple bins and features a working safety circuit to prevent injury. The physical fabrication of the system provides robustness, and longevity for many generations of students to come. The 3D printed parts allow for customization as well as easy replacement if any get broken. Finally, the system features documentation that accurately depicts the electrical wiring and coding logic associated with the machine.

REFERENCES

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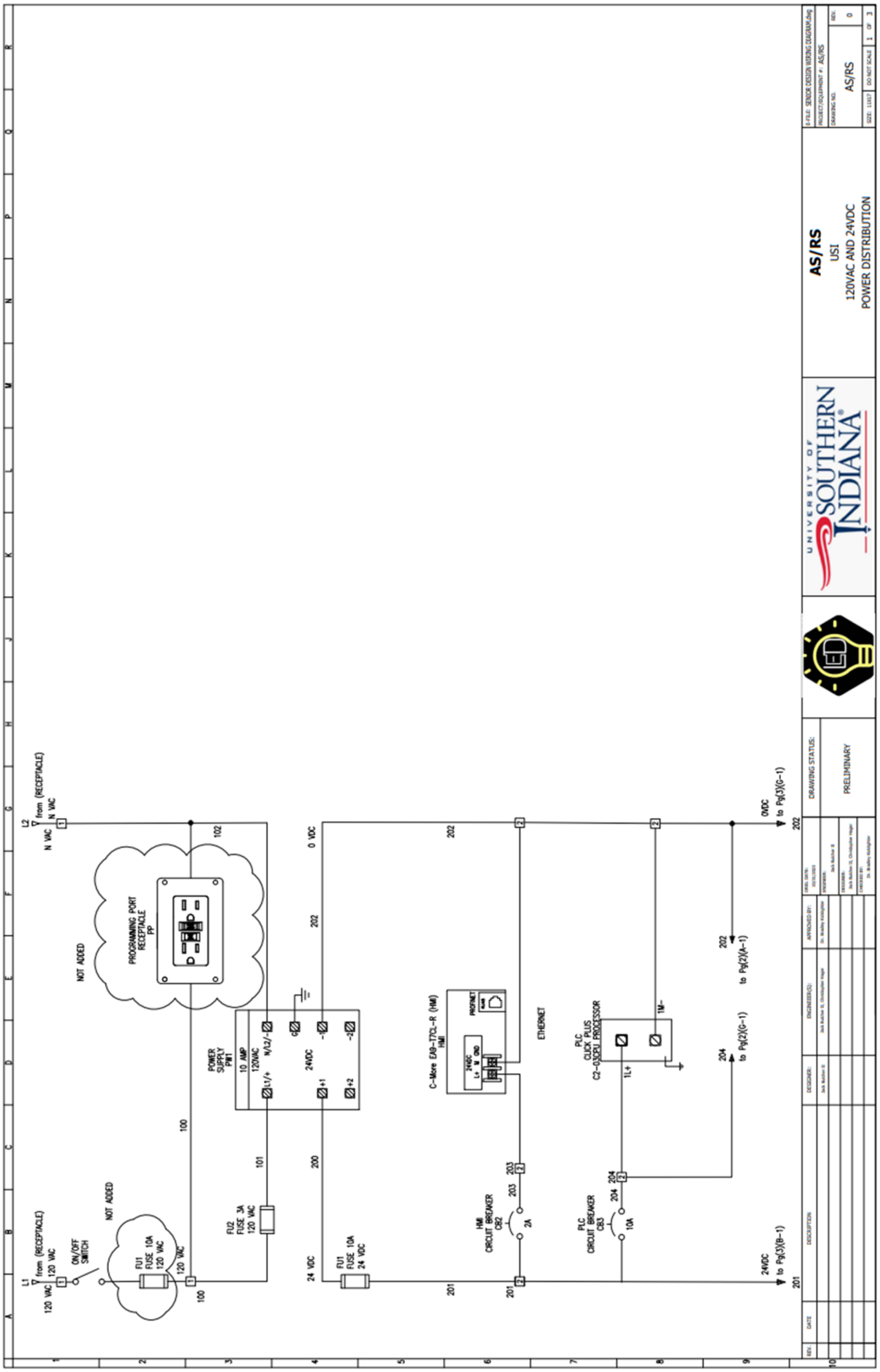
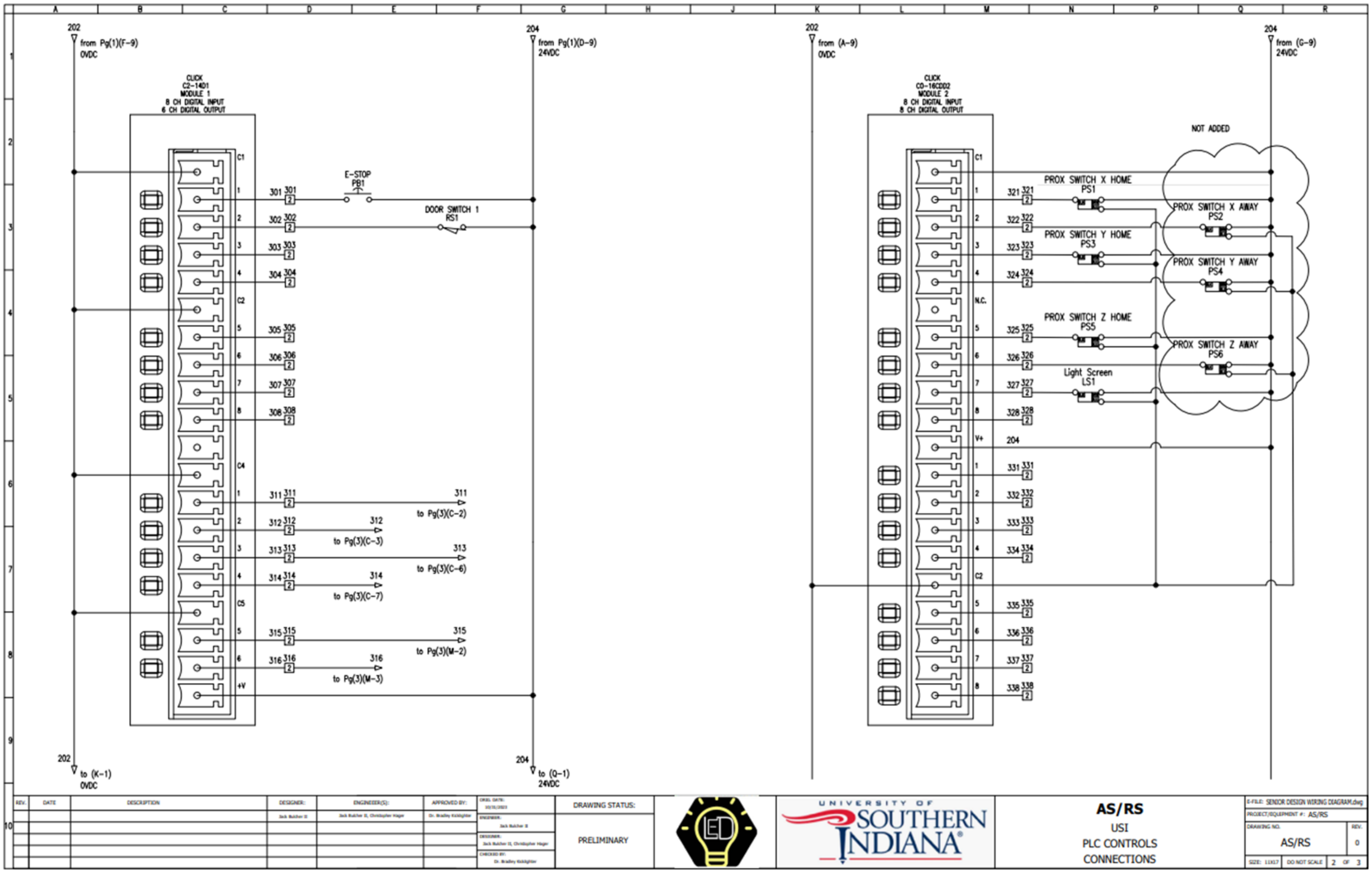
APPENDIX A: ABET DESIGN CONSIDERATIONS

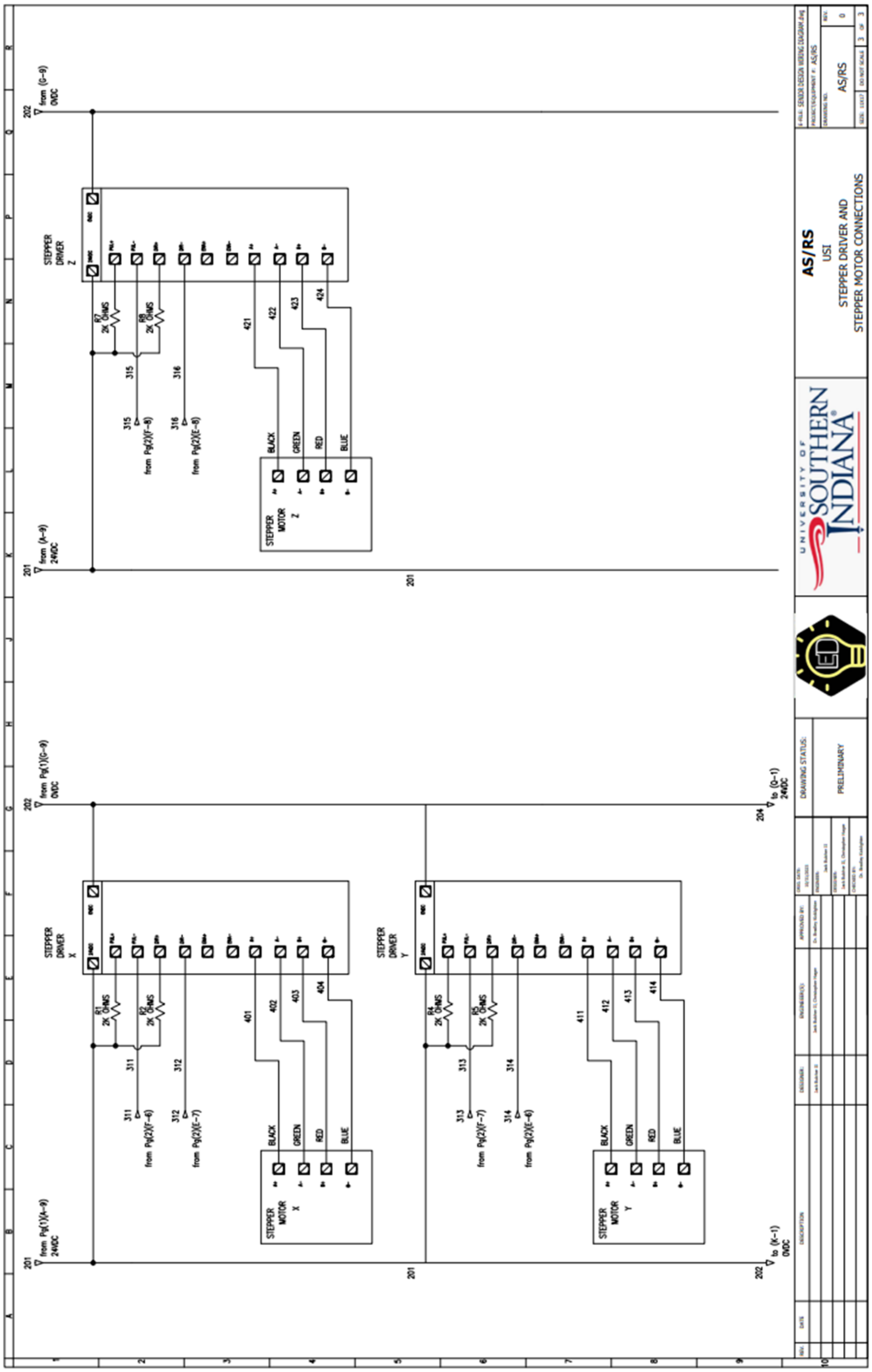
Public health safety, and welfare- The automated storage and retrieval system demonstrator had a forefront focus on the safety of the public and the teaching of safety features in industry. This system utilized four different physical safety features. It also had other electronic safety features to show students possible ways to create safe and practical solutions for the welfare of the public. By teaching students about these small but useful components, they will understand the importance of safety in manufacturing engineering and industrial engineering.
Global- Automation, industry, and any manufacturing fields can be found in almost every country. Compartmentability and land usage is an incredibly important issue that these factories face, and so utilizing their land & resources can become difficult. The automated storage & retrieval system demonstrator shows students a possible solution to this issue. The AS/RS Demonstrator provides a look into solutions for storage issues faced by all businesses and industry in the world.
Cultural-There is not a cultural significance to this item as its used universally and has no real connotation to any cultural sphere.
Social- There is not a social significance to the automated storage and retrieval system, so this design is not applicable here.
Environmental In terms of environmental design factors, the automated storage and retrieval demonstrator system shows how machines can be created to aid in saving space. This machine was created for students to show how verticality can be used to save land space. Factories typically are on scales of several acres wide. With the automated storage & retrieval system demonstrator, this machine teaches students that space can be saved for the same if not more optimal functionality and storage.
Economic- The economic design factors for the automated storage & retrieval demonstrator shows that PLC-led automation can be much more cost effective and optimal than Arduino & other microcontroller products. Microcontroller products for large scale systems can typically

be costly, with several microcontrollers and large amounts of code to coordinate them all. For automation and industrial fields of industry, the automation & storage retrieval system demonstrator shows that a programmable logic controller is the perfect choice for these settings.
Ethical & Professional- The automated storage and retrieval system attempted to mimic safety and professional automation standards. The system also focused on showcasing a close to realistic depiction of automation storage and retrieval systems, which can be found in a number of factories all across the world.
Reference for Standards- The automated storage and retrieval system demonstrator focused on utilizing NEC (National Electric Code) and IEEE (Institute of Electrical & Electronics Engineers) standards when in fabrication. Everything from the wiring to the electrical orientation of items in the backplate was done with these standards in mind. This is important, as it exposes students studying the automated storage and retrieval system to these important standards that exist in the modern engineering world.

APPENDIX B: WIRING DIAGRAM

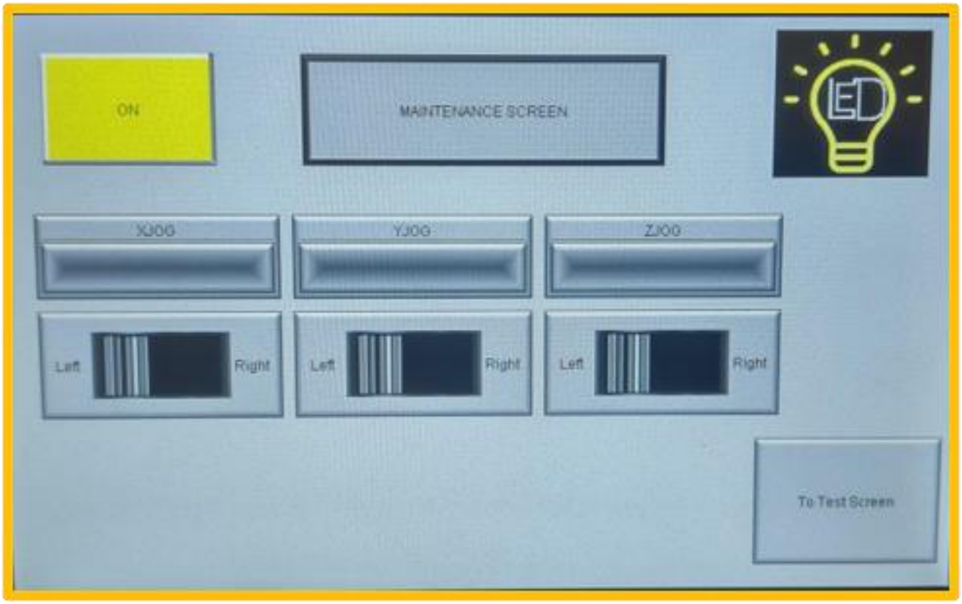



202
from Pg(1)(F-9)
0VDC
204
from Pg(1)(D-9)
24VDC
CLICK
C2-14D1
MODULE 1
8 CH DIGITAL INPUT
6 CH DIGITAL OUTPUT
E-STOP
PB1
DOOR SWITCH 1
RS1
to Pg(3)(C-2)
to Pg(3)(C-3)
to Pg(3)(C-6)
to Pg(3)(C-7)
to Pg(3)(M-2)
to Pg(3)(M-3)
202
to (K-1)
0VDC
204
to (Q-1)
24VDC
202
from (A-9)
0VDC
204
from (G-9)
24VDC
CLICK
C0-16CDD2
MODULE 2
8 CH DIGITAL INPUT
8 CH DIGITAL OUTPUT
NOT ADDED
PROX SWITCH X HOME
PS1
PROX SWITCH X AWAY
PS2
PROX SWITCH Y HOME
PS3
PROX SWITCH Y AWAY
PS4
PROX SWITCH Z HOME
PS5
PROX SWITCH Z AWAY
PS6
Light Screen
LS1
DRAWING STATUS:
PRELIMINARY
UNIVERSITY OF SOUTHERN INDIANA
AS/RS
USI
PLC CONTROLS
CONNECTIONS
E-FILE: SENIOR DESIGN WIRING DIAGRAM.dwg
PROJECT/EQUIPMENT #: AS/RS
DRAWING NO.
AS/RS
REV.
0
SIZE: 11X17
DO NOT SCALE
2 OF 3



AS/RS
USI
STEPPER DRIVER AND
STEPPER MOTOR CONNECTIONS
DRAWING STATUS:
PRELIMINARY
STEPPER DRIVER X
STEPPER DRIVER Y
STEPPER DRIVER Z
STEPPER MOTOR X
STEPPER MOTOR Y
STEPPER MOTOR Z
BLACK
GREEN
RED
BLUE
from Pg(1)(A-9) 24VDC
from Pg(1)(G-9) 0VDC
from (A-9) 24VDC
from (G-9) 0VDC
to (K-1) 0VDC
to (Q-1) 24VDC
UNIVERSITY OF SOUTHERN INDIANA

APPENDIX C: HMI FOR XJOG PROGRAM



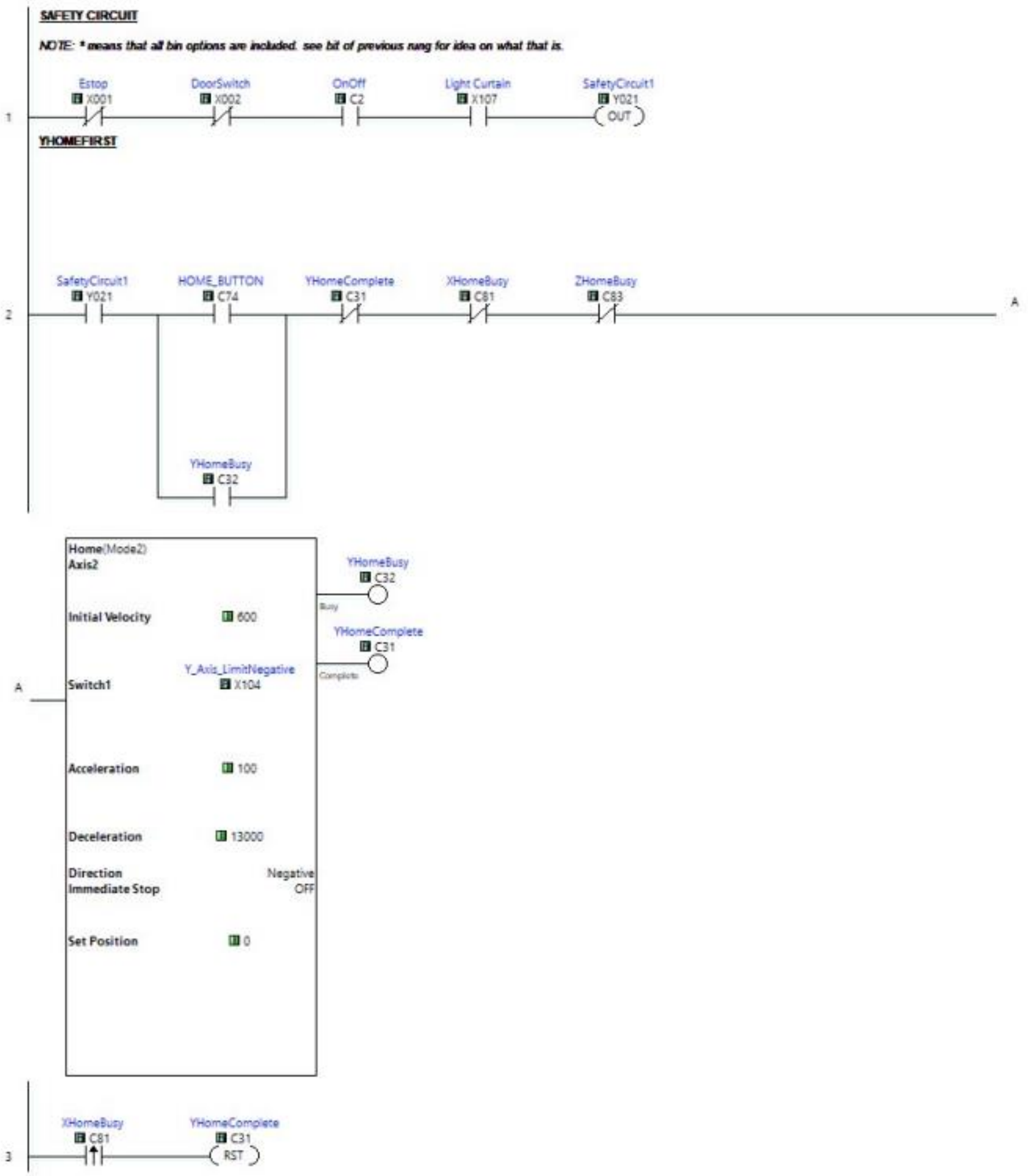
APPENDIX D: PLC CODE ADDRESSES

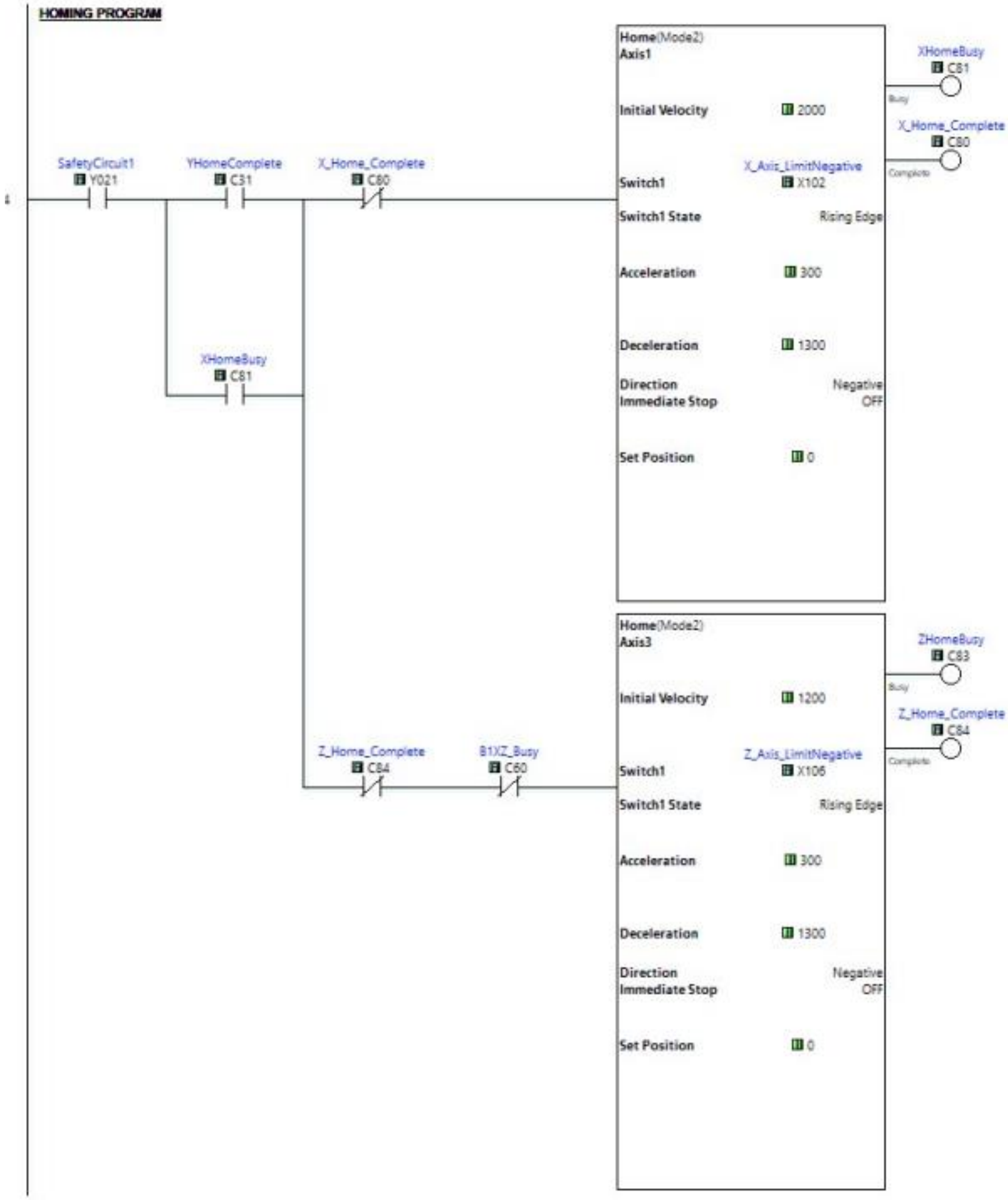
Address	Data Type	Nickname
X001	BIT	Estop
X002	BIT	DoorSwitch
X101	BIT	X_Axis_LimitPositive
X102	BIT	X_Axis_LimitNegative
X103	BIT	Y_Axis_LimitPositive
X104	BIT	Y_Axis_LimitNegative
X105	BIT	Z_Axis_LimitPositive
X106	BIT	Z_Axis_LimitNegative
X107	BIT	Light Screen
Y001	BIT	X_Axis_Pulse
Y002	BIT	X_Axis_Direction
Y003	BIT	Y_Axis_Pulse
Y004	BIT	Y_Axis_Direction
Y005	BIT	Z_Axis_Pulse
Y006	BIT	Z_Axis_Direction
Y010	BIT	Yprox02
Y021	BIT	SafetyCircuit1
Y101	BIT	RESETTING
C1	BIT	SafteyCircuit
C2	BIT	OnOff
C3	BIT	1stScanBit
C5	BIT	YHomeProx2
C10	BIT	B1XZ_Position
C11	BIT	B1Choice
C12	BIT	B2Choice
C20	BIT	B1XZ Complete
C21	BIT	B1ReturnChoice
C22	BIT	B2ReturnChoice
C30	BIT	ZHome Program
C31	BIT	YHomeComplete
C39	BIT	YINSERT_COMPLETE
C40	BIT	YINSERT_SUCCESS
C41	BIT	ZGRAB_DONE
C42	BIT	YRETRACT_DONE
C43	BIT	XZ_RETRACT_DONE
C44	BIT	HOME_SUCCESS
C50	BIT	XHomeProxBreak
C51	BIT	YHomeProxBreak
C52	BIT	ZHomeProxBreak
C60	BIT	B1XZ_Busy
C70	BIT	B1XZPOSITION
C71	BIT	YINSERT
C72	BIT	ZGRAB
C73	BIT	YRETRACT
C74	BIT	HOME_BUTTON

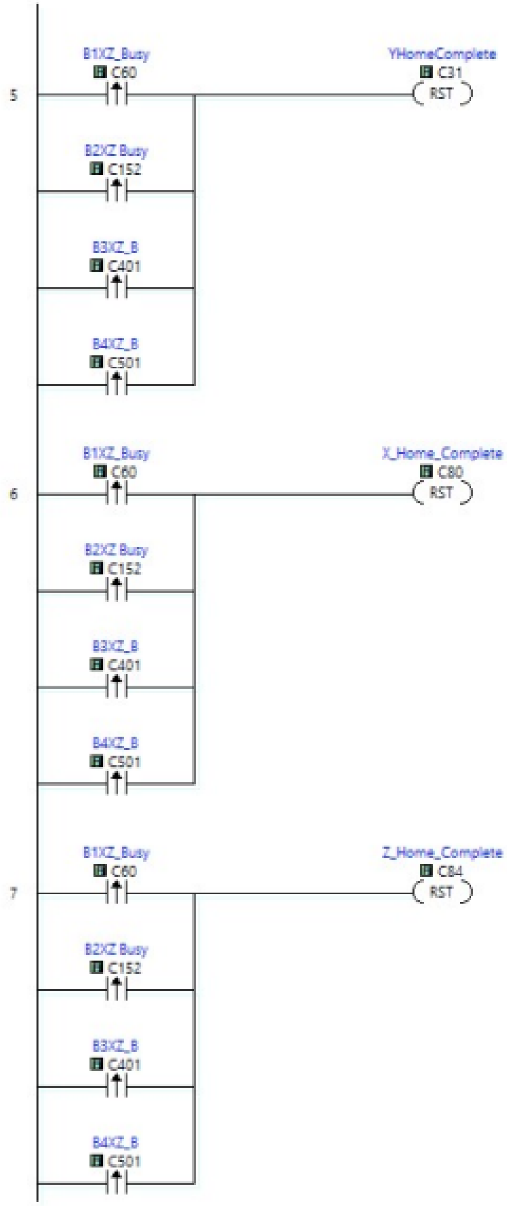
C75	BIT	WAIT
C76	BIT	YINSERTDELIVER
C77	BIT	WAIT_RESET
C80	BIT	X_Home_Complete
C82	BIT	Y_Home_Complete
C84	BIT	Z_Home_Complete
C87	BIT	B1XZ_C
C89	BIT	Yinsert_C
C91	BIT	Zgrab_C
C92	BIT	Yretract_C
C94	BIT	Homeretract_X_C
C96	BIT	Homeretract_Y_C
C98	BIT	Homeretract_Z_C
C100	BIT	XYZ_RETRACT_HOME
C101	BIT	XJog
C102	BIT	XDir
C103	BIT	YJog
C104	BIT	YDir
C105	BIT	ZJog
C106	BIT	ZDir
C110	BIT	B1StorePopup
C111	BIT	B1ReturnButton
C112	BIT	B2StorePopup
C113	BIT	B2ReturnButton
C119	BIT	YHomeFirst2Busy
C120	BIT	YDeliverComplete
C121	BIT	YDeliverSuccess
C130	BIT	Yret_store_C
C131	BIT	X_bin_store C
C132	BIT	B1_BinStore_C
C133	BIT	B1_BinStore_Busy
C134	BIT	Yinsert_Bin_C
C135	BIT	Z_Release_C
C136	BIT	Yretract_Store_C
C137	BIT	X_Home_C
C140	BIT	B2XZ2_B
C141	BIT	B2XZ2_C
C150	BIT	B2XZPOSITION
C151	BIT	B2XZ_C
C152	BIT	B2XZ Busy
T1	BIT	YINSERT_TIMER
SC1	BIT	_Always_ON
SC2	BIT	_1st_SCAN
DD1	INT2	X_Axis_CurrentPosition
DD2	INT2	X_Axis_CurrentVelocity
DD3	INT2	Y_Axis_CurrentPosition
DD4	INT2	Y_Axis_CurrentVelocity

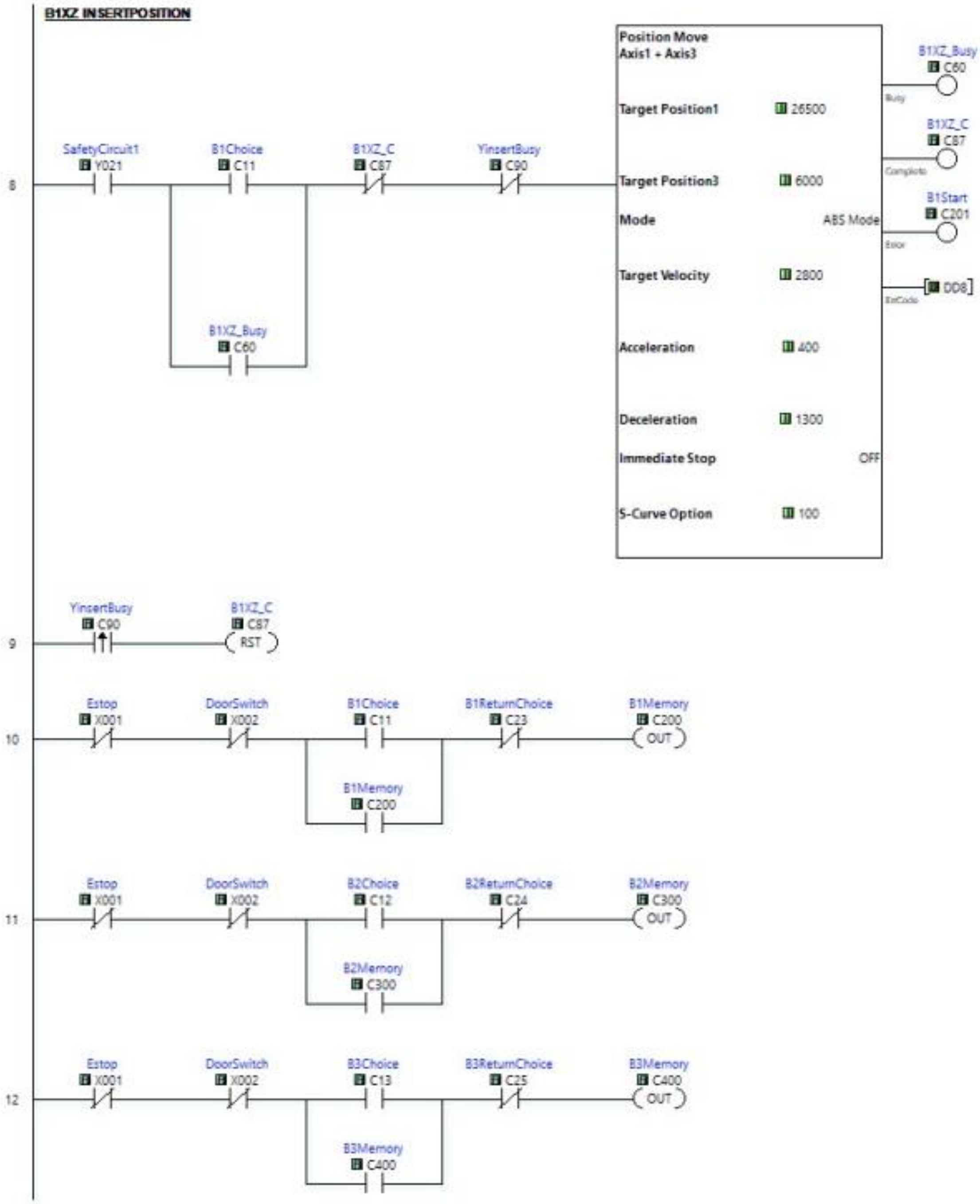
DD5	INT2	Z_Axis_CurrentPosition
DD6	INT2	Z_Axis_CurrentVelocity

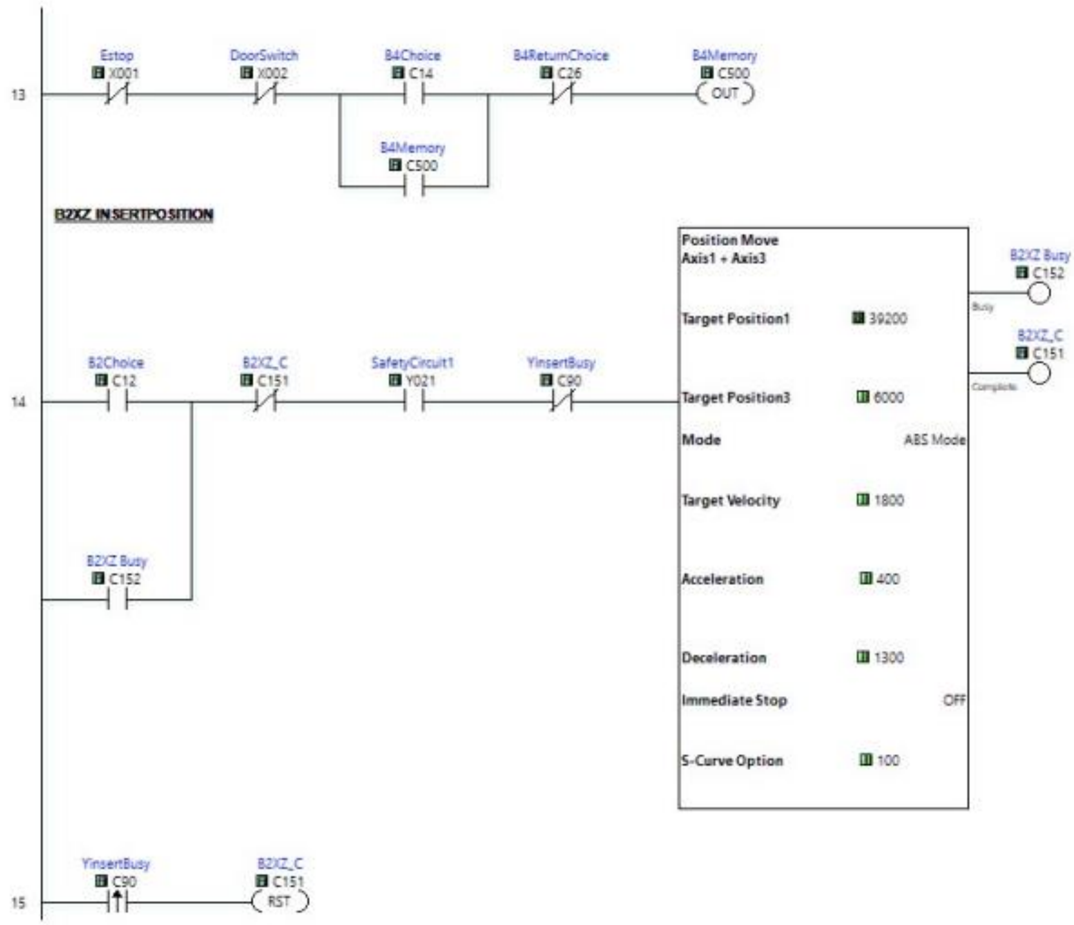
APPENDIX E: WORKING CODE UTILIZED

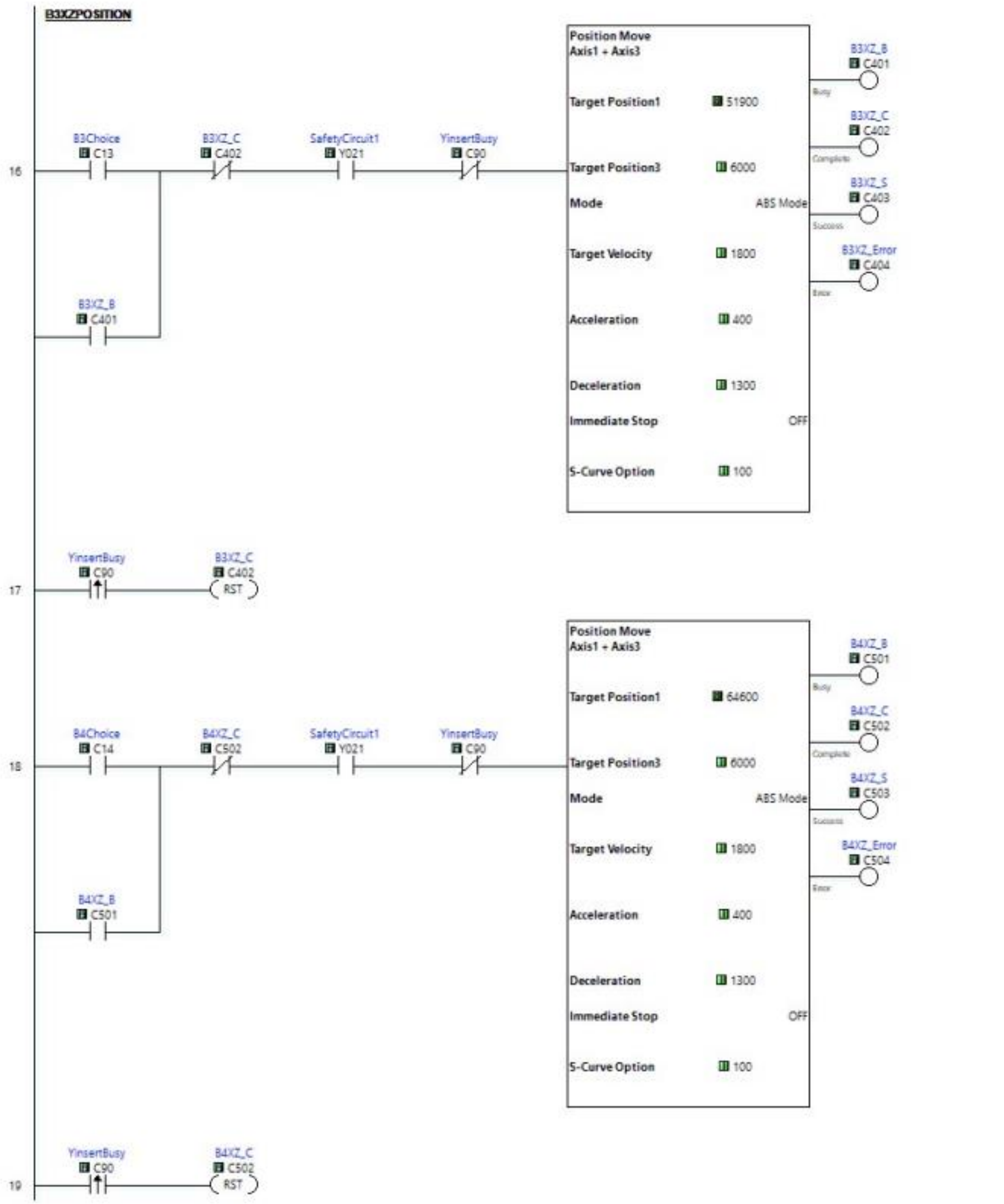


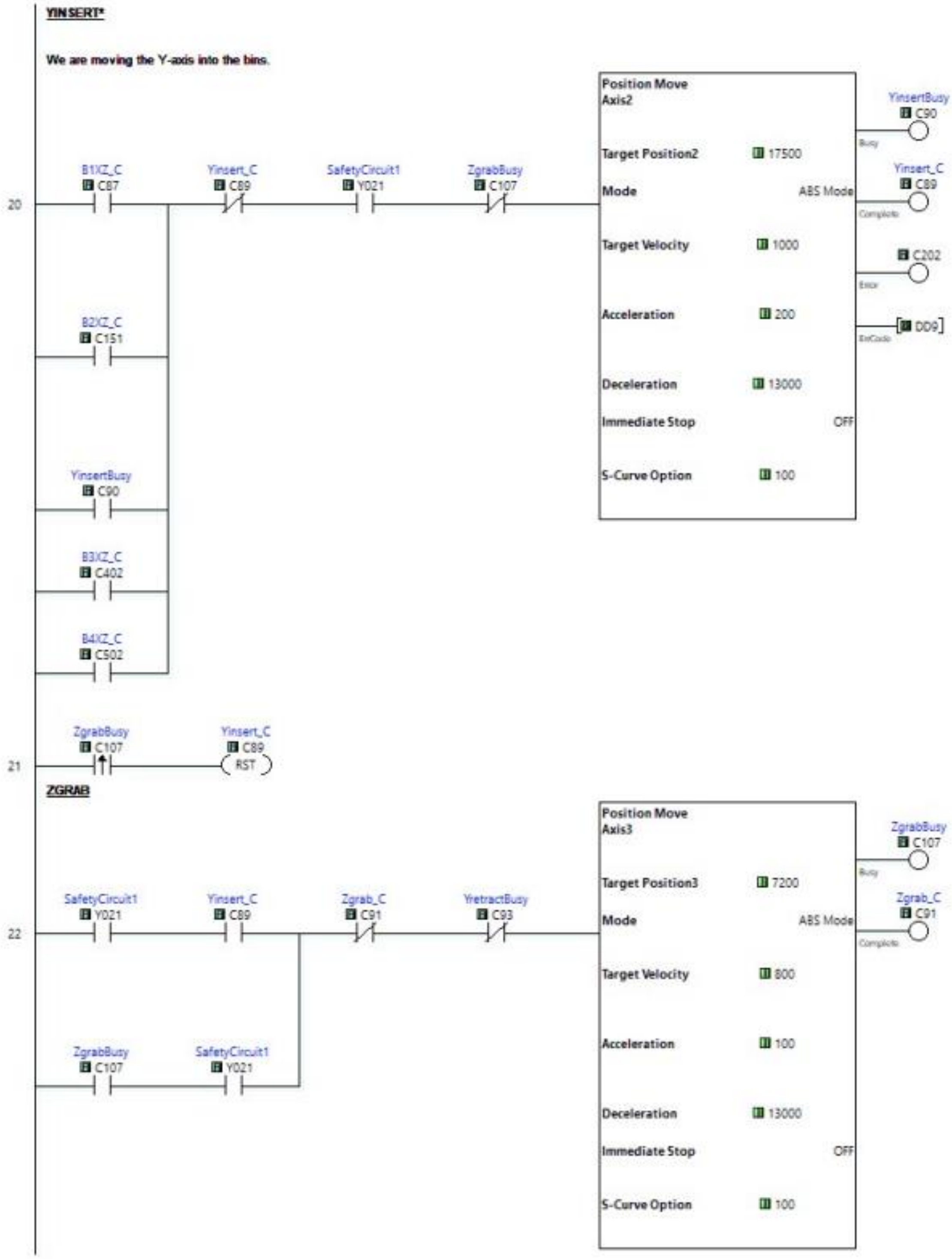

HOMING PROGRAM
4
SafetyCircuit1
Y021
YHomeComplete
C31
X_Home_Complete
C80
XHomeBusy
C81
Home(Mode2)
Axis1
Initial Velocity 2000
Switch1 X_Axis_LimitNegative X102
Switch1 State Rising Edge
Acceleration 300
Deceleration 1300
Direction Negative
Immediate Stop OFF
Set Position 0
Busy
XHomeBusy C81
Complete
X_Home_Complete C80
Z_Home_Complete
C84
B1XZ_Busy
C60
Home(Mode2)
Axis3
Initial Velocity 1200
Switch1 Z_Axis_LimitNegative X106
Switch1 State Rising Edge
Acceleration 300
Deceleration 1300
Direction Negative
Immediate Stop OFF
Set Position 0
Busy
ZHomeBusy C83
Complete
Z_Home_Complete C84

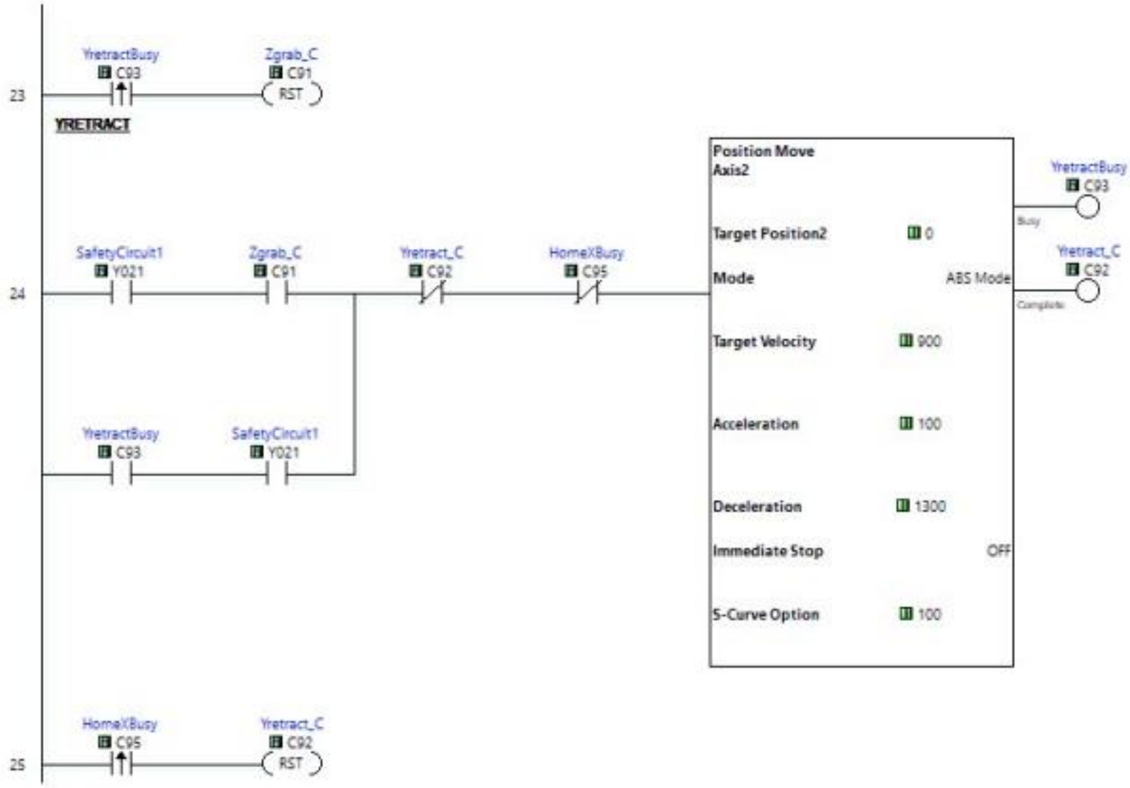

5
B1XZ_Busy
C60
YHomeComplete
C31
RST
B2XZ Busy
C152
B3XZ_B
C401
B4XZ_B
C501
6
B1XZ_Busy
C60
X_Home_Complete
C80
RST
B2XZ Busy
C152
B3XZ_B
C401
B4XZ_B
C501
7
B1XZ_Busy
C60
Z_Home_Complete
C84
RST
B2XZ Busy
C152
B3XZ_B
C401
B4XZ_B
C501

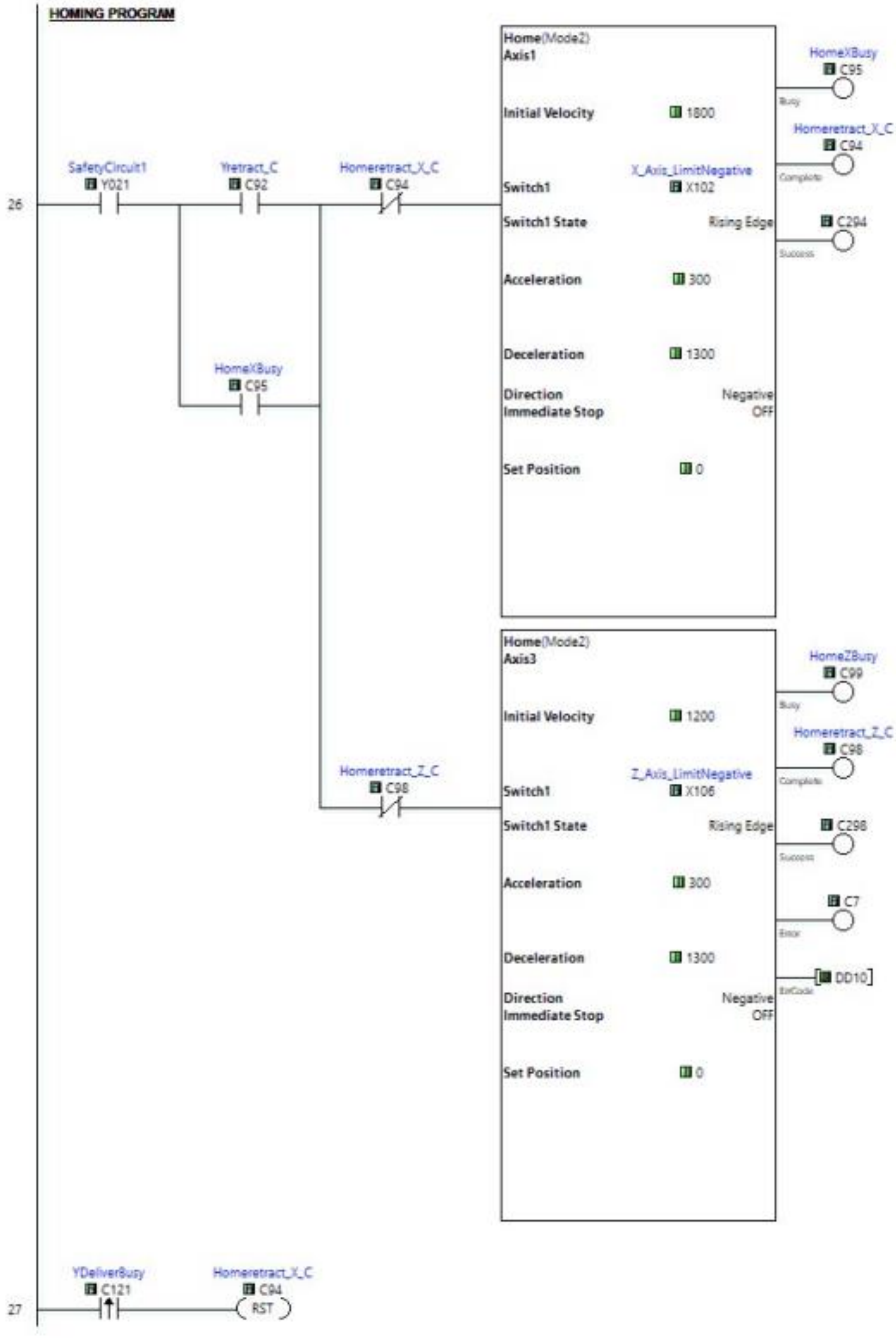

B1XZ INSERTPOSITION
8
SafetyCircuit1
Y021
B1Choice
C11
B1XZ_C
C87
YinsertBusy
C90
B1XZ_Busy
C60
Position Move
Axis1 + Axis3
Target Position1
26500
Target Position3
6000
Mode
ABS Mode
Target Velocity
2800
Acceleration
400
Deceleration
1300
Immediate Stop
OFF
S-Curve Option
100
B1XZ_Busy
C60
Busy
B1XZ_C
C87
Complete
B1Start
C201
Error
DD8
ErrCode
9
YinsertBusy
C90
B1XZ_C
C87
RST
10
Estop
X001
DoorSwitch
X002
B1Choice
C11
B1ReturnChoice
C23
B1Memory
C200
OUT
B1Memory
C200
11
Estop
X001
DoorSwitch
X002
B2Choice
C12
B2ReturnChoice
C24
B2Memory
C300
OUT
B2Memory
C300
12
Estop
X001
DoorSwitch
X002
B3Choice
C13
B3ReturnChoice
C25
B3Memory
C400
OUT
B3Memory
C400

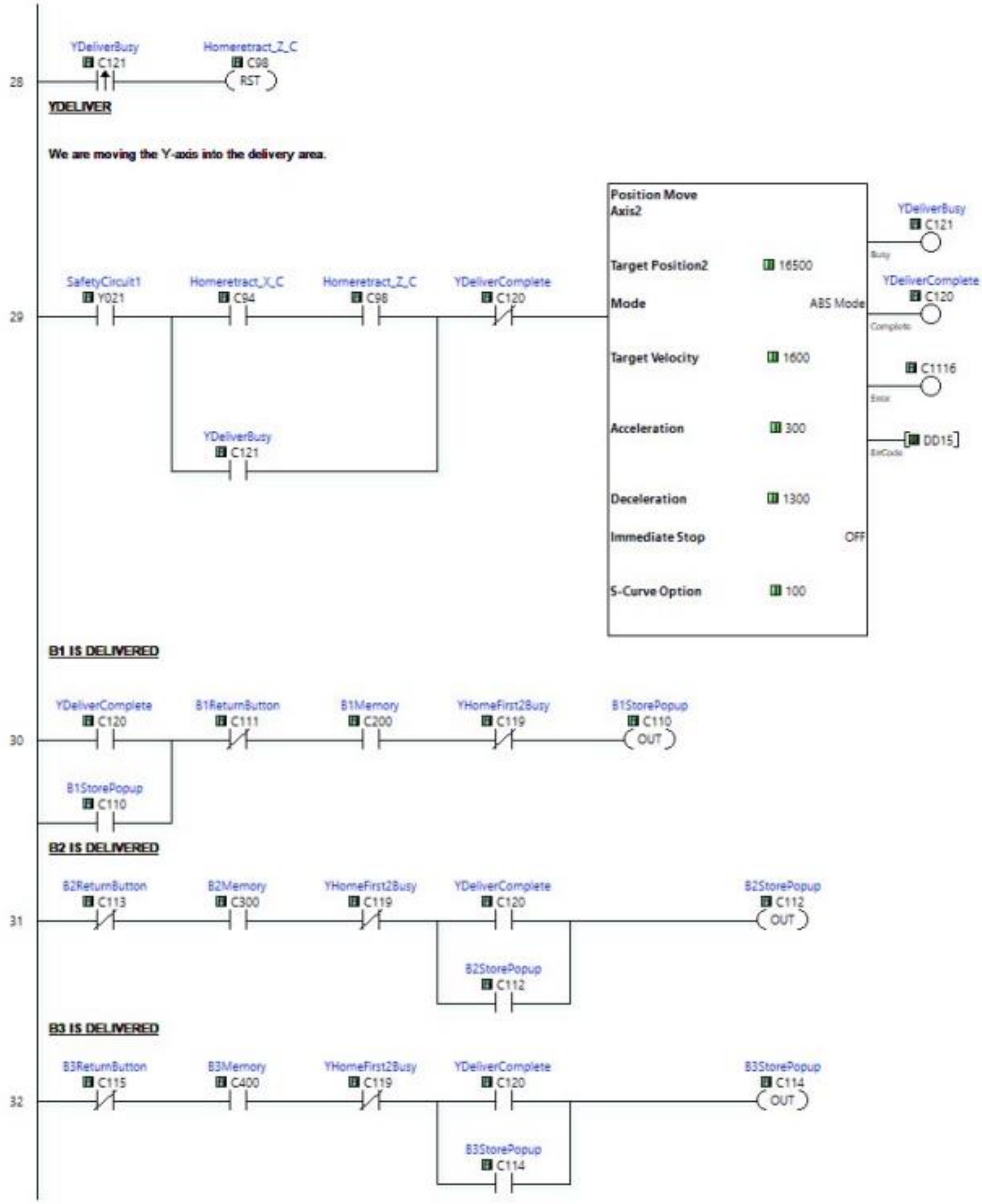

13
Estop
X001
DoorSwitch
X002
B4Choice
C14
B4ReturnChoice
C26
B4Memory
C500
OUT
B4Memory
C500
B2XZ INSERTPOSITION
Position Move
Axis1 + Axis3
Target Position1
39200
Target Position3
6000
Mode
ABS Mode
Target Velocity
1800
Acceleration
400
Deceleration
1300
Immediate Stop
OFF
S-Curve Option
100
B2XZ Busy
C152
Busy
B2XZ_C
C151
Complete
14
B2Choice
C12
B2XZ_C
C151
SafetyCircuit1
Y021
YinsertBusy
C90
B2XZ Busy
C152
15
YinsertBusy
C90
B2XZ_C
C151
RST

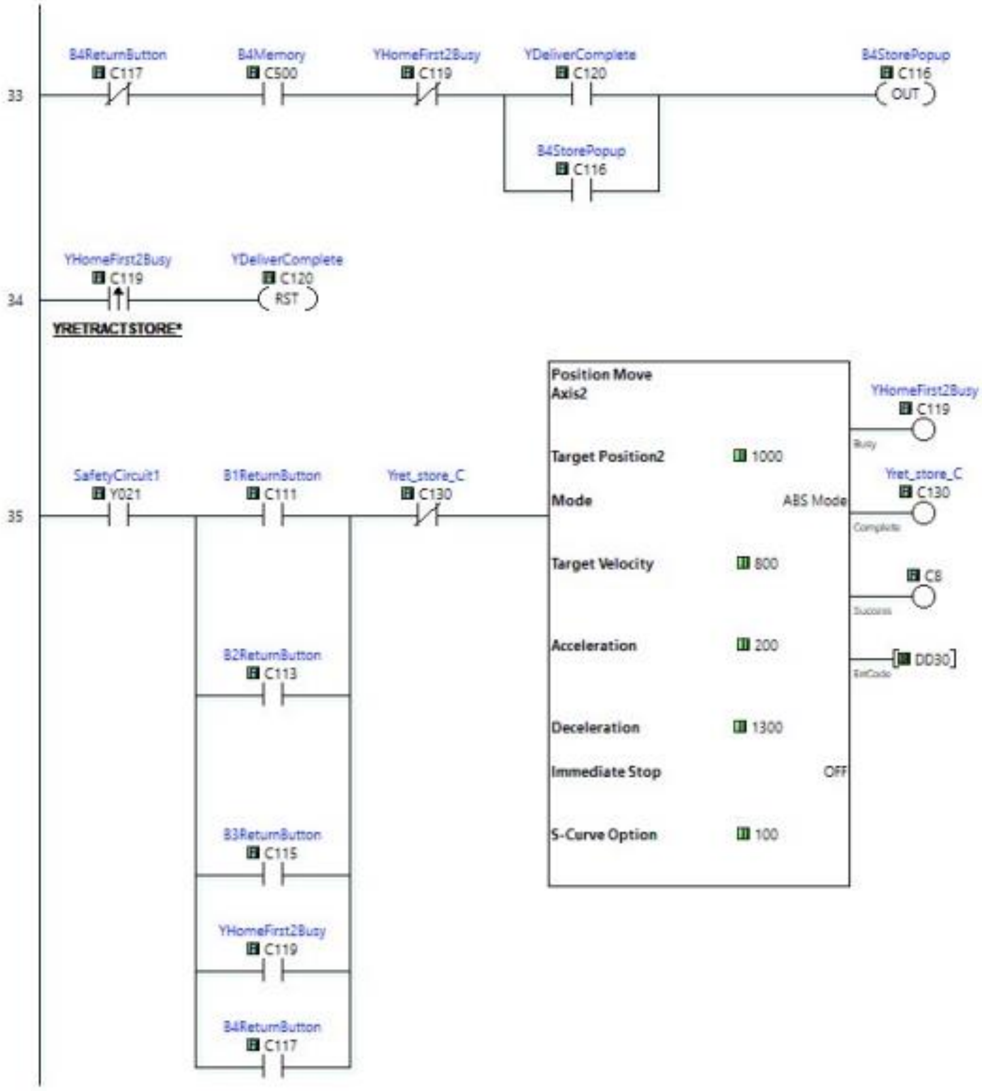

B3XZPOSITION
16
B3Choice
C13
B3XZ_C
C402
SafetyCircuit1
Y021
YinsertBusy
C90
B3XZ_B
C401
Position Move
Axis1 + Axis3
Target Position1 51900
Target Position3 6000
Mode ABS Mode
Target Velocity 1800
Acceleration 400
Deceleration 1300
Immediate Stop OFF
S-Curve Option 100
B3XZ_B
C401
B3XZ_C
C402
B3XZ_S
C403
B3XZ_Error
C404
17
YinsertBusy
C90
B3XZ_C
C402
RST
18
B4Choice
C14
B4XZ_C
C502
SafetyCircuit1
Y021
YinsertBusy
C90
B4XZ_B
C501
Position Move
Axis1 + Axis3
Target Position1 64600
Target Position3 6000
Mode ABS Mode
Target Velocity 1800
Acceleration 400
Deceleration 1300
Immediate Stop OFF
S-Curve Option 100
B4XZ_B
C501
B4XZ_C
C502
B4XZ_S
C503
B4XZ_Error
C504
19
YinsertBusy
C90
B4XZ_C
C502
RST

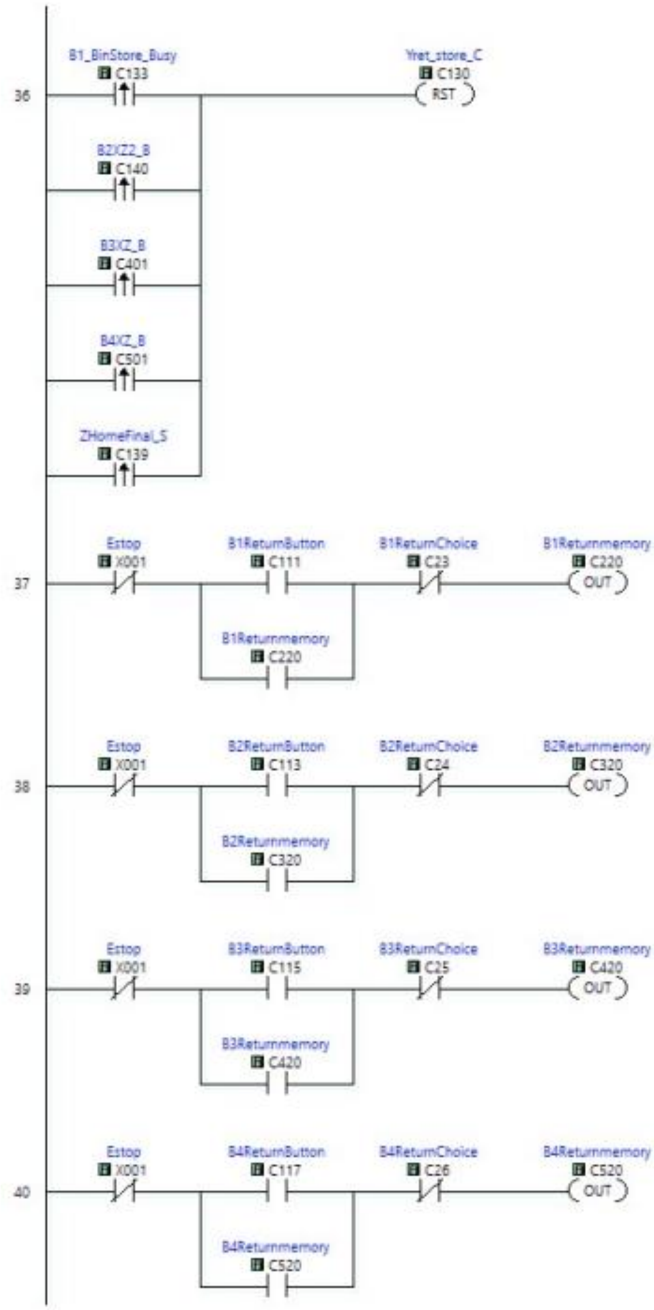

YINSERT*
We are moving the Y-axis into the bins.
20
B1XZ_C
C87
Yinsert_C
C89
SafetyCircuit1
Y021
ZgrabBusy
C107
B2XZ_C
C151
YinsertBusy
C90
B3XZ_C
C402
B4XZ_C
C502
Position Move
Axis2
Target Position2
17500
Mode
ABS Mode
Target Velocity
1000
Acceleration
200
Deceleration
13000
Immediate Stop
OFF
S-Curve Option
100
YinsertBusy
C90
Busy
Yinsert_C
C89
Complete
C202
Error
DD9
ErrCode
21
ZgrabBusy
C107
Yinsert_C
C89
RST
ZGRAB
22
SafetyCircuit1
Y021
Yinsert_C
C89
Zgrab_C
C91
YretractBusy
C93
ZgrabBusy
C107
SafetyCircuit1
Y021
Position Move
Axis3
Target Position3
7200
Mode
ABS Mode
Target Velocity
800
Acceleration
100
Deceleration
13000
Immediate Stop
OFF
S-Curve Option
100
ZgrabBusy
C107
Busy
Zgrab_C
C91
Complete

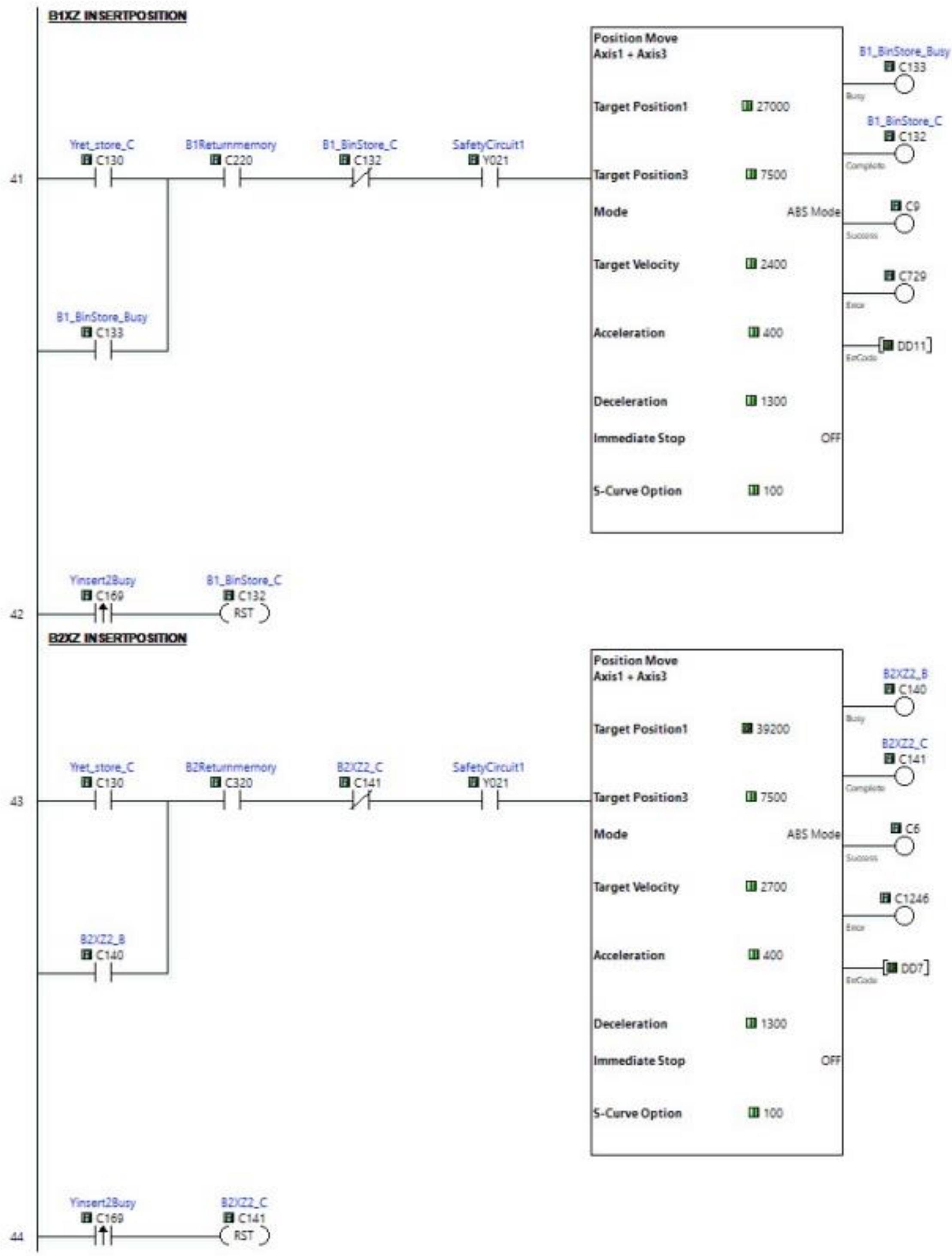

23
YretractBusy
C93
Zgrab_C
C91
RST
YRETRACT
24
SafetyCircuit1
Y021
Zgrab_C
C91
Yretract_C
C92
HomeXBusy
C95
YretractBusy
C93
SafetyCircuit1
Y021
Position Move
Axis2
Target Position2
0
Mode
ABS Mode
Target Velocity
900
Acceleration
100
Deceleration
1300
Immediate Stop
OFF
S-Curve Option
100
YretractBusy
C93
Busy
Yretract_C
C92
Complete
25
HomeXBusy
C95
Yretract_C
C92
RST

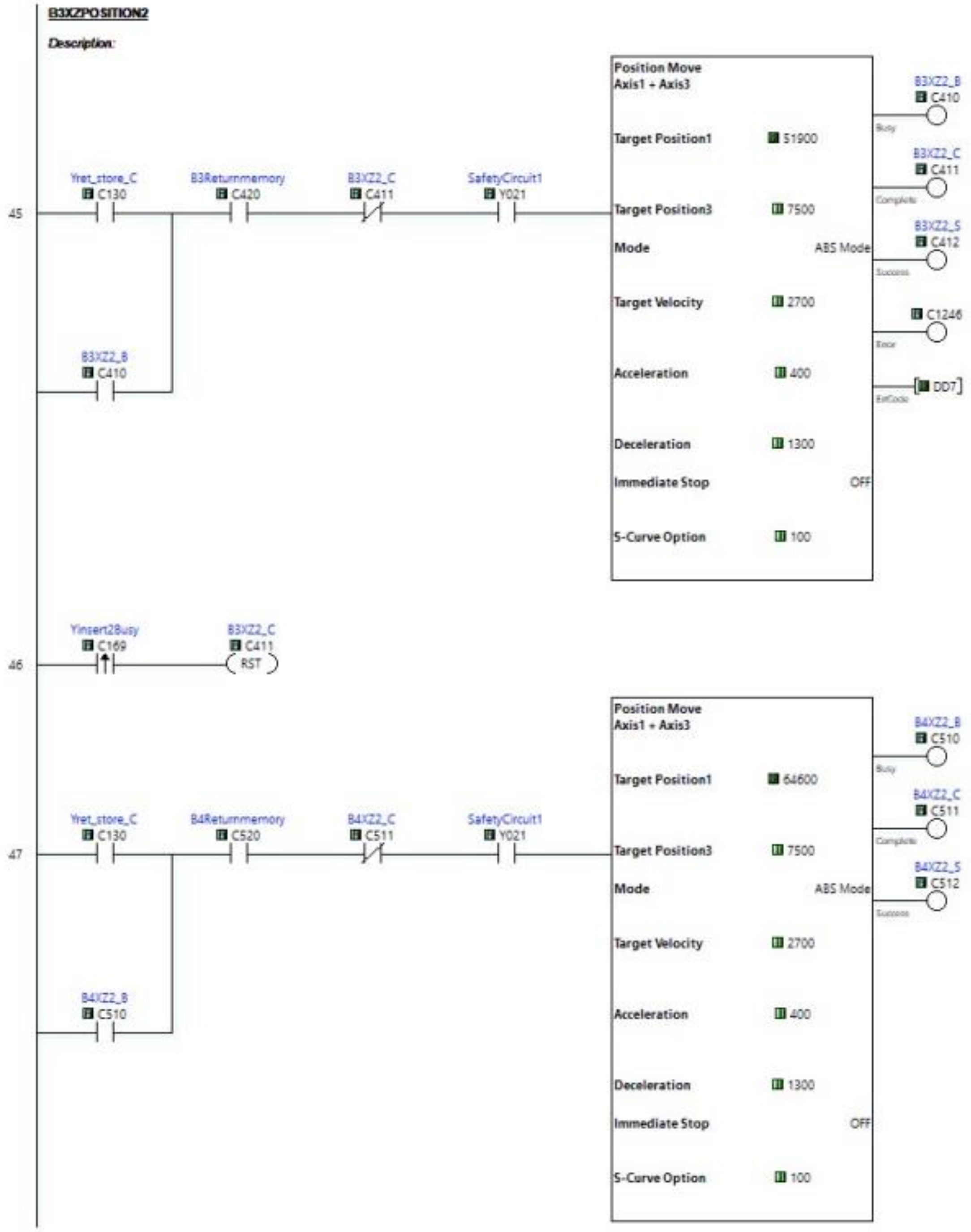

HOMING PROGRAM
26
SafetyCircuit1
Y021
Yretract_C
C92
Homeretract_X_C
C94
HomeXBusy
C95
Home(Mode2)
Axis1
Initial Velocity 1800
Switch1 X_Axis_LimitNegative X102
Switch1 State Rising Edge
Acceleration 300
Deceleration 1300
Direction Negative
Immediate Stop OFF
Set Position 0
HomeXBusy C95 Busy
Homeretract_X_C C94 Complete
C294 Success
Homeretract_Z_C
C98
Home(Mode2)
Axis3
Initial Velocity 1200
Switch1 Z_Axis_LimitNegative X106
Switch1 State Rising Edge
Acceleration 300
Deceleration 1300
Direction Negative
Immediate Stop OFF
Set Position 0
HomeZBusy C99 Busy
Homeretract_Z_C C98 Complete
C298 Success
C7 Error
DD10 ErrCode
27
YDeliverBusy
C121
Homeretract_X_C
C94
RST


28
YDeliverBusy
C121
Homeretract_Z_C
C98
RST
YDELIVER
We are moving the Y-axis into the delivery area.
Position Move
Axis2
Target Position2
16500
Mode
ABS Mode
Target Velocity
1600
Acceleration
300
Deceleration
1300
Immediate Stop
OFF
S-Curve Option
100
YDeliverBusy
C121
Busy
YDeliverComplete
C120
Complete
C1116
Error
DD15
ErrCode
29
SafetyCircuit1
Y021
Homeretract_X_C
C94
Homeretract_Z_C
C98
YDeliverComplete
C120
YDeliverBusy
C121
B1 IS DELIVERED
30
YDeliverComplete
C120
B1ReturnButton
C111
B1Memory
C200
YHomeFirst2Busy
C119
B1StorePopup
C110
OUT
B1StorePopup
C110
B2 IS DELIVERED
31
B2ReturnButton
C113
B2Memory
C300
YHomeFirst2Busy
C119
YDeliverComplete
C120
B2StorePopup
C112
OUT
B2StorePopup
C112
B3 IS DELIVERED
32
B3ReturnButton
C115
B3Memory
C400
YHomeFirst2Busy
C119
YDeliverComplete
C120
B3StorePopup
C114
OUT
B3StorePopup
C114

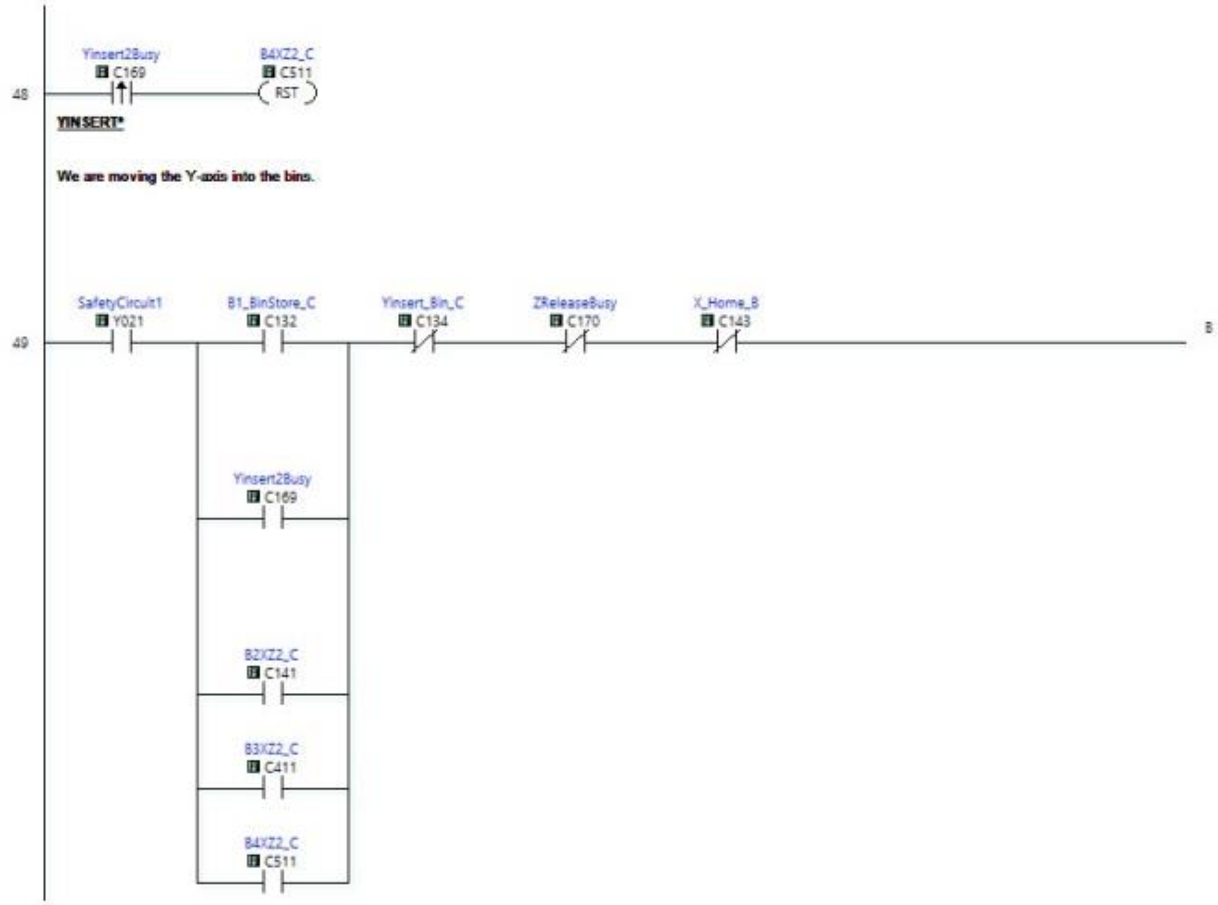

33
B4ReturnButton
C117
B4Memory
C500
YHomeFirst2Busy
C119
YDeliverComplete
C120
B4StorePopup
C116
OUT
B4StorePopup
C116
34
YHomeFirst2Busy
C119
YDeliverComplete
C120
RST
YRETRACTSTORE*
Position Move
Axis2
Target Position2
1000
Mode
ABS Mode
Target Velocity
800
Acceleration
200
Deceleration
1300
Immediate Stop
OFF
S-Curve Option
100
YHomeFirst2Busy
C119
Busy
Yret_store_C
C130
Complete
C8
Success
DD30
ErrCode
35
SafetyCircuit1
Y021
B1ReturnButton
C111
Yret_store_C
C130
B2ReturnButton
C113
B3ReturnButton
C115
YHomeFirst2Busy
C119
B4ReturnButton
C117

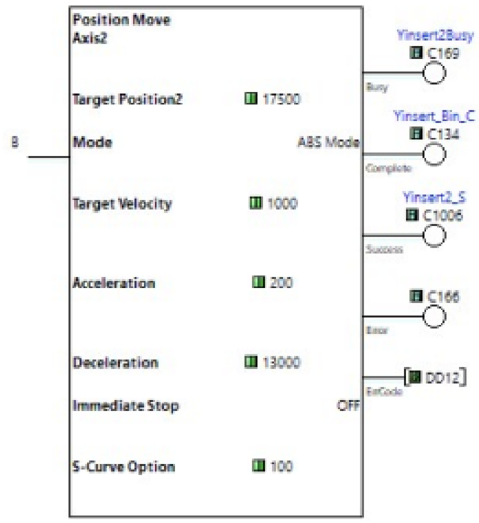

36
B1_BinStore_Busy
C133
Yret_store_C
C130
RST
B2XZ2_B
C140
B3XZ_B
C401
B4XZ_B
C501
ZHomeFinal_S
C139
37
Estop
X001
B1ReturnButton
C111
B1ReturnChoice
C23
B1Returnmemory
C220
OUT
B1Returnmemory
C220
38
Estop
X001
B2ReturnButton
C113
B2ReturnChoice
C24
B2Returnmemory
C320
OUT
B2Returnmemory
C320
39
Estop
X001
B3ReturnButton
C115
B3ReturnChoice
C25
B3Returnmemory
C420
OUT
B3Returnmemory
C420
40
Estop
X001
B4ReturnButton
C117
B4ReturnChoice
C26
B4Returnmemory
C520
OUT
B4Returnmemory
C520

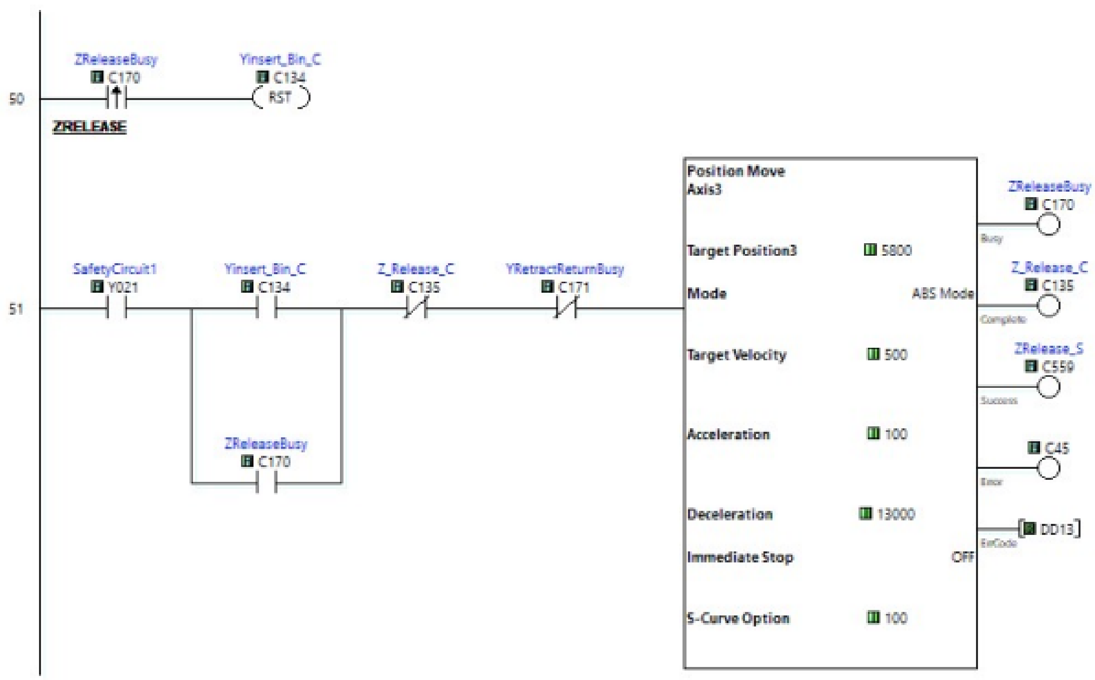

B1XZ INSERTPOSITION
41
Yret_store_C C130
B1Returnmemory C220
B1_BinStore_C C132
SafetyCircuit1 Y021
B1_BinStore_Busy C133
Position Move Axis1 + Axis3
Target Position1 27000
Target Position3 7500
Mode ABS Mode
Target Velocity 2400
Acceleration 400
Deceleration 1300
Immediate Stop OFF
S-Curve Option 100
B1_BinStore_Busy C133
B1_BinStore_C C132
C9
C729
DD11
42
Yinsert2Busy C169
B1_BinStore_C C132 RST
B2XZ INSERTPOSITION
43
Yret_store_C C130
B2Returnmemory C320
B2XZ2_C C141
SafetyCircuit1 Y021
B2XZ2_B C140
Position Move Axis1 + Axis3
Target Position1 39200
Target Position3 7500
Mode ABS Mode
Target Velocity 2700
Acceleration 400
Deceleration 1300
Immediate Stop OFF
S-Curve Option 100
B2XZ2_B C140
B2XZ2_C C141
C6
C1246
DD7
44
Yinsert2Busy C169
B2XZ2_C C141 RST

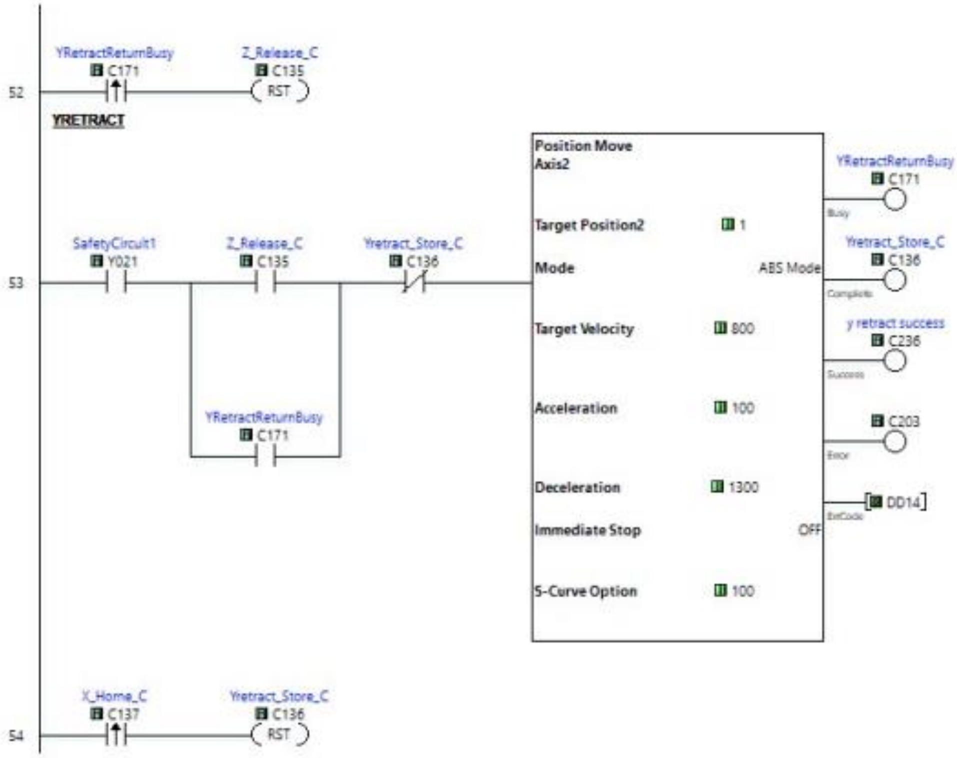


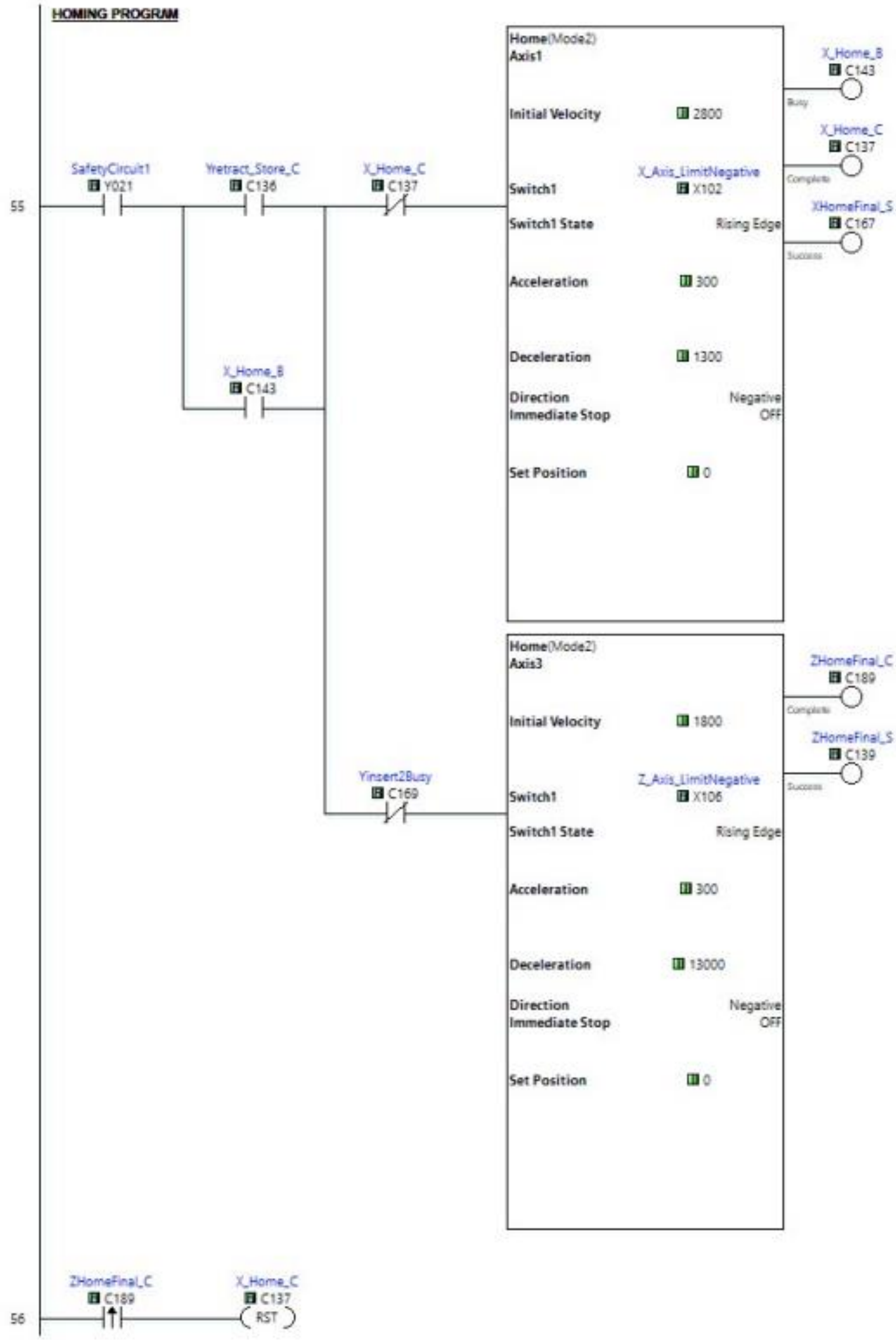
B3XZPOSITION2
Description:
45
Yret_store_C
C130
B3Returnmemory
C420
B3XZ2_C
C411
SafetyCircuit1
Y021
B3XZ2_B
C410
Position Move
Axis1 + Axis3
Target Position1
51900
Target Position3
7500
Mode
ABS Mode
Target Velocity
2700
Acceleration
400
Deceleration
1300
Immediate Stop
OFF
S-Curve Option
100
B3XZ2_B
C410
B3XZ2_C
C411
B3XZ2_S
C412
C1246
DD7
46
Yinsert2Busy
C169
B3XZ2_C
C411
RST
47
Yret_store_C
C130
B4Returnmemory
C520
B4XZ2_C
C511
SafetyCircuit1
Y021
B4XZ2_B
C510
Position Move
Axis1 + Axis3
Target Position1
64600
Target Position3
7500
Mode
ABS Mode
Target Velocity
2700
Acceleration
400
Deceleration
1300
Immediate Stop
OFF
S-Curve Option
100
B4XZ2_B
C510
B4XZ2_C
C511
B4XZ2_S
C512

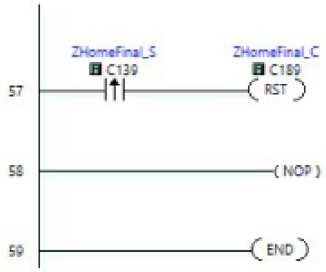

48
Yinsert2Busy
C169
B4XZ2_C
C511
RST
YINSERT*
We are moving the Y-axis into the bins.
49
SafetyCircuit1
Y021
B1_BinStore_C
C132
Yinsert_Bin_C
C134
ZReleaseBusy
C170
X_Home_B
C143
B
Yinsert2Busy
C169
B2XZ2_C
C141
B3XZ2_C
C411
B4XZ2_C
C511


Position Move
Axis2
Target Position2 17500
8
Mode ABS Mode
Target Velocity 1000
Acceleration 200
Deceleration 13000
Immediate Stop OFF
S-Curve Option 100
Yinsert2Busy
C169
Busy
Yinsert_Bin_C
C134
Complete
Yinsert2_S
C1006
Success
C166
Error
DD12
ErrCode


50
ZReleaseBusy
C170
Yinsert_Bin_C
C134
RST
ZRELEASE
51
SafetyCircuit1
Y021
Yinsert_Bin_C
C134
Z_Release_C
C135
YRetractReturnBusy
C171
ZReleaseBusy
C170
Position Move
Axis3
Target Position3 5800
Mode ABS Mode
Target Velocity 500
Acceleration 100
Deceleration 13000
Immediate Stop OFF
S-Curve Option 100
ZReleaseBusy
C170
Busy
Z_Release_C
C135
Complete
ZRelease_S
C559
Success
C45
Error
DD13
ErrCode


52
YRetractReturnBusy
C171
Z_Release_C
C135
RST
YRETRACT
53
SafetyCircuit1
Y021
Z_Release_C
C135
Yretract_Store_C
C136
YRetractReturnBusy
C171
Position Move
Axis2
Target Position2
1
Mode
ABS Mode
Target Velocity
800
Acceleration
100
Deceleration
1300
Immediate Stop
OFF
S-Curve Option
100
YRetractReturnBusy
C171
Busy
Yretract_Store_C
C136
Complete
y retract success
C236
Success
C203
Error
DD14
ErrCode
54
X_Home_C
C137
Yretract_Store_C
C136
RST


HOMING PROGRAM
55
SafetyCircuit1 Y021
Yretract_Store_C C136
X_Home_C C137
X_Home_B C143
Home(Mode2) Axis1
Initial Velocity 2800
Switch1 X_Axis_LimitNegative X102
Switch1 State Rising Edge
Acceleration 300
Deceleration 1300
Direction Negative
Immediate Stop OFF
Set Position 0
X_Home_B C143
Busy
X_Home_C C137
Complete
XHomeFinal_S C167
Success
Yinsert2Busy C169
Home(Mode2) Axis3
Initial Velocity 1800
Switch1 Z_Axis_LimitNegative X106
Switch1 State Rising Edge
Acceleration 300
Deceleration 13000
Direction Negative
Immediate Stop OFF
Set Position 0
ZHomeFinal_C C189
Complete
ZHomeFinal_S C139
Success
56
ZHomeFinal_C C189
X_Home_C C137
RST


ZHomeFinal_S
C139
ZHomeFinal_C
C189
RST
57
58
NOP
59
END

Data Communication Module

No	Name	Slot0 Port1	Slot0 Port2	Slot1 Port1	Slot1 Port2
1	Protocol	-	-	-	-
2	Node	-	-	-	-
3	Baud Rate	-	-	-	-
4	Parity Bit	-	-	-	-
5	Stop Bit	-	-	-	-
6	Data Bit	-	-	-	-
7	Time-out	-	-	-	-
8	Char Time-out	-	-	-	-
9	RTS ON Delay	-	-	-	-
10	RTS OFF Delay	-	-	-	-
11	Response Delay Time	-	-	-	-