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Vertical Carousel Storage System – Senior Design Report

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ENGR491 - Senior Design Fall 2024

ABSTRACT

Vertical carousel storage systems (VCSS) implemented in the manufacturing setting utilize vertical storage space, decrease product pick time, and assist with inventory accuracy through implementation of an inventory control system. A tabletop prototype of a vertical carousel storage system was designed by a previous senior design team in 2022. This report details the redesign of the previous vertical carousel storage system. The carousel's safety features, mechanical components, software implementation, and electrical design will be revised and improved upon. The VCSS creates an educational opportunity for up-and-coming manufacturing engineers and manufacturing engineering technology students. The main constraint that must be abided by is that of the product's tabletop size. The finished product will be a prototype required to provide the product to the user quickly, safely, and all while being user friendly. The engineering team set to complete the project are educated well enough to do so correctly and efficiently.

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1 INTRODUCTION

Vertical carousel storage is a high-density storage solution that moves on the vertical axis creating more storage space than an ordinary static shelf unit [4]. The vertical carousel storage system was first developed during the Great Depression when manufacturers could not keep their equipment organized [2]. As a result, the Supreme Company introduced the vertical carousel concept as a solution to the manufacturer's predicament. The vertical carousel storage system is now used in many fields including manufacturing, healthcare systems, libraries, aerospace, and law enforcement [2].

In manufacturing and industrial settings floor space is needed for optimization, productivity, accessibility, quality control, and inventory management. Vertical carousel storage systems (VCSS) maximize storage capacity by utilizing vertical space, saving up to 90% of space in warehouses. Manufacturers are able to store more pieces of equipment, materials, and components by using this type of automated system.

A VCSS provides organized storage with multiple bins, shelves, and trays. These parts rotate vertically, which allows categorization and location of parts. This is a beneficial resource in facilities that require access to numerous parts, tools, and components. After VCSS implementation, users will spend less time searching for a specific item, increasing productivity in warehouses, distribution centers, and other facilities. The automation of vertical carousel storage systems allows precision of inventory. The automated nature permits tracking of items, which minimizes the risk of human error and ensures accuracy. The VCSS offers an all-in-one solution to the needs of manufacturing.

1.1 CURRENT SOLUTIONS/PRODUCTS

Companies and warehouses implement different types of Automated Storage Systems to enhance operational efficiency, streamline inventory, and optimize space utilization. The systems are designed to meet specific needs and accommodate specific product types, volumes, and handling requirements. In warehouses the most common ASRS include vertical carousel modules, horizontal carousel modules, vertical lift modules, and robotic storage.

Vertical carousel modules (illustrated in Fig. 1.1) consist of a series of carriers mounted on a chain drive, powered by a motor that enables bi-directional movement in a vertical loop along a track [8]. This storage system provides fast and secure delivery of items as well as a reliable and cost-effective storage solution [8].

Figure 1. 1 ***Vertical Carousel Module [20]***

Horizontal carousel modules (see in Fig 1.2) are dense storage systems with bins mounted on a rotating oval track. The bins rotate horizontally, offering high storage density and easy access to slow-to-medium-moving products. This type of storage system handles both individual items and pallets. [8]. The system is typically installed with pods to maximize picking speed, and automated door systems to enhance security and efficiency.

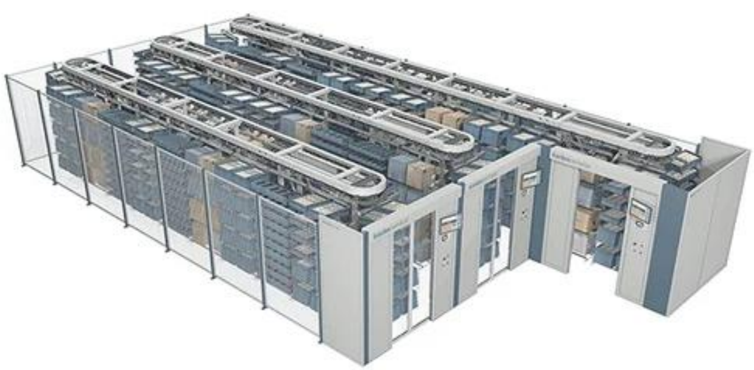

Figure 1. 2 ***Horizontal Carousel Module [3]***

Vertical lift modules (see in Figure 1.3) consist of two columns of trays with an inserter/extractor in the center. The inserter/extractor locates the specific product and presents it to the operator. These systems are highly customizable, accommodating a wide range of product sizes and weights, and they are often equipped with inventory management software for seamless operation. Vertical lift modules are the most flexible storage system in this category [8].

Figure 1. 3 ***Vertical Lift Module [8]***

Robotic systems (seen in Fig 1.4) utilize robotic technology to automate the movement of items. These systems typically encompass a wide range of robots including robotic arms, drones, and vehicles to navigate storage aisles. These bots are responsible for retrieving items and delivering them to operators. Equipped with sensors, artificial intelligence algorithms, and precise actuators, robotic storage systems are able to execute complex tasks with speed, accuracy, optimization, and efficiency.

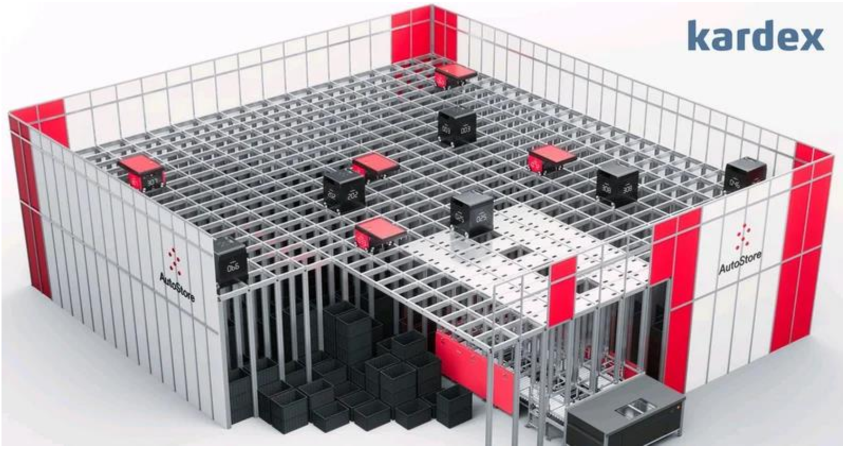

Figure 1. 4 ***Robotic Storage Retrieval System [8]***

1.2 IMPORTANT PARTS

The carousel storage system is able to store items in bins of different sizes. The bins are located in carriages, attached to a roller chain fixed by sprockets. In order to operate the system, a user will use a digital interface to locate and obtain the desired item. The interface consists of an LCD touch screen and microcontrollers to perform the tasks selected by the user. The motors are essential as they drive the chain system which ultimately produces the requested carriage and bin for the user.

1.3 OBJECTIVE STATEMENT

The Engineering Department at USI has identified a need to educate its manufacturing engineering and manufacturing engineering technology students on the equipment they will encounter in their future careers. This includes familiarizing students with the Vertical Carousel Storage System (VCSS) and its operational capabilities.

The project was initially developed by senior design students in Spring 2022, but some operational enhancements were still needed to fully meet the stakeholder's expectations. As shown in Figure 1.5 below, further improvements were required to optimize the system's functionality.

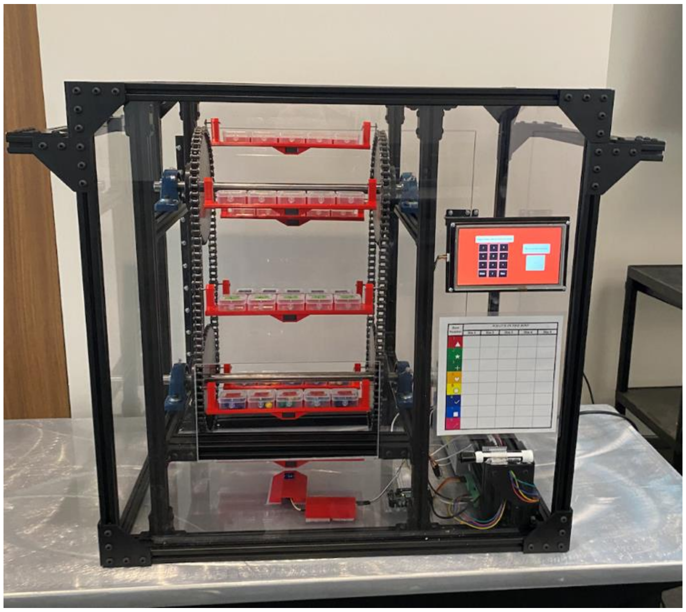

Figure 1. 5 ***Current Carousel Designed By 2022 Seniors [13]***

The project resulted in a functioning proof-of-concept prototype of a tabletop Vertical Carousel Storage System (VCSS), designed specifically for use in educational settings, rather than as a production-ready machine for industrial use. While not intended for factory environments, the prototype provides a valuable hands-on learning tool for students, allowing them to gain practical experience with VCSS technology. This system helps students understand the operation of such equipment in real-world manufacturing contexts, enhancing their knowledge and preparing them for future roles in the manufacturing industry. Emphasis was placed on ensuring the system's safety and operational functionality for effective and secure use during lab sessions.

1.5 SPECIFIC AIMS

The Vertical Carousel Storage System will be designed and built to enhance safety, refine motor control for bi-directional operation, and variable speed all while maintaining a user-friendly interface. Achieving these goals will produce an efficient carousel storage system capable of quick retrieval times, maintaining inventory accuracy, all while taking up little space.

1.6 REQUIREMENTS/CONSTRAINTS

The constraints imposed on the design project, coupled with the requirements for the finished prototype, will guide the design team to a functional vertical carousel storage system. The main constraint the team will have to consider through the redesign of the project is that the finished prototype must be small enough to fit on a tabletop. The project requirements, however, more closely define the project goals and expectations. The requirements matrix seen below (Fig 1.6) demonstrates the requirements and performance measures set for the project and how they correspond to one another.

		Performance Measures	Cost	Profit Margin	Pick To Light Feature	Quick Retrival Time	Number of Clicks to Product Delivery
	Market Requirements (What is wanted)	Importance	1	2	3	4	5
1	Operation Safety	1					
2	Maximize Available Vertical Storage Space	2					
3	Quick Retrival Time	3					
4	Provides Inventory Information	7					
5	Enclosed Carousel	4					
6	Increases Inventory Accuracy	6					
7	Simple Mechanical Design	8					
8	User-Friendly Interface	5					

Figure 1. 6 ***Requirements Matrix for The Redesign of The Vertical Carousel Storage System***

Operational Safety is the most important factor when designing a product for market use. Without proper safety mechanisms, the product will be undesirable to users, lawsuits will pose a threat, and safety codes must be met for the system to be implemented. According to ANSI MH 24.1 2005 code 5.4.4 “when a carousel is equipped with an Inserter/Extractor mechanism, personnel shall be protected from accidental contact with moving parts by a guard” [10]. Our operational safety is guaranteed using light sensors in the picking area that ensure the system shuts down if the barrier is impeded during rotation. An emergency stop (E- Stop) button was added to the exterior of the carousel enclosure so that the system may be quickly shut down in an emergency. The maintenance door implemented at the back of the machine is be equipped with a locking mechanism to make sure the system, and user, are secure from behind the machine. Accomplishing these safety features ensures the team has met the operational safety requirement.

Quick product retrieval time is another important aspect of the project. Having a quick product retrieval time is what ensures pick times decrease after system implementation. To create a desirable return rate, the system must make the company more productive, this quick retrieval time will assist. In manufacturing full size vertical carousels reduced “approximately 40 percent of refill order total waiting time” [9]. This ability to speed up manufacturing processes is what makes the VCSS extremely desirable for industry. The team has created a carousel storage system that is able to make a full vertical rotation in 20 seconds or less. Implementation of bi-directional operation and speed variation assists in achieving this requirement. This goal was initially achieved by the previous team, but some technical errors resulted in the motor rotating in one direction. Speed variation to allow slow, medium, and fast movements is intended for this project. Additionally, the finished product is completed with a bin spotlight to mitigate any human error present in the picking process. The bin spotlight allows the user the ability to select and obtain a particular bin in a particular row. The bin spotlight will illuminate the requested bin for the operator to easily locate and pick it up. A system capable of delivering and illuminating the bin requested by the user in under 20 seconds will have met these requirements.

Finally, the team has requested a user-friendly interface to be implemented at all costs as simplicity is most desirable when creating a product to be used by people of ages 14+. Keeping the interface easy to navigate makes the lift system accessible to all and more desirable for manufacturers. This requirement will be met after test subjects are able to operate the machine quickly and efficiently. The team may also use the “number of clicks” method to determine how user-friendly the process is. Typically known as the “3-click rule” is the suggestion that if users cannot find what they are searching for after three clicks they often become frustrated and leave their search [18]. Although most used as guidelines for web applications, the same standards will be used for the VCSS. A user-friendly interface will be determined as such by keeping the number of clicks to deliver less than four.

The requirements matrix seen in Figure 1.6 above outlines how the requirements interact with performance measures dictated by the design team. Cost efficiency is the most important measure to compare requirements with as there is a project budget the team must comply with. Operation safety and quick retrieval time must also be kept in mind throughout meeting the requirements. Thus, if the requirements are met, yet the system is not safely operable, or slow to pick, the system is not ideal as it does not comply with the performance measures.

1.7 PREVIOUS KNOWLEDGE

The vertical carousel storage system project requires knowledge acquired by the team through their engineering academic career. During the sprocket and chain sizing process, the team will call upon their knowledge of gear ratios and angular velocity information. The team will use a dynamics of machinery textbook to aid in the selection process, as the book proves a great resource for gear sizing and gear behavior in a system [11]. The team will demonstrate their SolidWorks skills during the design phase as drawings and assemblies of the system will be produced. Throughout the design process the team will become familiar with subjects they have not yet learned. The VCSS will require coding of a Hall sensor, LCD touchscreen, and an Arduino. A book on sensor systems will be used as a guide throughout the familiarization process of sensor function and provide different sensor options [12]. The team also anticipates learning how to code in the language required to operate the electrical components listed. Learning these new concepts and skills, coupled with preexisting knowledge will ensure the final design and product is efficient and effective.

1.8 SUBSYSTEM BREAKDOWN

The Vertical Carousel Storage System consists of three main systems that can be broken down into other subsystems as seen in Fig 1.7 below. The main subsystems include the mechanical, electrical, and software systems. The mechanical system includes carriage design, sprocket and chain configuration, as well as the bearing and axle interface. The electrical system includes the powering of the system coupled with the sensor and screen components. The software subsystem involves the interfacing of the sensors with the safety and operation subsystems that are discussed in other sections. The design of the carousel base is an additional subsystem that will be discussed.

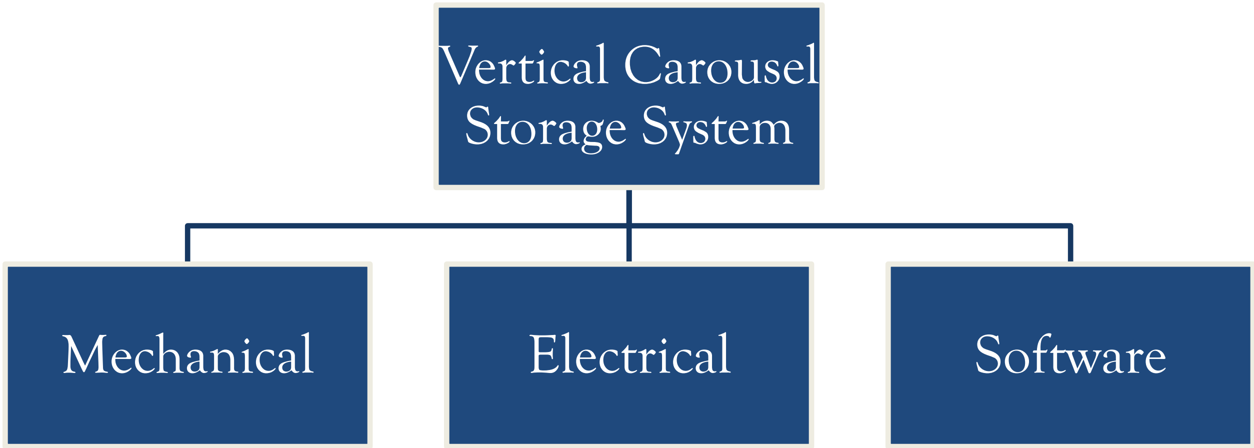

Figure 1. 7 VCSS Subsystem Breakdown

2 DESIGN

2.1 DESIGN OF THE ENCLOSURE AND STORAGE SOLUTIONS

The enclosure and storage subsystems of the vertical carousel project will be discussed here. All components that will be purchased to implement the storage designs can be seen in Appendix A.

2.1.1 THE PREVIOUS CAROUSEL ENCLOSURE

The carousel was initially surrounded by a Lexan box implemented by the previous design team in 2022, this encasement will remain through the redesign of the carousel. The Lexan barrier around the machine provides the operator with safety from any malfunction or entanglement that may otherwise occur. Keeping the existing enclosure met the expectation of ANSI code MH24.1-5.4.4. which details the requirement of a guard to be in place when inserting or extracting material from a carousel [19]. At the back of the enclosure there is a service door that can be opened to perform maintenance on the machine; when the machine is not being operated on the door to the back of the machine is shut and bolted. Additionally, at the front of the carousel there is a small pick window that restricts access to the moving components of the carousel. These are all important design features that assist the team in meeting their safety requirements.

2.1.2 STORAGE

The carousel enclosure was previously equipped with carrying handles on either side of the machine, because of the need for easy transportation of the unit between classrooms, a base cabinet was designed. See Figure 2.1.1 below.

Figure 2.1.1 ***Original carousel enclosure with two fixed handles (circled) on either side to aid in the transportation of the machine. [13]***

2.1.3 Conceptual Design of the Carousel Base

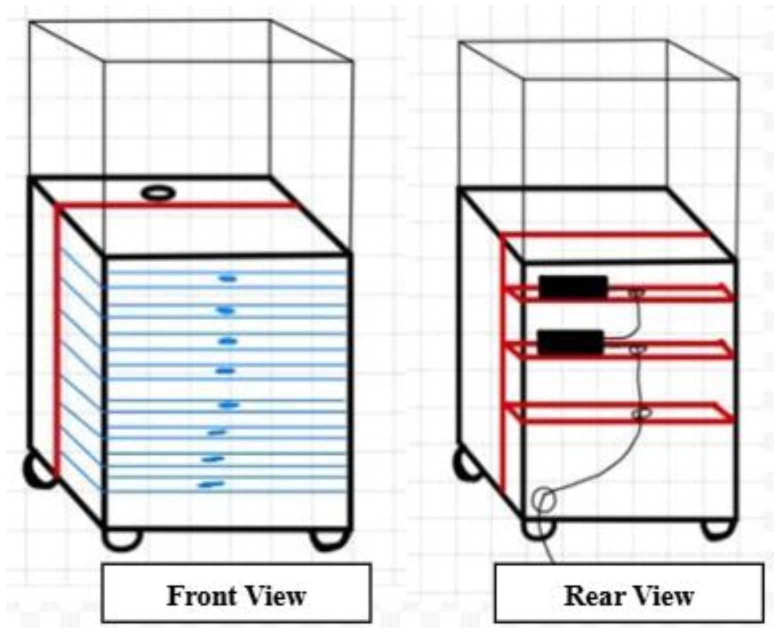

Figure 2.1.2 Conceptual *drawing of the base component.*

A conceptual sketch of the carousel base design can be seen above in Figure 2.1.2. A dividing wall separates the base into both rear and front compartments. The front of the carousel base, because it is to be used for classroom purposes, was initially designed to house drawers. The drawers would have offered an organized storage solution for any extra parts that are stored in the carousel bins. Ultimately this was decided against because drawer slides aren't widely sold in lengths less than ten inches. The rear of the carousel base was designed initially to contain shelves where the electrical components of the carousel will be housed. Storing the converter, Arduino, and breadboard components in the base of the carousel would have allowed for a more aesthetic look of the machine, as well as ensure the components stay properly connected. To accommodate the electrical components in the back of the carousel base, there would be a two-inch hole running down through all the rear shelves to keep the wires running through the shelving system neatly organized, and safe from breakage. This design was decided against due to the short length of the electrical wires and the overall small size of the electrical components. The SolidWorks design can be seen below in Figure 2.1.3.

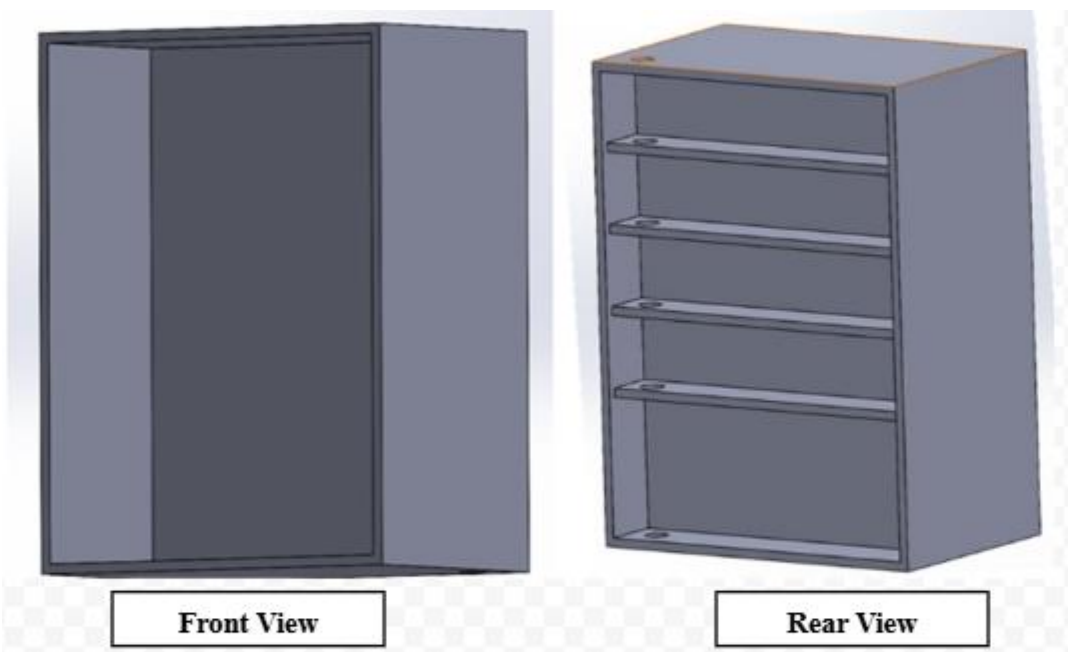

Figure 2.1.3 ***SolidWorks model of the cabinet base onto which the carousel enclosure was mounted. The dimensions of the base component were found by measuring the existing enclosure.***

2.1.4 Final Design of the Carousel Base

The final design was that of the above without the drawers in the front of the enclosure, or the shelves in the rear. The dividing wall was kept in the final design as it adds to the overall structural integrity of the base, as well as leaving opportunity for future design work.

The dimensions of the original carousel enclosure were measured to be 30 inches wide, 30 inches tall, and 20 inches deep. These were used in the design of the base cabinet to ensure a flush fit upon assembly. See completed carousel base below in Figure 2.1.4.

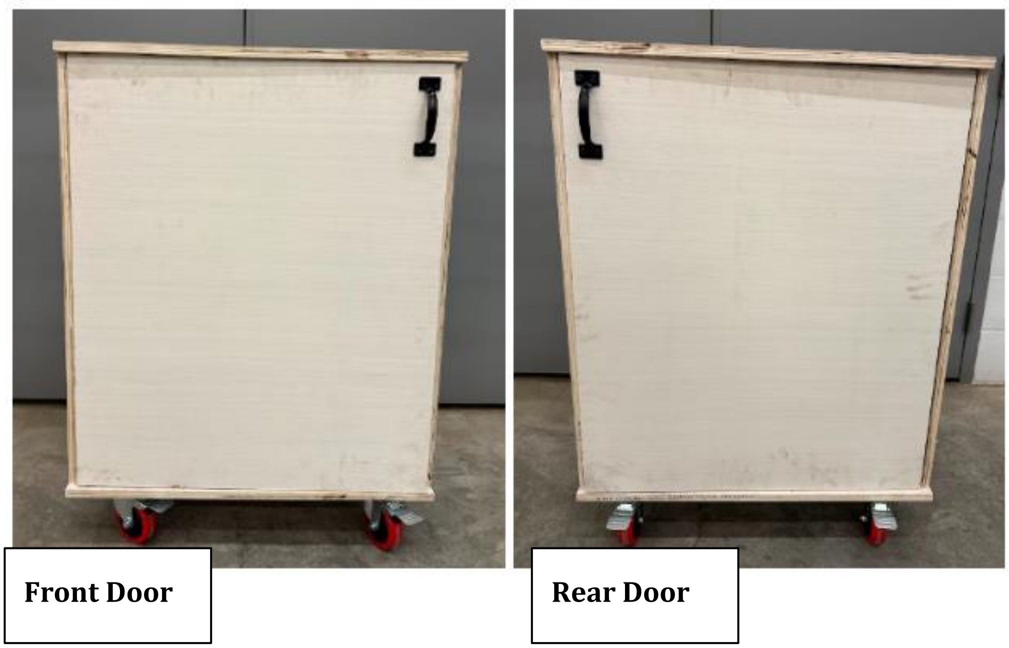

Figure 2.1.4 ***Completed carousel base equipped with handles on the front and rear doors***

Locking caster wheels on the bottom of the cabinet makes it easily transportable by one person, and able to be safely locked into place. Door handles and latches fixed to both the front and rear doors prohibit the base from opening unless prompted. This feature adds to the overall safety of the carousel. The encased carousel was fixed to the top of the base, making the two systems one unit. See Figure 2.1.5 below.

Figure 2.1.5 ***Complete cabinet base with carousel fixed to the tabletop***

The cabinet base provides easy transport of the carousel from classroom to classroom without being a “team lift” situation. The storage and the ease of transport provided by the base made it a necessary upgrade to the original design. The base of the carousel will be a functional component during classroom use of the storage system.

2.2 MECHANICAL DESIGN

All components that will be purchased to implement the mechanical design can be seen in Appendix A.1. The figure below shows the block diagram for this system.

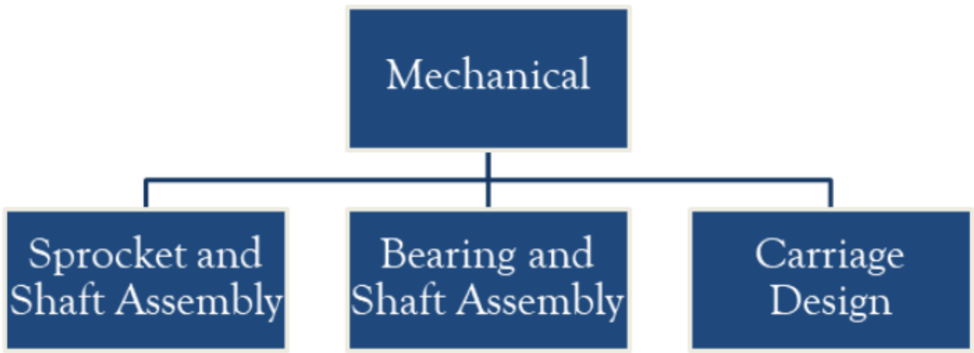

Figure 2.2.1 ***Diagram of the mechanical system breakdown***

2.2.1 Previous Carriage Design and Attachment

The carriages equipped by the previous senior design team housed five 2.04 in^3 bins. Across the eight total carriages in the system, the total bin storage volume equated to 81.6 in^3. The carriages were 3D printed using PLA filament, this provides a lightweight carriage solution that will be maintained by the team throughout the redesign of the system. On either side of the carriage are two extruded arms, with holes at the top that allow the carriages to be attached to the roller chain using specialty links. The previous carriage design can be seen below in Figure 2.2.2.

Figure 2.2.2 ***Previous carriage design implemented by the 2022 senior design team. Five slots allotted for the bins to be placed. [13]***

2.2.2 Redesign of the Carriage Components

The redesigned carriages include two carriage models. Model one includes capacity for five, 2.31 in^3 bins, while model two includes slots for three 3.4 in^3 bins and one additional 2.31 in^3 bin. Having two different bin models, one with the capacity for larger bins, adds diversity to what can be stored within the carriage while also increasing the overall volumetric storage capacity. See models one and two carriage designs below in Figure 2.2.3.

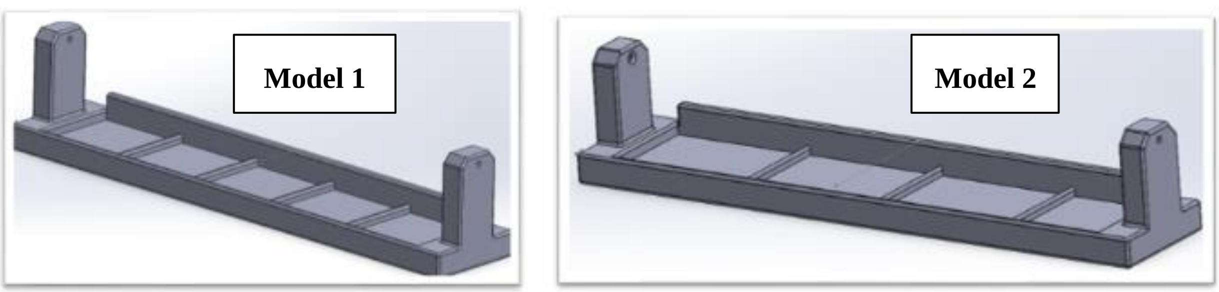

Figure 2.2.3 ***SolidWorks model of the two carriage designs to be implemented into the system.***

The carriage designs seen above were found not compatible with the carousel as their carriage arms were too long. Upon rotation around the system the deck of the carriage contacted the top axle, spinning the carriage 360° about the clevis pin. This is not ideal as during operation the bins would fall completely out of the carriage as they spun. The carriages were redesigned as seen below, to have shorter carriage arms. The re-designed carriages have an arm length of 1.45 inches, this is a suitable height as it is less than the radius of the top sprocket. The redesigned carriages can be seen below in Figure 2.2.4.

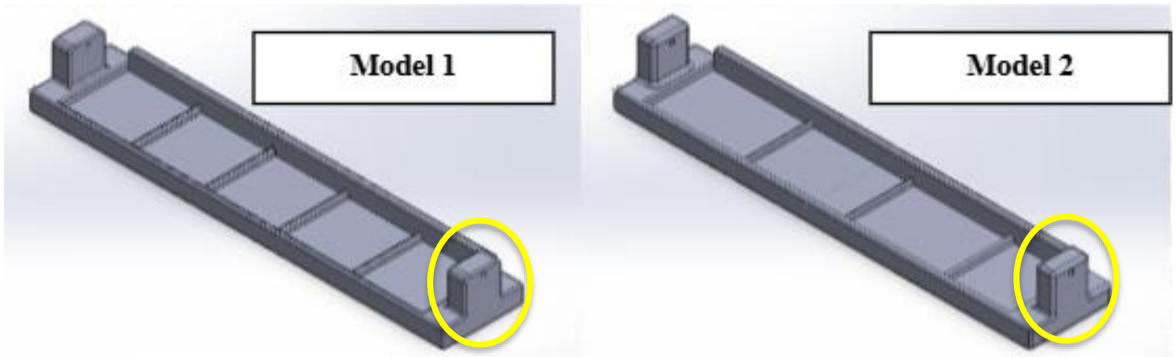

Figure 2.2.4 ***SolidWorks model of the two bin designs with shorter carriage arms (circled)***

Four carriages will be model one and the remaining four will be model two carriages. The total volumetric storage capacity of the system is 96.29 in³, this is a 14.7 in³ increase from the storage capacity achieved by the previous team. See Table 2.2.1 below which contains the bin volume comparison between the previous design and the redesigned carousel.

	L	W	D	Quantity/ Carriage	Number of Carriages	Total Volume in^3	
Previous Carriage Design							Old Design Total Bin Volume (in^3)
Original Carriage	1.5	1.7	0.8	5	8	81.6	81.6
New Carriage Design							New Design Total Bin Volume (in^3)
Model 1 Carriages	1.7	1.7	0.8	5	4	46.24	
Model 2 Carriages	1.7	2.5	0.8	3	4	40.8	
	1.7	1.7	0.8	1	4	9.248	96.288
						Total Volume Gain:	14.7 in^3

Table 2.2.1 ***Comparison of in-carriage bin storage capacity between the previous and current carousel design.***

Having two carriage models that house larger bins aided the team in meeting the requirement of maximizing in-carriage storage capacity. See Figure 2.2.5 below.

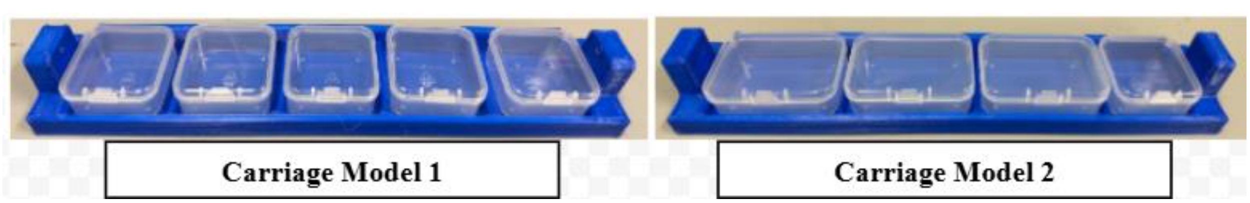

Figure 2.2.5 ***Carriage models one and two with their respective bins in place.***

The team maintained the previously used attachment method of the carriages onto the roller chain. The original design included eight sets of link inserts that were unevenly separated over the length of the chain. Upon redesigning the sprocket assembly and because of changes made to the carriage identification process (using a singular homing magnet instead of eight), chain links had to be removed from the original chain length. The system now requires equal spacing between carriages, which resulted in eleven total links being removed from either chain. The link inserts used to attach the carriages to the chain provide a hole that a clevis pin is run through that the carriages are attached to, to allow the carriages to remain oriented upright as they rotate about the carousel. The link inserts can be seen below in Figure 2.2.6.

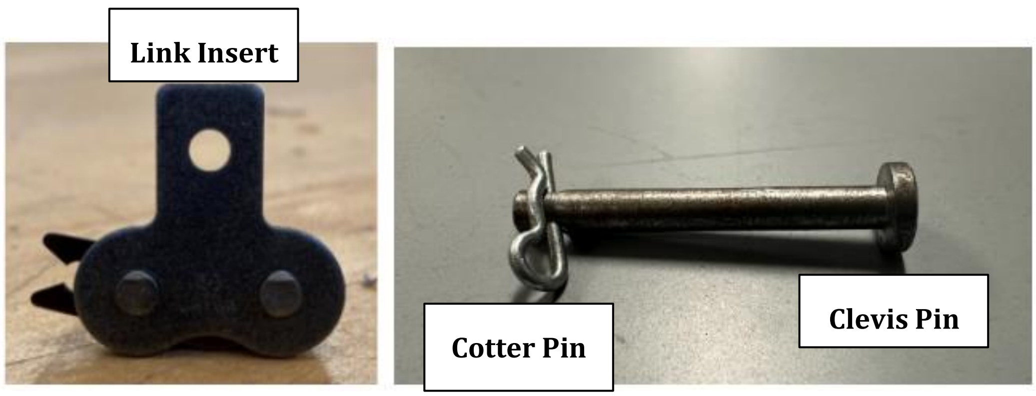

Figure 2.2.8 ***Link insert, clevis pin, and cotter pin***

The attachment method can be seen below in Figure 2.2.7, where the clevis pin is fed through the hole at the top of the carriage arm and is then secured by a cotter pin. The specialty chain links, clevis pins, and securing cotter pins provide a stable connection of carriage and chain [13].

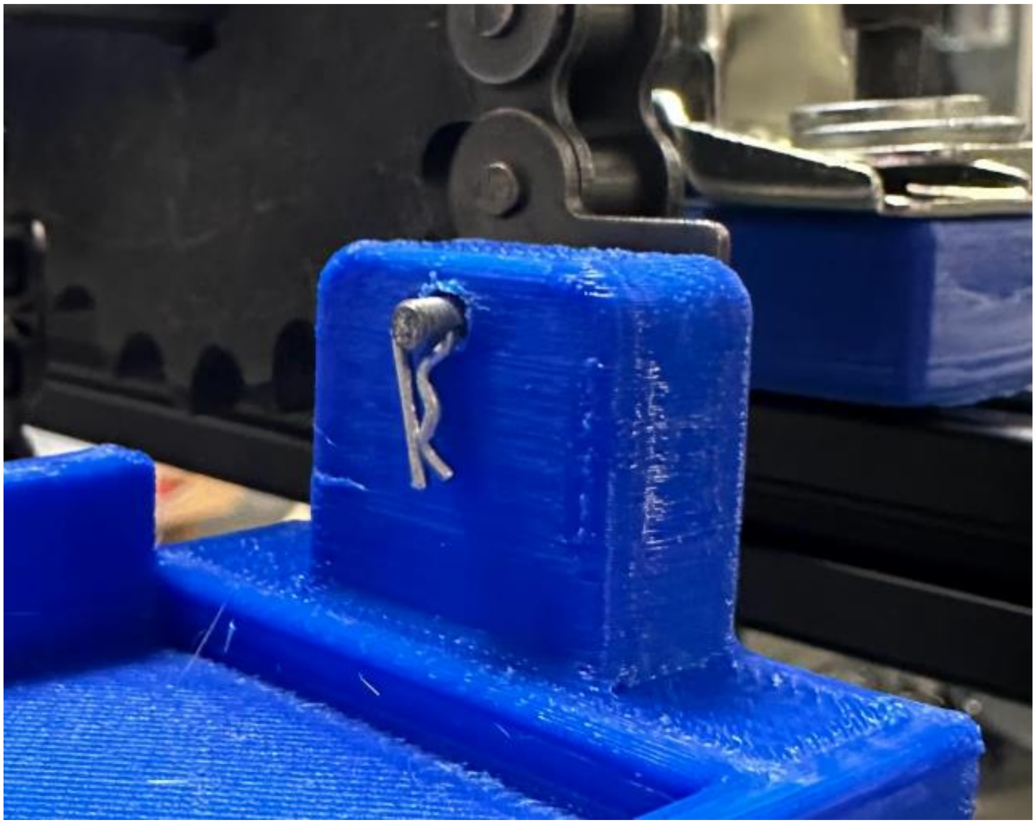

Figure 2.2.9 ***Chain and carriage attachment method- Clevis pin fed through the hole in the arm of the carriage and cotter pin to secure the assembly.***

2.2.3 PREVIOUS DESIGN OF THE MECHANICAL CONFIGURATION

The mechanical subsystem includes the sprocket and chain system and the bearing and axle configuration. The project being a continuation of a previous senior design project, the vertical carousel had already been built. In Figure 2.2.8 below, the previous mechanical arrangement can be seen.

Figure 2.2.8 ***Mechanical System Designed by Previous Team***

The mechanical design of the vertical carousel storage system completed by a previous senior design team included four 50 tooth sprockets connected with roller chain #40. Using four gears of the same size yielded a gear ratio of one, this gear ratio provided no mechanical advantage to the system. The overall largeness of the sprockets was unappealing to the current design team, exploration into the advantages of gear ratios assisted the team during the redesign process. Although keeping the original sprocket and chain system would mitigate expenses, ultimately the previous lift system was overdesigned and not operating at its full capability.

2.2.4 CONCEPTUAL DESIGN OF THE SPROCKET AND SHAFT ASSEMBLY

The initial approach was reducing all four of the sprocket sizes. This would have created a smaller carousel allowing for size reduction of the enclosure and would have more closely met the tabletop size constraint. The finished carousel would have been lighter as the reduction of all four sprockets would have justified smaller axles and chain. This decrease in the overall weight of the carousel would have made the motor's job easier, as it would not have had to work as hard to rotate the system, however downsizing all four sprockets would have led to another gear ratio of 1:1. In addition, this design would have detrimental effects on the project budget due to the need to purchase four new components.

2.3 FINAL MECHANICAL DESIGN

2.3.1 DESIGN OF THE SPROCKET AND SHAFT ASSEMBLY

The final design was constructed through a combination of the conceptual designs discussed above. Two of the original 50 tooth sprockets remained in the final assembly yet two, smaller, 21 tooth sprockets were added. The sprocket size comparison can be seen in Figure 2.3.1 below.

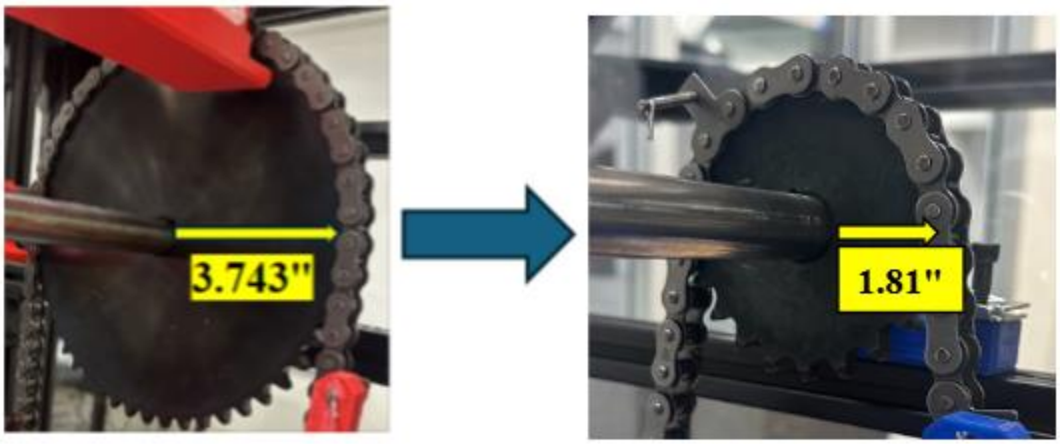

Figure 2.3.1 Previous driven *sprocket radius (larger) vs. radius of new sprockets (smaller)*

By decreasing the size of only two sprockets and using two of the previously used sprockets, a gear ratio of 0.42:1 was achieved through the purchase of only two new components (Eqn 2.3.1). The two large 50 tooth sprockets remain the driving gears at the bottom of the carousel, the smaller 21 tooth sprockets were fixed to the top shaft to be the driven gears. The smaller, driven, sprockets increase the speed of the carousel mechanically rather than pulling more power from the motor to increase the speed electrically.

$$Gear\ Ratio = \frac{\#\ of\ Teeth\ Driven\ Gear}{\#\ of\ Teeth\ Driving\ Gear} = \frac{21}{50} = Gear\ Ratio\ of\ 0.42{:}\,1$$

Equation 2.3.1 Equation used to find the gear ratio obtained by resizing the driven sprockets

This design would have reduced the revolution time by nine and a half seconds as can be seen below in Equations 2.3.2 and 2.3.3.

$$3.484\frac{rev}{min} * \frac{1\ min}{60\ s} = 0.06\frac{rev}{s}$$

$$\frac{1\ rev}{0.06\frac{rev}{s}} = 16.66\ s$$

Equation 2.3.2 Equation used to find the time in seconds for one revolution, with a gear ratio of 1:1.

$$\frac{3.484\frac{rev}{min}}{0.42} = 8.295\frac{rev}{min}$$

$$8.295\frac{rev}{min} * \frac{1min}{60\ s} = 0.14\frac{rev}{s}$$

$$\frac{1\ rev}{0.14\frac{rev}{s}} = 7.14\ s$$

Equation 2.3.3 Equation used to find the time in seconds for one revolution about the carousel, with a gear ratio of 0.42:1.

Where testing of the original carousel design, with a gear ratio of 1:1, resulted in a full carousel rotation in 32.3 seconds, or 3.484 revolutions per minute. The new gear ratio was used above to calculate the speed of the new design, the previous and present design are then compared using revolutions per second. The new sprocket and chain design allows the bottom sprocket of the carousel to make a full rotation in 7.14 seconds which is 9.5 seconds faster than that of the original design. These numbers are based solely upon the gear ratios and initial tests, they are baseline results that do not include any alterations to the actual programming of the system.

Although this arrangement increased the speed of the system, it decreased the overall torque output. This was a design tradeoff recognized by the team. Quick retrieval time being a requirement, the speed of the system remained the top concern when redesigning the sprocket system. Decreasing torque output was not recognized as a problem, being that the overall mass of the system was decreased upon resizing the two top sprockets and removing twenty-two total chain lengths. As the motor no longer has to provide the torque it previously was required to due to the decrease in overall system weight, and because it was chosen by the previous design team who considered a safety factor of two, the tradeoff in torque for additional speed was considered a valid design choice.

2.3.2 DESIGN OF THE BEARING AND SHAFT ASSEMBLY

The final design utilizes the previous ¾ inch axles, as well as the #40 roller chain, however new bearings were implemented in the redesign of the system. The decision to keep the axles, and chain was made largely with the project budget in mind, keeping the shaft and chain components makes room in the design budget to upgrade the bearings to more suitable standards.

The original bearings used were large, cast iron, pillow block mounted bearings (see Fig 2.3.2 below). These bearings were traded for four low-profile mounted, sealed steel, ball bearings (see Fig 2.3.2 below). The new bearings are designed with thin and compact housing that makes them ideal for space constrained spaces. The steel housing provides more strength than other aluminum or stainless options, as well as ensure longevity. Most importantly, the new bearings are self-aligning to compensate for any shaft misalignment that may occur. These bearings were chosen by the design team because of this feature [17]. Due to the mobile nature of the vertical carousel, self-aligning bearings ensure that the system will still spin properly after traveling to a new location.

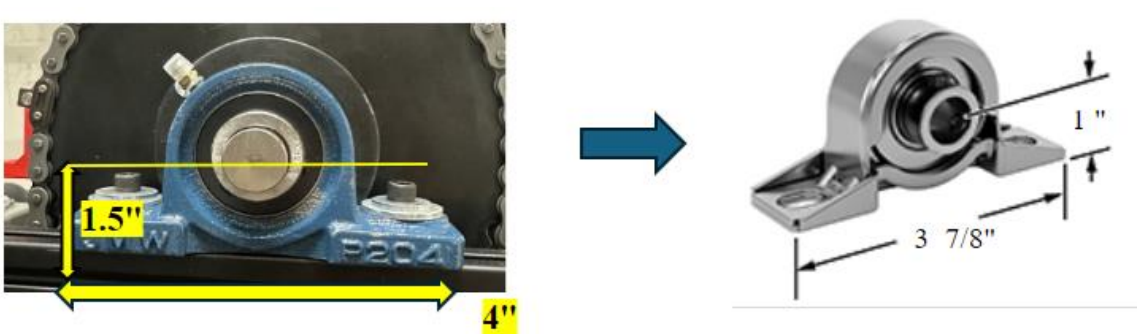

Figure 2.3.2 Previous Pillow Block Bearing vs. New Low Profile Steel Bearing

The new bearings sit ½ inch lower than the previous pillow block bearings, this was accounted for without disassembling the T-slot aluminum frame. Under the two top bearings a

0.7-inch, 3D printed spacer block was inserted. Similarly, under the bottom bearings galvanized washers were used to raise the assembly to align with the shaft of the motor. The spacer blocks can be seen below in Figure 2.3.3.

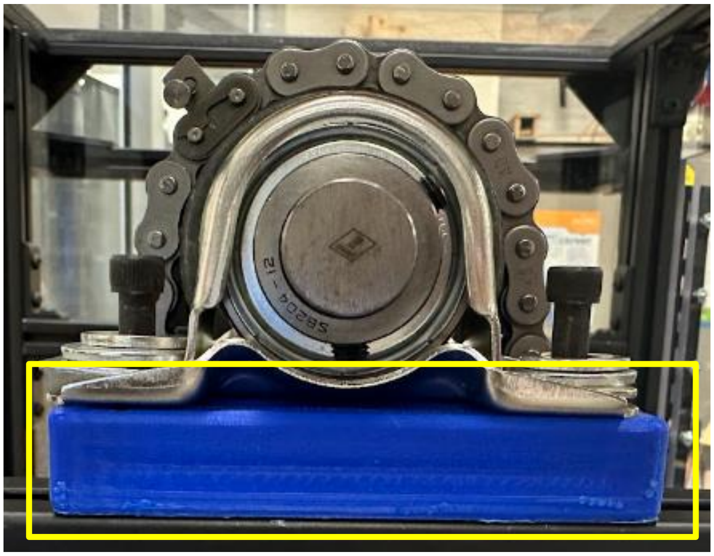

Figure 2.3.3 3D printed spacer blocks printed at 100% infill, placed under the top bearing assembly.

The updated bearings are a “frictionless” design, this is another reason the bearings were chosen for this application. The “frictionless” nature of these bearings is expected to decrease the amount of vibration experienced within the carousel when it begins rotation. Vibrational analysis was performed on the previous carousel design in order to establish a baseline frequency experienced upon rotational startup.

A bi-directional accelerometer was used to collect data, as upon the system initial rotation starts occurs along the Y- axis. The accelerometer was attached to the oscilloscope, which displays the electrical data that is collected by the accelerometer. The accelerometer was calibrated before testing and then fixed to the center of a carriage as seen below in Figure 2.3.4. Calibration data can be seen in detail in Appendix C.1.

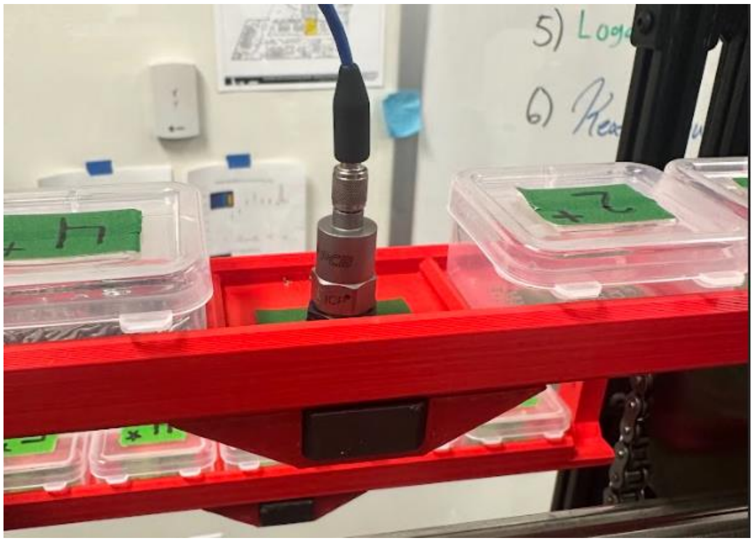

Figure 2.3.4 Accelerometer placement onto carriages to retrieve vibration data upon system startup

The system was then turned on and a carriage was selected for delivery using the touchscreen. The oscilloscope was set to the trigger function and upon startup, triggered and began collecting data as the carousel rotated. The results collected from the oscilloscope and output by MATLAB can be seen below in Figure 2.3.5. MATLAB code used to convert Voltage vs. Time diagrams can be seen in Appendix C.2.

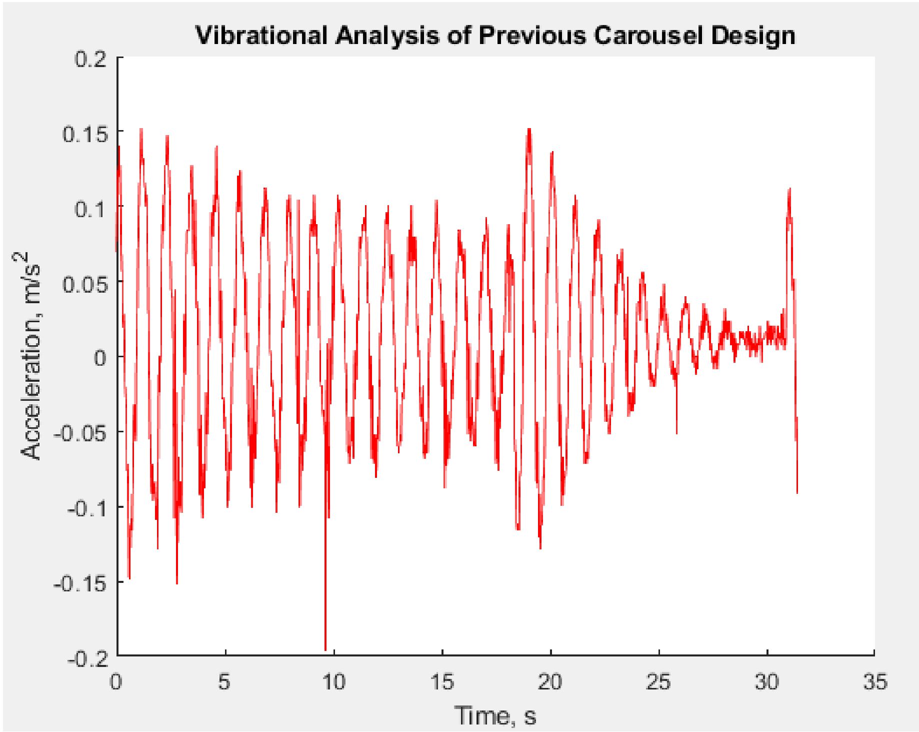

Figure 2.3.5 Vibrational analysis results from previous vertical carousel design

The initial acceleration of the results graph seen above is 0.132 m/s^2. The addition of frictionless bearings decreases resistance while the system is beginning rotation, and while running at speed. Had the team been successful in getting the carousel to run, vibrational analysis would have been performed once again on the finished carousel design. The voltage time graph of the redesigned carousel, if it had had a lower amplitude of motion would have suggested that the bearings were successful in damping out some of the initial vibration experienced by the carriages upon startup. Had the amplitudes been larger than 0.132 m/s^2, the bearings would have been a failed attempt at damping the startup vibrations experienced. The initial acceleration experienced by the carriages is important to mitigate as it causes vibrations in the carriages which causes them to swing. Extreme carriage movement is not dangerous for the user due to the protective nature of the Lexan enclosure but poses a threat to the system itself. Excessive carriage movement can lead to the bins falling out of their carriages and parts, or bins themselves, jamming the sprocket and chain system. Attempting to decrease the resistance of rotation through the implementation of frictionless bearings was a vital design choice.

2.3.3 MOTOR COMPONENT

The motor component purchased by the design team in 2022 was repurposed by the current team. The 2.2-volt stepper motor equipped is an ideal motor for the project as it can hold a load at a given “step” or location. When a bin is ready to be picked from the carousel the system must first stop spinning and be able to hold the requested carriage at the pick window. Using the motor specifications, the maximum speed of the motor shaft without loading can be calculated as seen below in Equation 2.3.1 where V=applied voltage, Imax=maximum current, L=inductance, and spr= steps per revolution.

$$Max\ Speed = \frac{V}{2L \cdot Imax \cdot spr} = \frac{2.2\ volts}{2 \cdot 3.5mH \cdot 200\,\frac{steps}{rev}}$$

$$Max\ Speed = 0.286\,\frac{rev}{sec} \cdot \frac{60sec}{1\ min}$$

$$Max\ Speed = 17.16\ \frac{rev}{min}$$

Equation 2.3.1 Calculating Maximum Speed of Motor

Based on the calculations above, the carousel exceeds the requirement of a full rotation in 20 seconds, however, the speed values calculated did not account for any weight in the system.

A baseline test was performed on the previous system to determine the bin delivery time before the re design. The results can be seen below in Table 2.3.1.

Table 2.3.1 Initial testing of bin delivery time performed on the previous carousel

Trial	Time	Gear Rotations
#	(s)	rev
1	31.99	1.875
2	32.6	1.875
3	31.9	1.875
4	32.9	1.875
5	32.12	1.875
AVG	32.302	

The previous carousel design was timed while doing a full rotation about the system, this test was performed five times, and the results were averaged. The carousel averaged 32.3 second revolution. This lengthy rotation was mainly due to the three second halt every carriage made over the hall effect sensor. This provided a baseline for improvement. The redesigned carousel will mitigate this issue as it will simply contain one magnet placed on the bottom of one homing carousel. This design feature is discussed further in the software section of this report. The finished carousel, had it run correctly, would have been tested similarly.

Upon redesigning the carriages, and loading the carousel with inventory, the speed of the loaded system was tested to ensure the 20 second rotation requirement is met. The completed carousel was unable to be tested due to unforeseen electrical issues. However, it was theorized in Equation 2.3.3 the system can complete a full rotation in 7.14 seconds. The project requirement of a full rotation being completed in 20 seconds was met.

2.4 ELECTRICAL SYSTEM DESIGN

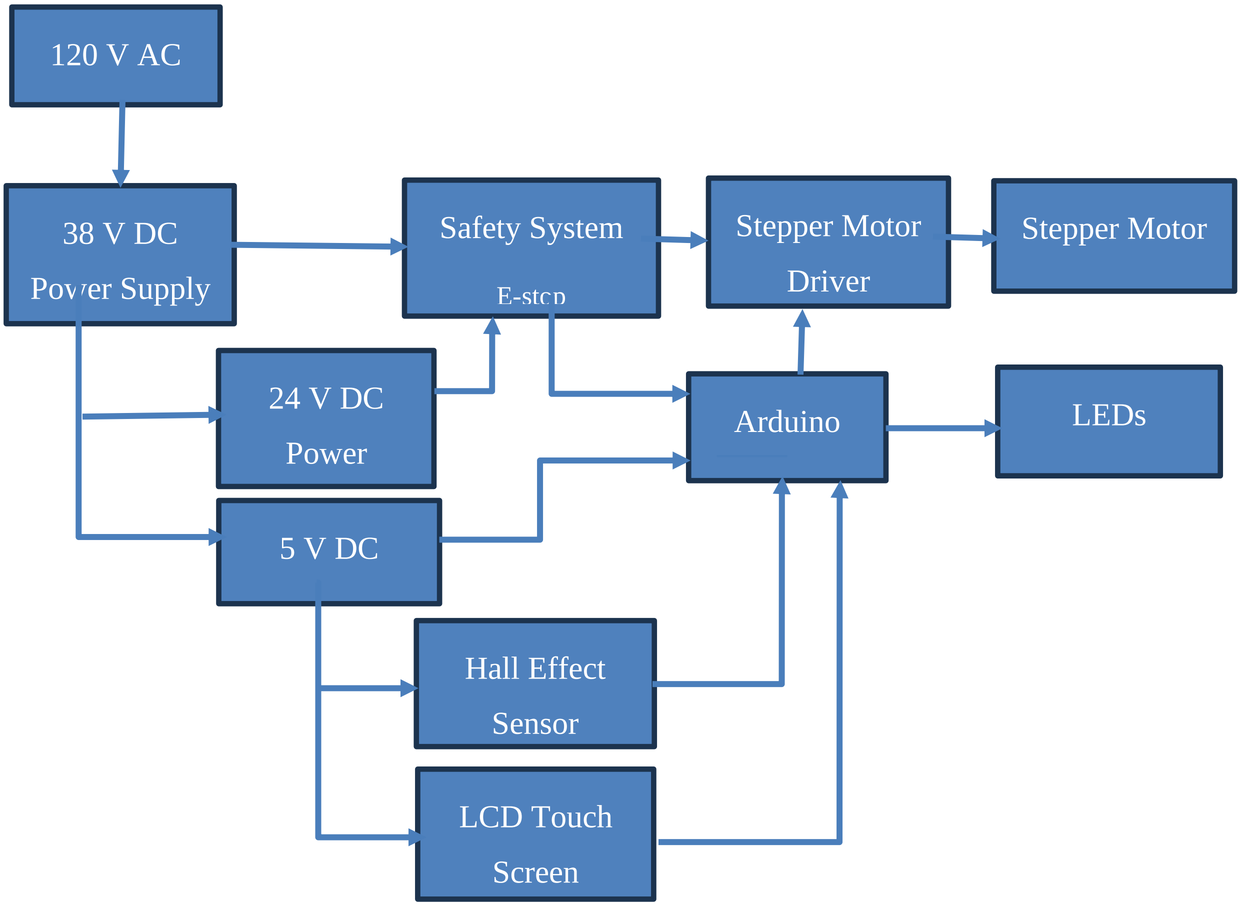

Figure 2.4.1 – Electrical System Breakdown

The electrical system breakdown structure gives an overview of how the power is distributed to the components throughout the system. The previous team designed the system to be powered with 120 V AC voltage from a wall outlet. The team used a power converter to convert the AC power to DC power as the components used for the system are operated with DC power. Moreover, the previous team used a step-down converter to decrease the voltage for the components that require lower voltage to operate.

Power Control Panel and Main POWER SWITCH

The power control panel seen in Figure 2.4.2 is no longer used in the new system. It is replaced with a main power switch which allows someone to turn the machine on and off. The toggle switch (Figure 2.4.3) is a double pole single throw (DPST) switch that leads the power from the wall outlet to the power supply converter.

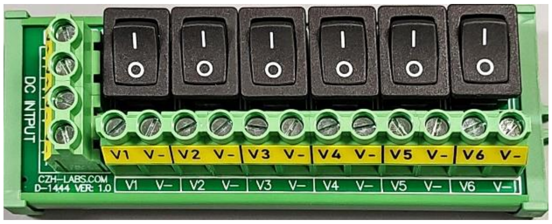

Figure 2.4.2 Control Panel

Figure 2.4.3 DPST Toggle Switch

2.4.1 Power Supply/Converter

This power supply seen below (Figure 2.4.4) is the one the previous team used for the system. It is used to convert the AC voltage from the wall outlet to DC voltage. There are 3 outputs in this power supply, and it can output 0 V DC to 48 V DC voltage and a current of 10 Amperes. This will still be used in the system because it has the capacity that is needed to make the system operational. It stays set on 38 V DC as it was previously because this voltage value is still enough to operate the system.

Figure 2.4.4 Current 0-48 VDC Variable Power Supply/Converter

2.4.2 Hardwired Emergency Stop (E-Stop)

The emergency stop system is important for the safety of humans and machines. It allows quick and safe disconnections of power of the system during an emergency. The emergency push-button chosen is a normally closed (NC) mushroom type button (Figure 2.4.5& Figure 2.4.6*)*. When it is pushed, the E-stop is set to interrupt the power to the stepper motor driver, and then it will send a signal to the Arduino. To connect it to the Arduino, a low voltage of 5 VDC is

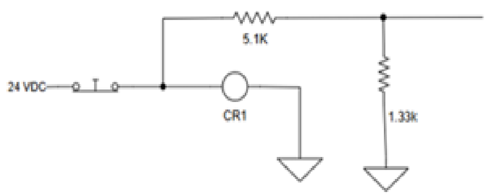

Figure 2.4 5: E-Stop Schematic Diagram

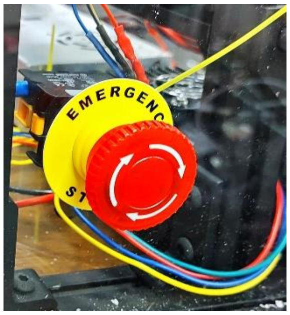

Figure 2.4.6 Emergency Stop Pushbutton

needed. A resistor divider is connected between the e-stop and Arduino *(Figure 2.9 below)*. The voltage divider equation is used to find resistance values (V_{in}= V_{out} x $\frac{R2}{R1+R2}$).

The resistance values found are R_1=2.33 kilo Ohm (kΩ) and R_2= 5.1 kΩ when using 24 volts for the input voltage and 5 V for the output voltage. A normally open relay is also used to connect the e-stop to the stepper motor driver.

2.4.3 Light Curtain Sensor

The light curtain sensor is part of the safety system. It is used to interrupt the power to the stepper motor driver if somebody sticks his or her hand inside of the Carousel while it is moving. That sensor needs 24 V DC to be operated. It is connected to the 24 V DC buck converter and a relay. Furthermore, with the relay, it is connected to a resistor divider to produce a low voltage value of 5 V DC that is then connected to the Arduino. The same resistance values used for the e-

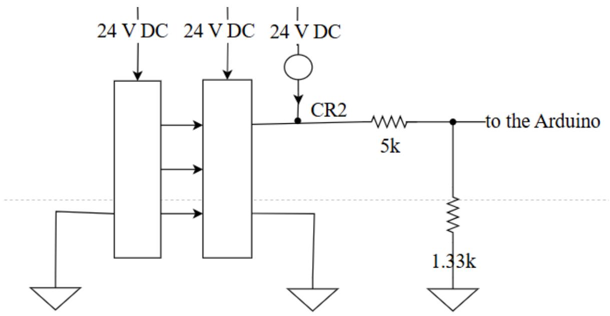

Figure 2.4.71 Schematic Diagram of the Light curtain sensor

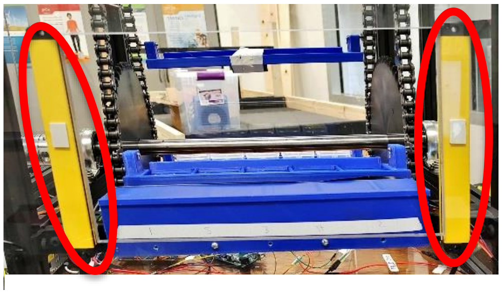

Figure *1*.4.8 Light Curtain mounted on the carousel

stop are also used for the light curtain sensor connection (see Figure 2.4.7). Figure 2.4.8 shows the light curtain sensor mounted in the retrieval opening of the carousel.

2.4.4 STEPPER MOTOR DRIVER

The purpose of the Stepper Motor Driver is to send pulses to the Stepper Motor to make it rotate. It receives information from the controller and transmits that information to the stepper motor for rotation. The same one used by the previous team is still used (Figure 2.4.9). It is the DM860T stepper motor driver. The Driver is set to supply a peak current of 5.14 A and a voltage of 38 V DC to make the stepper motor rotate properly. The team decides to repurpose the same driver because the same motor will be used.

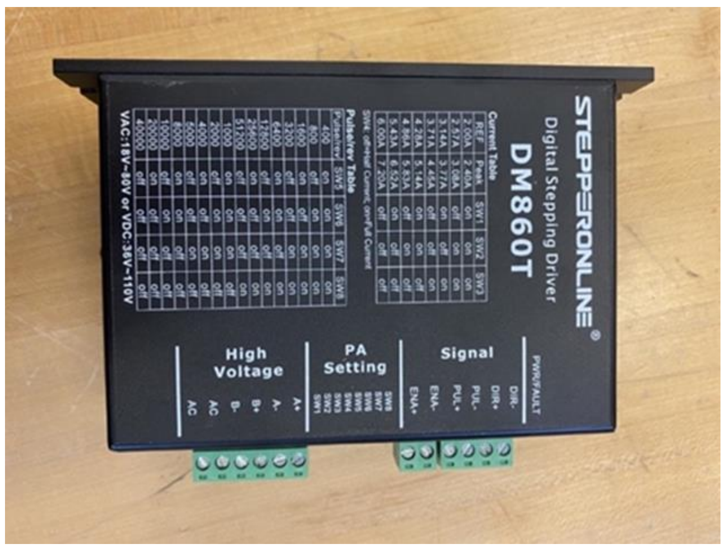

Figure 2.4.9 Current Stepper Motor Driver

2.4.5 STEP-DOWN BUCK CONVERTER

The Step-Down Buck converters are used to lower the 38 V DC from the power supply to the voltages needed for the other electrical components. The old Step-Down buck converter is replaced with this smaller and more reliable buck converter shown in Figures 2.4.10 and 2.4.11 below, where Figure 2.4.10 is the schematic diagram of the connection of the buck converter. It lowers the 38 V DC from power supply to 5 Volts for the smaller components like Arduino, Hall Effect sensor, LCD screen and LEDs. These components are placed in parallel to one other, so that they receive the same amount of voltage.

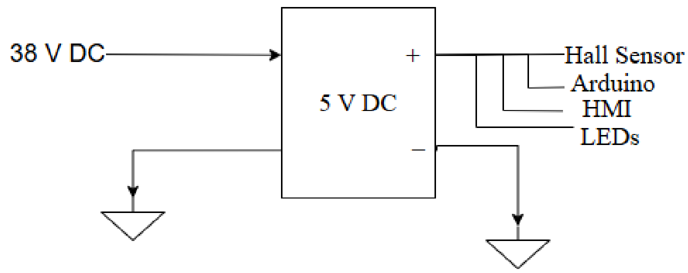

Figure 2.4.102 5 V DC Buck Converter Schematic Diagram

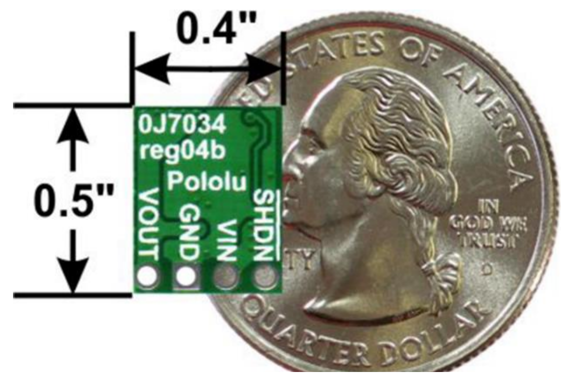

Figure 2.4.11 New 5 V DC Step-down Buck Converter [20]

Another DC/DC step-down voltage regulator is used to give a 24 VDC that is needed to power the e-stop and the light curtain sensor (see Figures 2.4.12 and 2.4.13 below). It converts the 38 VDC from the power converter to 24 VDC.

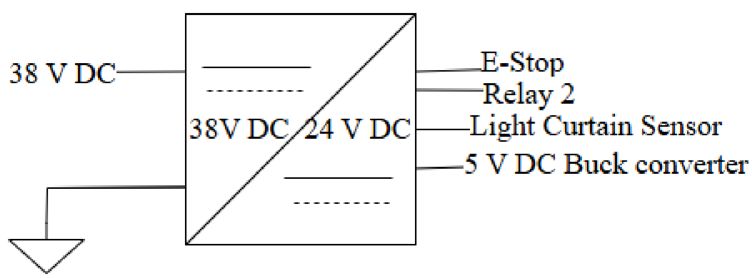

Figure 2.4.12 24 V DC Voltage Regulator Schematic Diagram

Figure 2.4.13 3 DC/DC Step-down Voltage Regulator

2.5. SOFTWARE DESIGN

2.5.1 Overall Functionality Of Software System

The software system of the Vertical Carousel Storage System is the core component that enables automation, facilitating the seamless selection and delivery of items to the user. This system orchestrates the movement of rotating rows within the carousel, ensuring that the correct item is retrieved and presented to the operator quickly and efficiently. The software integrates three major subsystems: safety, user interface, and operation. Figure 3.1 shows the components that each major subsystem incorporates.

The three key components of the system are safety, user interface, and operation

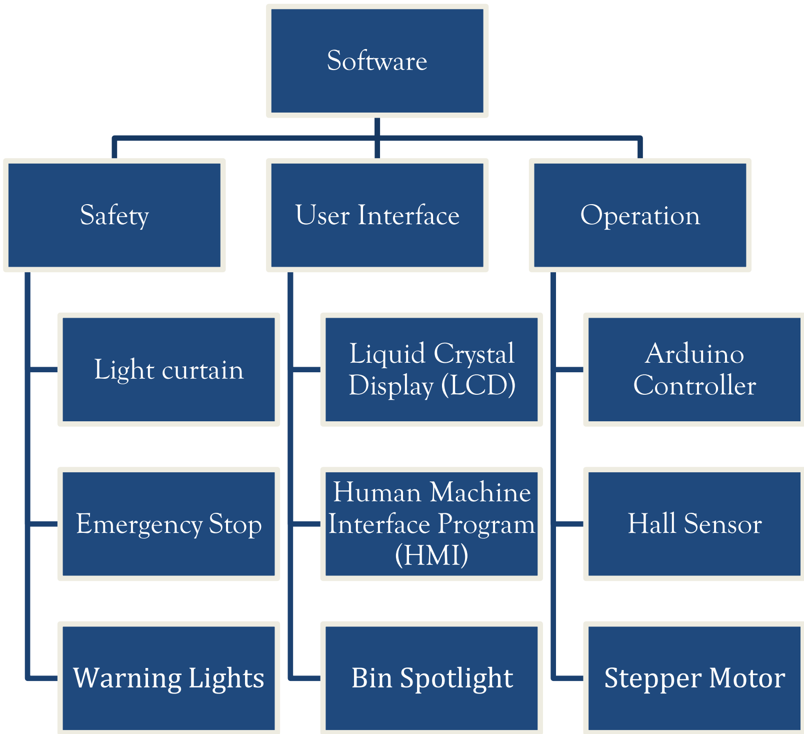

Figure 3. 1 – Software System Breakdown

2.5.2 SAFETY

Safety is a critical aspect of the carousel storage system, particularly in an educational setting, where students are interacting with the system as part of their learning experience. The primary goal of the safety subsystem is to prevent accidents and injuries by mitigating potential risks during system operation. Given the moving parts and proximity to users, ensuring a safe operating environment is essential for both the protection of individuals and the integrity of the equipment. The Vertical Carousel Storage System integrates safety standards, which are designed to ensure that material handling operations are safe for operators, minimizing the risks from moving parts and electrical hazards [19].

The safety subsystem includes several key components: light curtain sensor, an emergency stop button, and warning LED lights, all of which work together to create a robust safety mechanism.

2.5.2.1 LIGHT CURTAIN SENSOR

The light curtain sensor used in the Vertical Carousel Storage System is a photoelectric sensor featuring 16 beams with a 10 mm resolution (Figure 3.2), allowing for precise finger detection**.** This sensor is capable of detecting any disturbance, such as a hand entering the system's opening while the machine is running, within a range of up to 2000 mm. Its fast response time ensures immediate reaction to any obstructions, enhancing user safety by halting machine operation in the event of an intrusion. The light curtain sensor is powered by a 24 V power supply.

Figure 3. 2 Light Curtain Sensor

Additionally, the sensor is designed for simple mounting and wiring, facilitating easy installation and integration into the system. The light curtain is strategically positioned at the opening of the Vertical Carousel Storage System Figure 3.3 below shows, ensuring that any motion within the critical zone is quickly detected and acted upon to prevent potential injuries or system malfunctions. This safety feature is a vital component in protecting users and ensuring the system operates efficiently and securely. Implementation of the light curtain sensor ensures the VCSS meets ANSI code MH24.1- 5.4.2. which details the requirements for emergency stop devices at the operator interface area [19].

Figure 3. 3 – Location of Light Curtain Sensor

2.5.2.3 Emergency Stop

The emergency stop acts as a second point of contact to shut the machine down if an operator enables it in the event of an emergency or dangerous situation. This button is in an accessible location to the operator for a fast response. The e-stop has a relay and a pull-up resistor. The emergency stop is implemented by continuously monitoring the E-stop button's state. When pressed, the relay is turned off, and the motor is stopped immediately. The motor will only run if the E-stop button is not pressed.

2.5.2.3 Warning LED lights

There are five light emitting diodes (LEDs), shown in Figure 3.4, on the opening of the machine facing the bins. They are positioned within a 3D housing unit (Fig.3.5), which is integrated and mounted at the back of the enclosure. The housing is designed with a strategic shooting angle to ensure the LEDs are clearly visible to users. These LEDs serve as a warning signal, alerting users to potential hazards within the system. When the light curtain sensor detects any disturbance, such as an obstruction or intrusion, the LEDs are triggered to blink, providing a clear visual indication of a present hazard. This blinking signal serves as a precautionary alert, notifying users that the system has detected an issue and that they should exercise caution or take corrective action.

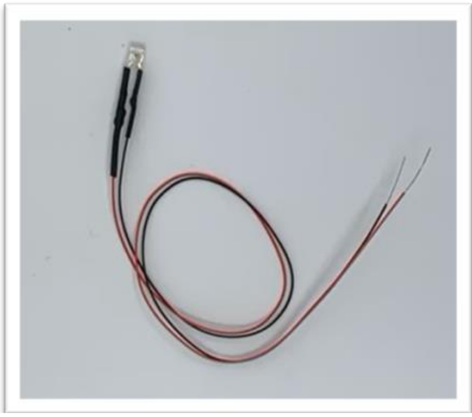

Figure 3. 4 - LEDs

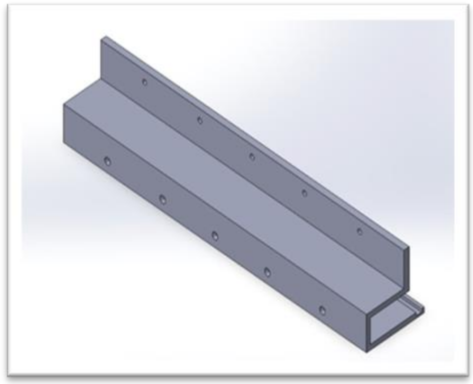

Figure 3. 5 – Housing Unit for LEDs

2.5.3 USER INTERFACE

The user interface defines how users interact with the system. It includes all visual elements, such as screens, pages, buttons, and other components that facilitate user interaction with the software platform. The user interface is designed to be intuitive, ensuring that users can efficiently operate the system. The users turn the machine on by using one switch attached to the carousel. The Liquid Crystal Display (LCD) screen turns on and displays different categories to select items. This interaction is simple and is shown in the flowchart diagram below. This system encompasses an LCD, a Human Machine Interface (HMI) program, and bin spotlight.

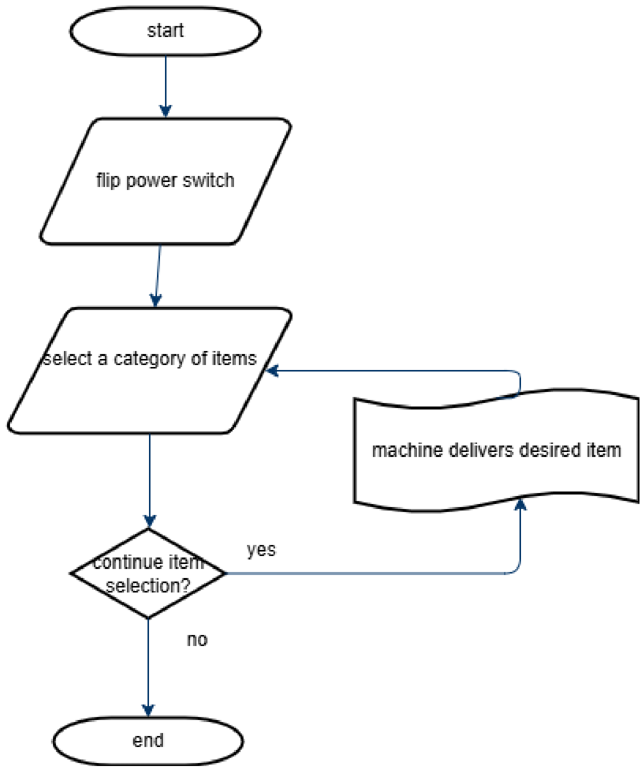

Figure 3. 6 – Flowchart Diagram of User Interface

2.5.3.1 LCD SCREEN

The user interface of the system is a 7-inch Nextion HMI display (Figure 3.7), which serves as a programmable Human Machine Interface (HMI). This touch-sensitive display enables direct interaction between the user and the machine, providing an intuitive platform for control and monitoring. The HMI communicates with the microcontroller via serial communication, enabling the seamless exchange of data both to and from the system.

For optimal user accessibility, the display is strategically mounted at the top of the carousel, ensuring it is easily reachable for interaction. The system is powered by a 5 V power supply, which is sufficient to drive the HMI display. This setup ensures a user-friendly experience, with clear visual feedback and a responsive touch interface to facilitate efficient machine operation.

Figure 3. 7 Nextion LCD Screen

2.5.3.2 HMI PROGRAM

To program the LCD screen, a specialized software environment is required. In this case, the Nextion Editor was used to design and configure the graphical user interface (GUI). This tool allowed for the creation of the various pages, buttons, and overall layout that users interact with. The interface is structured around distinct categories of items stored in the VCSS, which organize the items into logical groups such as electrical, mechanical, electronic, and fastener components. This categorization not only enhances the organization of the items but also contributes to a more intuitive and user-friendly experience, streamlining the sorting process and improving operational efficiency. A visual representation of these categories is provided in Figure 3.8.

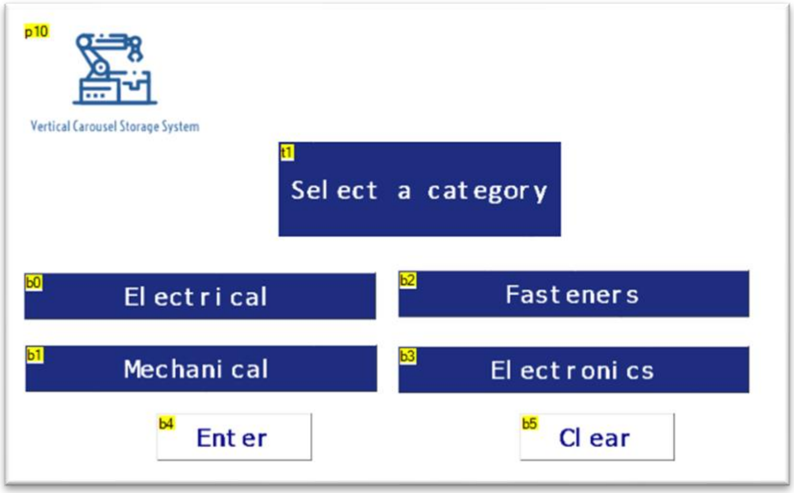

Figure 3. 8 Page 1 of HMI: Main Categories

To ensure seamless communication between the HMI and the microcontroller, the components defined in the Nextion Editor were integrated into the microcontroller's firmware. This integration enables the microcontroller to send and receive signals via serial communication, facilitating the interaction between the user interface and the underlying hardware.

The system includes a total of five distinct pages (Figures 3.9-3.12) on the HMI display, each designed to provide specific information or functionality. For each page, the text, buttons, and interactive elements had to be meticulously defined in the program code. This customization ensures that the interface is fully aligned with the intended functionality of the system, with each component specifically programmed to respond to user input and trigger the appropriate system actions. Users are able to click three times and expect delivery. This makes navigation more practical for the users [18].

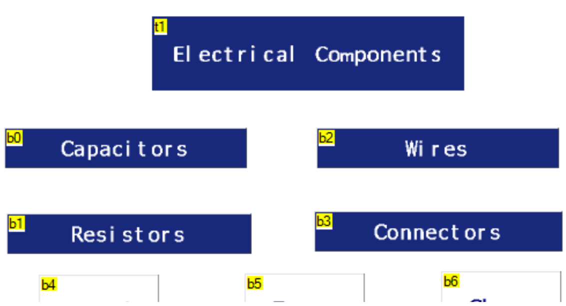

Figure 3. 10 – Page 2 of HMI

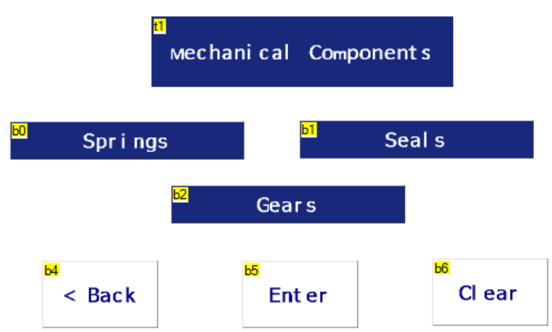

Figure 3. 9 – Page 3 of HMI

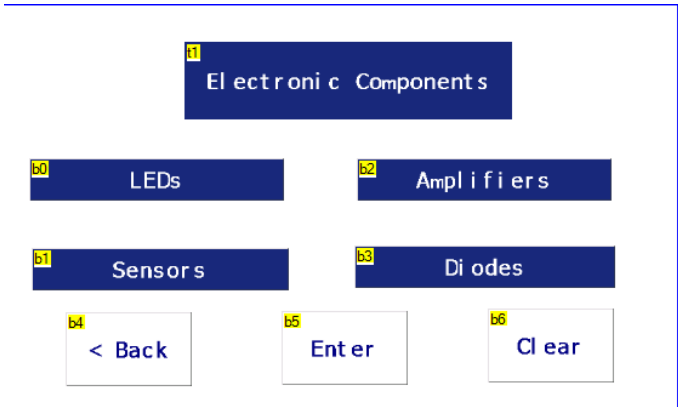

Figure 3. 11 – Page 4 of HMI

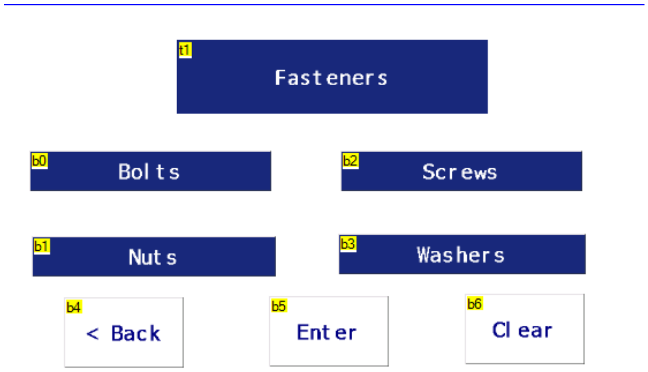

Figure 3. 12 – Page 5 of HMI

2.5.3.3 BIN SPOTLIGHT

The bin spotlight is an integral feature designed to enhance the user interface environment by providing clear visual indicators for users. It serves as a demonstration tool, visually signaling when items are ready for delivery or pickup. The spotlight consists of five LEDs strategically placed by the opening of the machine and reflecting into the bins to illuminate in a specific pattern, guiding users to the correct bin or location for item retrieval.

2.5.4 OPERATION

The operation subsystem represents the core framework responsible for executing the key actions and processes that enable the system to perform its intended functions. This subsystem encompasses not only the hardware components that facilitate the physical operation of the system, but also the software elements that ensure smooth interaction with users and external systems, as well as maintaining operational integrity, security, and responsiveness. This system consists of three main elements, which are the Arduino microcontroller, the Hall sensor, and the stepper motor.

2.5.4.1 ARDUINO MICROCONTROLLER

Central to the operation subsystem is the Arduino microcontroller, which functions as the central processing unit, or "brain," of the system. It coordinates and manages the various hardware components, processing input data from sensors and issuing commands to the actuator, the stepper motor. In this specific implementation, the system utilizes the Arduino Mega 2560 Rev 3

(Figure 3.13), a versatile and powerful microcontroller board well-suited for complex systems requiring multiple I/O connections and communication interfaces.

The Arduino Mega 2560 is equipped with a substantial number of 54 digital I/O pins, providing ample connectivity for a wide range of sensors, actuators, and other components. Among these, 4 dedicated UART (Universal Asynchronous Receiver/Transmitter) pins are available, enabling robust serial communication with external devices or subsystems. The LCD has two main pins for serial communication. The TX pin sends data from the LCD screen to the Arduino, and the RX pin receives data from the Arduino. These pins are connected to the appropriate serial ports—in this case, Serial 2 on the Arduino. The Nextion TX connects to the Arduino Mega RX2.

The Arduino Mega is powered by a 5 V supply, which is sufficient to drive both the microcontroller and the connected components.

The Arduino microcontroller is programmed using the Arduino Integrated Development Environment (IDE), a powerful platform that allows for the creation, testing, and deployment of control software. The IDE provides a user-friendly interface for writing and uploading code to the microcontroller, enabling the seamless integration of hardware and software components. Through this programming environment, the microcontroller can interpret user inputs, process sensor data, and control outputs with precision and reliability.

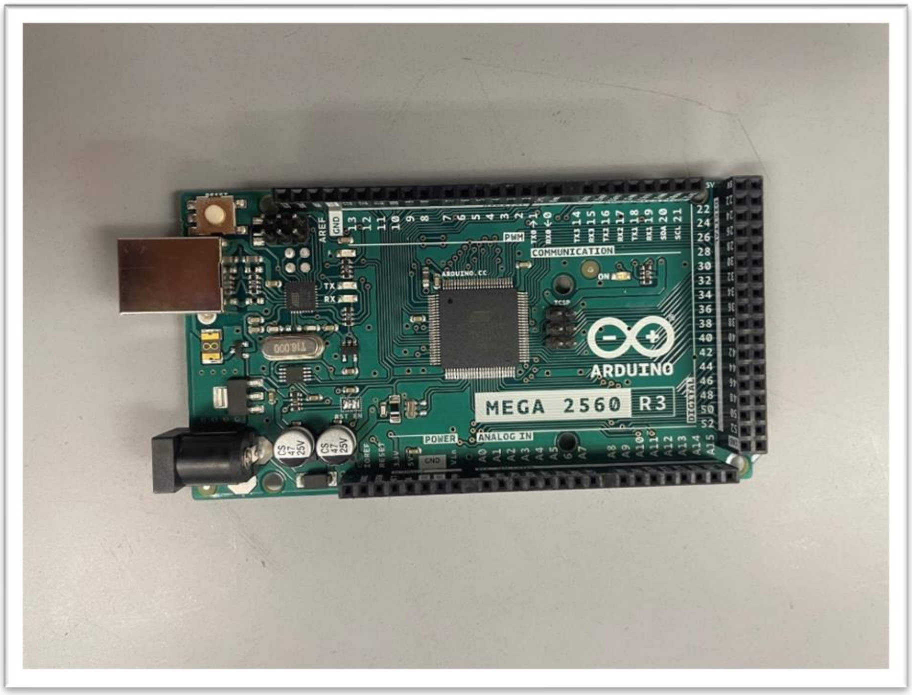

Figure 3. 13 – Arduino Microcontroller

2.5.4.2 HALL SENSOR

The Hall sensor is essential for detecting the position of carriages in the carousel system by responding to a magnetic field. It switches to low (ON) when the magnetic field is perpendicular to the sensor, and to high (OFF) when no field is detected. This on/off behavior allows the sensor to track carousel positions, acting as both a counter and a reset mechanism.

In this system, a Grove Hall sensor is used (Figure 3.14), powered by a 5 V input, ensuring compatibility with the Arduino microcontroller. A magnet is attached to the first row, and as the carousel rotates, the Hall sensor detects the magnet when it aligns perpendicularly. This serves as a "homing" signal, marking the starting position of the carousel.

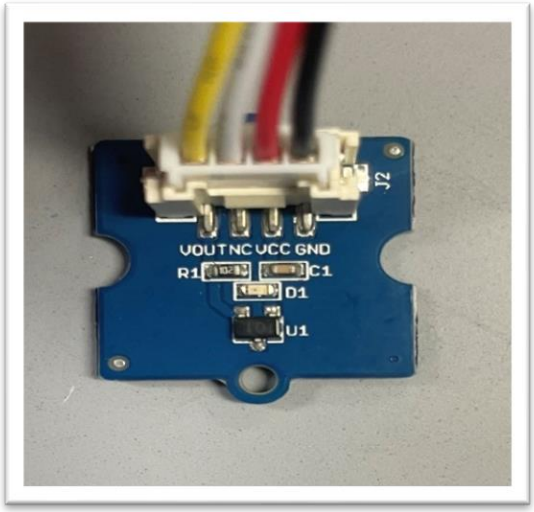

Figure 3. 14 Grove Hall Sensor

2.5.4.3 STEPPER MOTOR

The stepper motor is an essential component of the system that receives signals from the Arduino microcontroller, which controls its movement and operation. The Arduino sends precise electrical pulses to the motor's control pins, instructing it to rotate in small, discrete steps. This enables the motor to move with high accuracy, making it ideal for applications requiring precise positioning, such as driving the conveyor belt in this system.

The motor's movement is controlled by the timing of these pulses, with each pulse causing the motor to move by a fixed increment. In this case, the system is configured to use a pulse delay of 510 microseconds, meaning that the motor receives a signal every 510 microseconds, controlling the speed and smoothness of its rotation. The delay time determines how fast the motor moves, and adjusting it alters the speed of the conveyor belt. A shorter delay would result in faster movement, while a longer delay would slow down the motor's rotation.

3. NEXT STEPS AND CONCLUSION

3.1 NEXT STEPS

Although the project was considered a success by the 2022 and 2024 senior design teams, there are still areas for improvement. The base enclosure presents an opportunity for additional storage solutions. Although metal drawer slides in the required 10-inch length are difficult to find, wooden drawers and slides could be manufactured to increase the storage capacity for in-carousel stock items. The rear of the base may also fit with the shelves discussed in the conceptual base design section in the future. To accommodate this design upgrade, the wires will need to be lengthened and reinforced, which presents another area for improvement. The T-slot aluminum frame, on which the bearings sit, can be disassembled and reassembled to widen the distance between the sprockets. This design change would allow for larger carriages to be created, thereby increasing the carousel's storage capacity. Additionally, more link inserts could be added to the chain, further increasing the storage capacity and enabling the implementation of more carriages.

The electrical system also requires improvements. It is recommended that some of the components be relocated to the base for tidiness. Currently, the wires inside the carousel make the interior appear messy. Moving the breadboard, Arduino, and 24V DC voltage regulator to the inside of the base will improve the appearance of the interior and allow the carriages to move more freely during rotation, without the risk of wires interfering with their movement.

Finally, adding a new stepper motor is crucial to getting the system back up and running.

3.2 CONCLUSION

Vertical carousel storage systems implemented in the manufacturing setting utilize vertical storage space, decrease product pick time, and assist with inventory accuracy through electrical interfacing. This industrial system largely increases manufacturing efficiency and safety. A tabletop prototype of a vertical carousel storage system was designed by the engineering team to create an educational opportunity for up-and-coming manufacturing engineers.

Vertical carousel storage systems, along with other automated storage solutions, are designed and implemented in manufacturing settings to increase efficiency. The prototype created by the design team is small and functional, with quick product retrieval times, user-friendly operation, and a focus on safety. The size constraint of the project is the most critical design factor, as the finished prototype must fit on a tabletop. The finished product was tested and met the requirements for operational safety, featuring a working light curtain to prevent accidents, an 18% increase in in-carriage storage space, and a user-friendly interface that requires only three clicks for product delivery. However, the full revolution test could not be performed due to a failure in the stepper driver. This failure may be attributed to the driver operating at a lower voltage or burnout after being used for over two years. The time calculations detailed in this report show that the team met the requirement of a retrieval time of less than 20 seconds. The operating light curtain meets safety expectations, and the user interface requirement of fewer than four clicks to deliver the product was successfully achieved. The engineers executing the project are fourth-year engineering students who have completed the required credit hours to begin their senior project.

REFERENCES

[1] "Carousel Systems" *Conveyco*. https://www.conveyco.com/technology/order-selection-systems/carousel-systems/ (accessed Feb. 27, 2024).

[2] T. Bass, "Kardex Hanel Vertical Lift Lektriever Rotomat Alabama Tennessee," *BSC*, May 14, 2018. https://www.bscstoragesolutions.com/kardex-and-hanel-storage-solutions-history/ (accessed Feb. 27, 2024).

[3] M. Sauceda, "Horizontal Carousels," *Increase Productivity With Space-Efficient Storage Solutions*. https://www.southwestsolutions.com/divisions/material-handling solutions/automated-storage-and-retrieval-systems/horizontal-carousels/ (accessed Feb. 27, 2024).

[4] A Guide to Understanding Vertical Carousels," *White Systems*. https://whitesystems.com/a-guide-to-understanding-vertical-carousels/#:~:text=A%20vertical%20carousel%20is%20a%20high-density%20storage%20solution (accessed Feb. 27, 2024).

[5] X. Wang, G. Wang, and X. Li, "Order Picking Optimization in Carousels Storage System," *Mathematical Problems in Engineering*, vol. 2013, pp. 1–8, 2013, doi: https://doi.org/10.1155/2013/692701.

[6] "Vertical Carousel – FA OToole Office and Industrial Systems." https://faotoole.com/automation/vertical-carousel/ (accessed Feb. 27, 2024).

[7] "Vertical Lift Modules | Vertical Storage Systems," *Outsource Equipment*. https://www.osequip.com/products/vertical-lift-modules-the-ultimate-storage-solution/ (accessed Feb. 27, 2024).

[8] C. Tarr, "8 Types of Automated Storage and Retrieval Systems (ASRS): A Deep Dive," *us.blog.kardex-remstar.com*. https://us.blog.kardex-remstar.com/types-of-automated-storage-and-retrieval-systems.

[9] Ashayeri, Jalal, and Willem Selen. "A storage assignment model for batch preparation in Process Industries." Journal of Manufacturing Technology Management, vol. 24, no. 6, 19 July 2013, pp. 830–849, https://doi.org/10.1108/jmtm-12-2011-0115.

[10] "American National Standards Institute - ANSI HOME." *ANSI*, American National Standards Institute, www.ansi.org/. Accessed 3 Apr. 2024.

[11] Norton, Robert L. Design of Machinery: An Introduction to the Synthesis and Analysis of Mechanisms and Machines. McGraw-Hill Education, 2020.

[12] W., De Silva Clarence. Sensor Systems: Fundamentals and Applications. CRC Press, Taylor & Francis Group, 2017.

[13] Sizemore, J., Starr, A., Wilson, L., & Zieg, N. (n.d.). (rep.). Automated Vertical Carousel Storage System (pp. 1–105).

[14] Trebilcock, Bob. "Big ideas [for small parts storage]." Modern Materials Handling, vol. 59, no. 6, 06, 2004, pp. 30-32. ProQuest, https://univsouthin.idm.oclc.org/login?qurl=https%3A%2F%2Fwww.proquest.com%2Fmagazines%2Fbig-ideas-small-parts-storage%2Fdocview%2F201491643%2Fse-2%3Faccountid%3D14752.

[15] "ASRS Mini Load Storage System - Racking System: Automated Warehouse System Malaysia." *Racking System | Automated Warehouse System Malaysia*, 20 July 2020, heli-tech.com.my/product/asrs-mini-load-storage-system/.

[16] "Vertical Lift Modules." *Wolter Inc.*, www.wolterinc.com/industrial-storage-handling/automated-industrial-storage/vertical-lift-modules/. Accessed 3 Apr. 2024.

[17] "Carr." *McMaster*, www.mcmaster.com/products/~/bearing-seal-type~sealed/low-profile-mounted-ball-bearings/?s=low%2Bprofile%2Bmounted%2Bsealed%2Bsteel%2Bball%2Bbearings. Accessed 25 Apr. 2024.

[18] Daivee. (2021, December 13). *The 3-click rule: Myth or fact?*. IEEE Brand Experience. https://brand-experience.ieee.org/the-3-click-rule-myth-or-fact/

[19] Scribd. (n.d.). *Safety standard for horizontal carousel material handling and associated equipment*. Scribd. https://www.scribd.com/document/228400660/Safety-Standard-for-Horizontal-Carousel-Material-Handling-and-Associated-Equipment

[20]

“Pololu - 5V, 600mA Step-Down Voltage Regulator D36V6F5,” *www.pololu.com*. https://www.pololu.com/product/3792

[20] “Vertical Carousel Storage System | Pricing | Vertical Storage USA,” *Vertical Storage USA*, Mar. 08, 2024. https://verticalstorageusa.com/storage-solutions/vertical-carousels/ (accessed Dec. 05, 2024).

APPENDIX A. BUDGET OF THE PROJECT

APPENDIX A.1. MECHANICAL BUDGET

Table 3. 1 – Mechanical Budget

Supplier	Item Description	Price ($)	Qty	Subtotal ($)
Lowes	3/4-in x 4-ft x 8-ft Whitewood Sanded Plywood	65.65	2	131.3
Lowes	14-in 3/4 Extension Self-closing Bottom Mount European 50-lb Load Capacity White Drawer Slide	6.48	4	25.92
Lowes	allen + roth 3-in Center to Center Satin Nickel Square Handle Drawer Pulls	4.78	6	28.68
Lowes	Style Selections 4-Pack 4-in Rubber Swivel Caster	27.98	1	27.98
McMastercar-Carr	Roller Chain Sprocket for ANSI 40 Chain, 21 Teeth, for 3/4" Shaft Diameter	40.48	2	80.96
McMastercar-Carr	Low-Profile Mounted Sealed Steel Ball Bearing with Set Screw, for 3/4" Shaft Diameter	11.78	4	47.12
Amazon	ELEGOO PLA Filament 1.75mm Dark Blue 1KG	16.19	3	48.57
Amazon	40 Pack 4 Size Small Clear Storage Box,Clear Plastic	12.99	1	12.99
USI	Misc. Screws	Donated by USI		N/A
Amazon	SATINIOR 24 Packs Small Clear Plastic Beads Storage Containers Box with Hinged Lid for Storage of Small Items, Crafts, Jewelry, Hardware (1.7 x 1.7 x 0.8 Inches)	9.85	1	9.85
Amazon	SATINIOR 24 Packs Small Clear Plastic Beads Storage Containers Box with Hinged Lid for Storage of Small Items, Crafts, Jewelry, Hardware (2.5 x 1.7 x 0.8 Inches)	13.25	1	13.25
Home-Depot	4-1/2 in. x 1-1/2 in. Bright Nickel 105 Degree Opening Euro Inset Hinge	12.29	4	49.16
Home-Depot	4 in. Red Polyurethane and Steel Swivel Plate Caster with Locking Brake and 250 lbs. Load Rating	15.98	4	63.92
Home-Depot	Everbilt 5-3/4 in. Black Door Pull	4.27	2	8.54
Home-Depot	Everbilt 25-Piece 3/8 in. Galvanized Flat Washer	5.97	1	5.97
	Total For All Items	N/A	N/A	554.21

APPENDIX A.2. ELECTRICAL BUDGET

Table 3. 2 – Electrical Budget

Item Names	Quantity	Price USD $
Screw Mount 6 Channel Rocker Switch DC Power Distribution Strip Module	1	25
22mm 2 NC Red Mushroom Push Button Switch AC 600V 10A (2PCS)	1	7.99
B1MBL Illuminated LED Red 22mm 1NC Push Button Emergency Stop Switch with Control Box (24V AC/DC)	1	22.95
ELEGOO 120pcs Multicolored Dupont Wire 40pin Male to Female, 40pin Male to Male, 40pin Female to Female Breadboard Jumper Ribbon Cables Kit Compatible with Arduino Projects	1	6.98
5V, 600mA Step-Down Voltage Regulator D36V6F5	1	6.95
HiLetgo 2pcs LM2596 Adjustable DC-DC Step Down Buck Power Convert Module 4.0-40V Input to 1.25-37V Output with LED Voltmeter Display	1	10.49
AZ2280-1C-24DEF	2	8.2
100FT 14/2 Gauge Red Black Cable Hookup Electrical Wire LED Strips Extension Wire 12V/24V DC, 14AWG Flexible Extension Cord for LED	1	18.99
Carling Technologies EK204-73 Toggle Switch, Dpst, 20A, 250V Pack of 1, Black/Silver	1	14
ElectroCookie Mini PCB Prototype Board Solderable Breadboard for DIY Electronics, Compatible for Mini Arduino Soldering Projects, Gold-Plated (6 Pack, Multicolor)	1	6.99
Total price $ US	11	128.54

Appendix A.3. Software Budget

Table 3. 3 – Software Budget

Supplier	Item Description	Price	Quantity	Subtotal
Amazon	Arduino Mega	$ 48.80	1	$ 48.80
Amazon	Laser Transmitter Sensor	$ 11.99	1	$ 11.99
Seed Studio	Grove - Hall Sensor	$ 6.50	1	$ 6.50
Temu	IR Sensors	$ 5.48	1	$ 5.48
Amazon	Electronics Component Kit	$ 15.77	1	$ 15.77
Amazon	Arduino Display Module - 3.2" Touchscreen LCD	$ 13.00	1	$ 13.00
Amazon	Light Curtain Sensor	$ 187.69	1	$ 187.69
Amazon	Nextion 7-inch LCD	$ 96.90	1	$ 96.90
Amazon	32 GB Micro SD Card	$ 13.99	1	$ 13.99
Total For All Items				**$ 400.12**

APPENDIX A.4. TABLE OF COMBINED BUDGET OF ALL SUBSYSTEMS

Table 3. 4 – Project Budget

Subsystem	**Subsystem Total**
Mechanial	$ 554.21
Electrical	$ 128.54
Software	$ 400.12
Project Total	$ 1,082.87

APPENDIX B. BUILD SCHEDULE

Build Schedule - Fall 2024			
System	**Task**	**Parties Involved**	**Due Date**
All	Parts delivered	All	Aug. 19
Electrical	Test electrical components	Dieufils	Aug. 21
Enclosure	Custom part designs finished, ready to be machined	All	Sept. 3
Storage			
Mechanical		Aly	
All	Have report started	All	
Software	Finished user interface	Melanie	Sept. 9
Mechanical	Test mechanical components	Aly	
Enclosure	Assembly new parts	All	Sept. 16
Storage			
Software	Code finished for safety	Melanie	Sept. 23
Electrical	Safety sensors installed	Dieufils	
All	Preliminary design review with Dr. Kuban, Dr, Diersing, Mr. Kicklighter, Dr. Nelson	All	Sept. 16-20
Electrical	Full retrieval and identification testing complete	Dieufils	Sept. 27
Mechanical		Aly	
Software	Test final code for operation	Melanie	Sept. 30
All	Succesfully complete full run	All	Oct. 14
	Full parts assembly, system fully finished		
	Fisrt draft of full written report		Oct. 30
	First draft of poster due		Nov. 4
	Final draft of full writtem report due to Dr. Kuban		Nov. 11
	Schedule dry run		
	Dry run presentation		Nov. 18-21
	Final poster due		
	Prepare demo videos		Nov. 23
	Senior design presentation		Nov. 29
	Poster night and final report due		Dec.6

APPENDIX C. VIBRATIONAL ANALYSIS

APPENDIX C.1. CALIBRATION DATA OF THE ACCELEROMETER

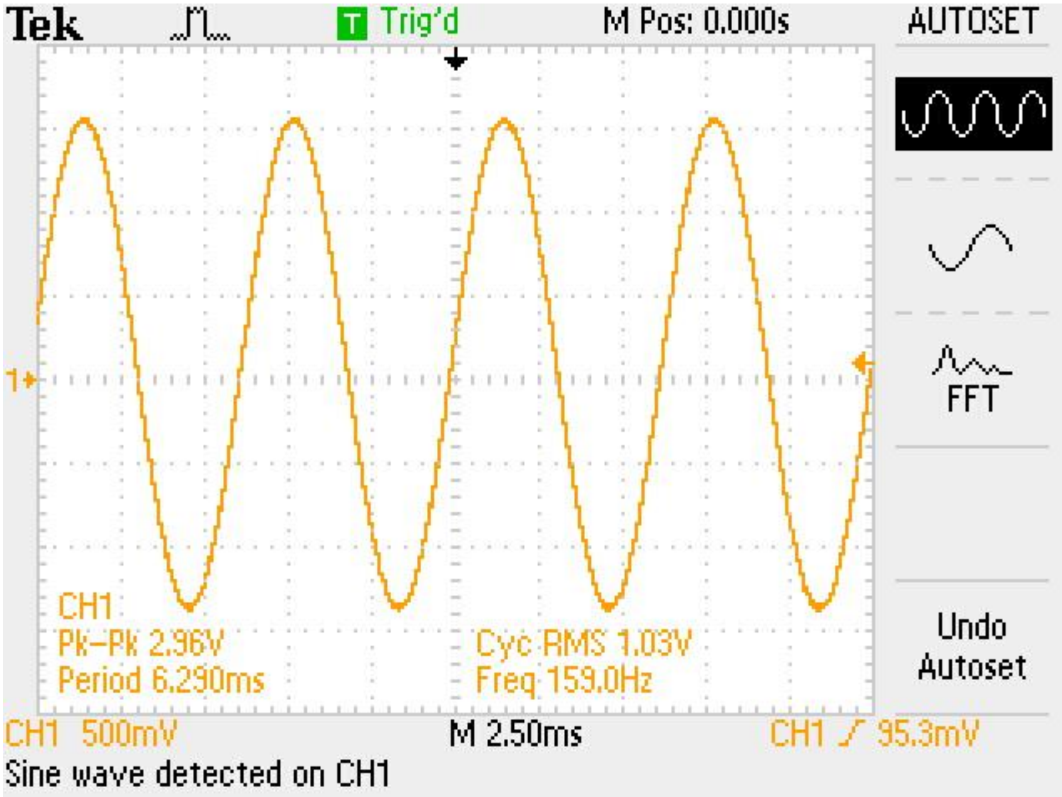

Figure A.C.1 ***Calibration data of the accelerometer used in baseline vibrations testing***

APPENDIX C.2. MATLAB CODE TURNING VOLTAGE VS. TIME GRAPHS INTO ACCELERATION GRAPHS

```
%% Reading an Excel or CSV file with Matlab
%% Clear the work space
% First "close all" plots, "clear all" the variables, and clear the command window.
close all
clear all
clc
%% Use a GUI to select the file
% These lines set up a GUI to allow you to select a file
% once you select a file from the GUI, the file name & file location are
% collected in the vibs_filename & vibs_pathname variables. The filter
% index is indicates the file extension of the file selected using the GUI
[vibs_filename, vibs_pathname, filterindex] = uigetfile( ...
{'*.xls;*.xlsx;*.csv;', 'All Excel Files (*.xls, *.xlsx,*.csv)';}, ...
'Pick a file');
%% EVAL-SPRINTF
% The "eval-sprintf" command are two commands in one that allow for
% flexibility in evaluating many different types of commands.
% The "sprintf" command prints a set of characters to the screen - it is a
% "Screen print" command
% The "eval" command evaluates that set of characters
% So looking inside the the "eval-sprintf" command you will see that we are
% using the "xlsread" command to read in a file and output the file to 3
% different varaibles. "Time_Num_ch1,Time_txt_ch1 and Time_raw." The "%s"
% characters are where the character strings contained in the 3 variables:
% 1) vibs_pathname, 2) vibs_filename & 3) vibs_pathname(end-4:end-1) will
% be entered into the "xlsread" commnand.
%
% This is example is set up for when two channels of data are collected. If
```

```
% only one data set is collected, you can comment the 2nd set of commands
eval(sprintf('[Time_Num_ch1,Time_txt_ch1,Time_raw]=xlsread("%s%s","F%sCH1");',vibs_pat
hname,vibs_filename,vibs_pathname(end-4:end-1)))
%
eval(sprintf('[Time_Num_ch2,Time_txt_ch2,Time_raw]=xlsread("%s%s","F%sCH2");',vibs_pat
hname,vibs_filename,vibs_pathname(end-4:end-1)))
% The eval-sprintf combination is useful when you have a common command
% that needs to be run several times on a variable, or file name that is
% changing
%% Plotting
figure(1)
title('Vibrational Analysis of Previous Carousel Design')
hold on
plot((9.81/1.56)*Time_Num_ch1(:,3),Time_Num_ch1(:,4),'-r')
%plot(Time_Num_ch2(:,3),Time_Num_ch2(:,4),'-ob')
xlim([0,35])
xlabel('Time, s')
ylabel('Acceleration, m/s^2')
```

APPENDIX D. ARDUINO CODE

```
int driverDIR = 6;    // DIR- pin
int pd = 510;         // Pulse Delay period
boolean setdir = LOW; // Set Direction
volatile byte half_revolutions;
unsigned int rpm;
unsigned long timeold;
int num = -1;
bool ENTER = false;
int desiredBin;
int currentBin;
int numSteps;
// Initialize other variables
unsigned long startTime, endTime;
volatile unsigned long travelTime = 0;
volatile bool rowMoved = false;
int BINS[8] = {1, 2, 3, 4, 5, 6, 7, 8};
int magnetPin = 2; // pin connected to the magnet sensor
int curtainPin = 4; // pin connected to the OUT of the sensor (light curtain)


class Stepper {
public:
   int is_moving;
   int direction;
```

```
};

Stepper motor;

// Hall effect sensor interrupt
void hallSensorInterrupt() {
   if (motor.is_moving) {
      rowMoved = true; // Row has moved when the sensor is triggered
   }
}

void start_motor(int direction) {
   motor.is_moving = 1;
   motor.direction = (direction > 0) ? HIGH : LOW;
   startTime = millis(); // Record start time
   numSteps = 0; // Reset the step count when starting the motor
}

void stop_motor(void) {
   motor.is_moving = 0;
   Serial.print("Total Steps: ");
   Serial.println(numSteps); // Output the total steps when motor stops
}
```

```
void motor_interval(void) {
  if (motor.is_moving) {
    pd = map(512, 0, 1023, 2000, 50);
    digitalWrite(driverDIR, motor.direction);
    digitalWrite(driverPUL, HIGH);
    delayMicroseconds(pd);
    digitalWrite(driverPUL, LOW);
    delayMicroseconds(pd);

    numSteps++; // Increment the step count with each pulse
  }
}

// Function to change the Nextion display page
void goToPage(int pageNumber) {
  Serial.print("Switching to Page ");
  Serial.println(pageNumber);
  NEXTION_SERIAL.print("page ");
  NEXTION_SERIAL.print(pageNumber);
  NEXTION_SERIAL.print("\xFF\xFF\xFF");  // End of command
}

// Define components for each page - Nextion objects
// page 0
```

```
NexButton buttonPage0_0 = NexButton(0, 13, "b0");
NexButton buttonPage0_1 = NexButton(0, 14, "b1");
NexButton buttonPage0_2 = NexButton(0, 15, "b2");
NexButton buttonPage0_3 = NexButton(0, 16, "b3");
//NexButton buttonPage0_4 = NexButton(0, 17, "b4");
//NexButton buttonPage0_5 = NexButton(0, 18, "b5");
NexText textDisplay0 = NexText(0, 11, "t1");
NexPicture imageDisplay0 = NexPicture(0, 10, "pic10");

// page 1
NexButton buttonPage1_0 = NexButton(1, 2, "b0");
NexButton buttonPage1_1 = NexButton(1, 3, "b1");
NexButton buttonPage1_2 = NexButton(1, 4, "b2");
NexButton buttonPage1_3 = NexButton(1, 5, "b3");
NexButton buttonPage1_4 = NexButton(1, 8, "b4");
NexButton buttonPage1_5 = NexButton(1, 9, "b5");
NexButton buttonPage1_6 = NexButton(1, 10, "b6");
NexText textDisplay1 = NexText(1, 1, "t1");

// Page 2 buttons and text objects
NexButton buttonPage2_0 = NexButton(2, 2, "b0");
NexButton buttonPage2_1 = NexButton(2, 3, "b1");
NexButton buttonPage2_2 = NexButton(2, 4, "b2");
NexButton buttonPage2_3 = NexButton(2, 5, "b3");
```

```
NexButton buttonPage2_4 = NexButton(2, 6, "b4");
NexButton buttonPage2_5 = NexButton(2, 7, "b5");
NexText textDisplay2 = NexText(2, 1, "t1");

// Page 3 buttons and text objects
NexButton buttonPage3_0 = NexButton(3, 2, "b0");
NexButton buttonPage3_1 = NexButton(3, 3, "b1");
NexButton buttonPage3_2 = NexButton(3, 4, "b2");
NexButton buttonPage3_3 = NexButton(3, 5, "b3");
NexButton buttonPage3_4 = NexButton(3, 8, "b4");
NexButton buttonPage3_5 = NexButton(3, 9, "b5");
NexButton buttonPage3_6 = NexButton(3, 10, "b6");
NexText textDisplay3 = NexText(3, 1, "t1");

// Page 4 buttons and text objects
NexButton buttonPage4_0 = NexButton(4, 2, "b0");
NexButton buttonPage4_1 = NexButton(4, 3, "b1");
NexButton buttonPage4_2 = NexButton(4, 4, "b2");
NexButton buttonPage4_3 = NexButton(4, 5, "b3");
NexButton buttonPage4_4 = NexButton(4, 8, "b4");
NexButton buttonPage4_5 = NexButton(4, 9, "b5");
NexButton buttonPage4_6 = NexButton(4, 10, "b6");
NexText textDisplay4 = NexText(4, 1, "t1");
```

```
// Touch event list
NexTouch *nex_listen_list[] = {
  &buttonPage0_0, &buttonPage0_1, &buttonPage0_2, &buttonPage0_3, //&buttonPage0_4,
&buttonPage0_5,
  &buttonPage1_0, &buttonPage1_1, &buttonPage1_2, &buttonPage1_3, &buttonPage1_4,
&buttonPage1_5, &buttonPage1_6,
  &buttonPage2_0, &buttonPage2_1, &buttonPage2_2, &buttonPage2_3, &buttonPage2_4,
&buttonPage2_5,
  &buttonPage3_0, &buttonPage3_1, &buttonPage3_2, &buttonPage3_3, &buttonPage3_4,
&buttonPage3_5, &buttonPage3_6,
  &buttonPage4_0, &buttonPage4_1, &buttonPage4_2, &buttonPage4_3, &buttonPage4_4,
&buttonPage4_5, &buttonPage4_6,
  NULL
};


// Function declarations for button callbacks


// Callback functions for button presses
// Page 0
void p0b0PushCallback(void *ptr) { goToPage(1); }
void p0b1PushCallback(void *ptr) { goToPage(2); }
void p0b2PushCallback(void *ptr) { goToPage(3); }
void p0b3PushCallback(void *ptr) { goToPage(4); }
//void p0b4PushCallback(void *ptr)
//void p0b5PushCallback(void *ptr)
```

```
// Page 1
void p1b0PushCallback(void *ptr) { num = 1; Serial.println(num); }
void p1b1PushCallback(void *ptr) { num = 1; Serial.println(num); }
void p1b2PushCallback(void *ptr) { num = 2; Serial.println(num); }
void p1b3PushCallback(void *ptr) { num = 2; Serial.println(num); }
void p1b4PushCallback(void *ptr) { Serial.println("Switching to Page 0"); goToPage(0); }
void p1b5PushCallback(void *ptr) { ENTER = true; desiredBin = num;
Serial.println("ENTERED"); }
void p1bdPushCallback(void *ptr) { num = -1; Serial.println(num); }

// page 2
void p2b0PushCallback(void *ptr) { num=3; Serial.println(num); }
void p2b1PushCallback(void *ptr) { num=3; Serial.println(num); }
void p2b2PushCallback(void *ptr) { num=3; Serial.println(num); }
void p2b4PushCallback(void *ptr) { Serial.println("Switching to Page 0"); goToPage(0); }
void p2b5PushCallback(void *ptr) { ENTER = true;desiredBin = num;
Serial.println("ENTERED");}
void p2bdPushCallback(void *ptr) { num = -1; Serial.println(num); }

// page 3
void p3b0PushCallback(void *ptr) { num=4; Serial.println(num); }
void p3b1PushCallback(void *ptr) { num=4; Serial.println(num); }
void p3b2PushCallback(void *ptr) { num=5; Serial.println(num); }
void p3b3PushCallback(void *ptr) { num=5; Serial.println(num); }
```

```
void p3b4PushCallback(void *ptr) { Serial.println("Switching to Page 0"); goToPage(0); }
void p3b5PushCallback(void *ptr) { ENTER = true;desiredBin = num;
Serial.println("ENTERED");}
void p3bdPushCallback(void *ptr) { num = -1; Serial.println(num); }
// page 4
void p4b0PushCallback(void *ptr) { num=6; Serial.println(num); }
void p4b1PushCallback(void *ptr) { num=6; Serial.println(num); }
void p4b2PushCallback(void *ptr) { num=7; Serial.println(num); }
void p4b3PushCallback(void *ptr) { num=8; Serial.println(num); }
void p4b4PushCallback(void *ptr) { Serial.println("Switching to Page 0"); goToPage(0); }
void p4b5PushCallback(void *ptr) { ENTER = true;desiredBin = num;
Serial.println("ENTERED");}
void p4bdPushCallback(void *ptr) { num = -1; Serial.println(num); }


void magnet_detect()
{
  half_revolutions++;
}
void setup() {
   Serial.begin(9600);
   NEXTION_SERIAL.begin(9600);


   pinMode(driverPUL, OUTPUT);
   pinMode(driverDIR, OUTPUT);
   pinMode(LED_PIN_1, OUTPUT);
```

```
pinMode(LED_PIN_2, OUTPUT);
pinMode(LED_PIN_3, OUTPUT);
pinMode(LED_PIN_4, OUTPUT);
pinMode(LED_PIN_5, OUTPUT);
pinMode(magnetPin, INPUT);
pinMode(HALL_SENSOR_PIN, INPUT_PULLUP); // Set Hall sensor pin
pinMode(curtainPin, INPUT); // Set light curtain sensor pin
pinMode(E_Stop_PIN, INPUT_PULLUP); // E-stop button with internal pull-up resistor

motor.is_moving = 0; // Initialize motor status

// Attach button callbacks
// Attach button callbacks
buttonPage0_0.attachPush(p0b0PushCallback);
buttonPage0_1.attachPush(p0b1PushCallback);
buttonPage0_2.attachPush(p0b2PushCallback);
buttonPage0_3.attachPush(p0b3PushCallback);
//buttonPage0_4.attachPush(p0b4PushCallback);
//buttonPage0_5.attachPush(p0b5PushCallback);
buttonPage1_0.attachPush(p1b0PushCallback);
buttonPage1_1.attachPush(p1b1PushCallback);
buttonPage1_2.attachPush(p1b2PushCallback);
buttonPage1_3.attachPush(p1b3PushCallback);
buttonPage1_4.attachPush(p1b4PushCallback);
```

```
    buttonPage1_5.attachPush(p1b5PushCallback);
    buttonPage2_0.attachPush(p2b0PushCallback);
    buttonPage2_1.attachPush(p2b1PushCallback);
    buttonPage2_2.attachPush(p2b2PushCallback);
    //buttonPage2_3.attachPush(p2b3PushCallback);
    buttonPage2_4.attachPush(p2b4PushCallback);
    buttonPage2_5.attachPush(p2b5PushCallback);
    buttonPage3_0.attachPush(p3b0PushCallback);
    buttonPage3_1.attachPush(p3b1PushCallback);
    buttonPage3_2.attachPush(p3b2PushCallback);
    buttonPage3_3.attachPush(p3b3PushCallback);
    buttonPage3_4.attachPush(p3b4PushCallback);
    buttonPage3_5.attachPush(p3b5PushCallback);
    buttonPage4_0.attachPush(p4b0PushCallback);
    buttonPage4_1.attachPush(p4b1PushCallback);
    buttonPage4_2.attachPush(p4b2PushCallback);
    buttonPage4_3.attachPush(p4b3PushCallback);
    buttonPage4_4.attachPush(p4b4PushCallback);
    buttonPage4_5.attachPush(p4b5PushCallback);

    nexInit();
    attachInterrupt(digitalPinToInterrupt(HALL_SENSOR_PIN), hallSensorInterrupt,
FALLING);  // Hall sensor interrupt
}
```

```
void loop() {
  nexLoop(nex_listen_list);  // Listen for touch events

   // Check the E-stop button
  if (digitalRead(E_Stop_PIN) == LOW) { // E-stop is pressed (LOW due to internal pull-up)
    // Stop motor immediately when E-stop is pressed
    stop_motor();
    digitalWrite(relayPin, LOW); // Turn off relay (stop motor)
    Serial.println("Emergency Stop Activated! Motor stopped.");
  } else {

  // If the desired bin is not equal to the current bin
  if (currentBin != desiredBin) {
    numSteps = BINS[desiredBin - 1] - BINS[currentBin - 1];
    start_motor(numSteps);

    // Process motor steps based on current state
    if (half_revolutions >= 1) {
      Serial.print("DESIRED BIN: ");
      Serial.println(desiredBin);
      Serial.print("CURRENT BIN: ");
      Serial.println(currentBin);
      Serial.print("NUM STEPS:");
```

```
        Serial.println(numSteps);
        rpm = 30 * 1000 / (millis() - timeold) * half_revolutions;
        timeold = millis();
        half_revolutions = 0;

        if (numSteps < 0) {
          currentBin = (currentBin == 1) ? 8 : currentBin - 1;
        } else if (numSteps > 0) {
          currentBin = (currentBin == 8) ? 1 : currentBin + 1;
        }
      }
    } else {
      stop_motor();
      // Turn on LEDs when stopped
      digitalWrite(LED_PIN_1, HIGH);
      digitalWrite(LED_PIN_2, HIGH);
      digitalWrite(LED_PIN_3, HIGH);
      digitalWrite(LED_PIN_4, HIGH);
      digitalWrite(LED_PIN_5, HIGH);
    }

    // Light curtain sensor logic
    if (digitalRead(curtainPin) == LOW) {
      stop_motor();  // Stop motor if curtain sensor is triggered
```

```
        goToPage(1);   // Change to page 1
    }


    }
}
```

APPENDIX N. ABET OUTCOME 2, DESIGN FACTOR CONSIDERATION

The Vertical Carousel Storage System has many different impacts on the world of manufacturing and are listed below.

APPENDIX N.1. IMPACT TO SAFETY

For this tabletop version of a vertical carousel storage system, safety is considered. A light curtain safety sensor was placed at the opening of the machine to shut down the system if any disturbance enters the path. An emergency stop (E-Stop) button was added to the exterior of the carousel to quickly shut the machine down in an emergency situation. The Lexan enclosure around the carousel provides yet another factor of safety while operating the machine. These safety features were added to ensure Instructors and students will be able to operate the device in a safe manner. See Table A.N.1 below for the standards mentioned throughout the vertical carousel storage system report.

Code or Standard:	Standard States:	Report Page Number:
ANSI MH24.1-5.4.4.a	When a carousel is equipped with an Inserter/Extractor mechanism, personnel shall be protected from accidental contact with moving parts by a guard	11
ANSI MH24.1-5.4.2.a	One or more Operator Interface Devices shall be required at each Operator Interface Area. These may include, but are not limited to, floormats, photoelectric sensors and emergency stop devices.	22

Table A.N.1 ***Table of the standards referenced in the design report***

APPENDIX N.2. IMPACT TO PUBLIC HEALTH

The VCSS does not have any impact on public health. It is used in a controlled classroom environment and is not to be released to the general public for use in its current state.

APPENDIX N.3. IMPACT TO WELFARE

The VCSS does not have any impact on the welfare of the public, it is not altering the day-to-day life of the public. The carousel will have no effect on the public's overall well-being or quality of life.

APPENDIX N.4. ECONOMIC IMPACT

As the tabletop carousel is intended for classroom use, the economic impact is minimal. The VCSS small size that makes it ideal for classroom demonstration, also makes the carousel cost efficient.

APPENDIX N.5. CULTURAL/SOCIAL

The operation of this system requires the interface to be in English since it will be operated in a classroom setting in the United States. The screen's code can be altered to display in any language. Arduinos can also be bought to suit different coding languages, this makes this VCSS design more culturally inclusive as students can buy their code specific Arduinos and recreate or improve upon the carousel software.

APPENDIX N.6. ENVIRONMENTAL

The VCSS project does not directly impact the environment. The materials used to construct the carousel are mostly biodegradable or recyclable, which makes disposal of the machine at the end of its life ecofriendly.