Computer-Controlled System for Sorting of Pathology Block Samples

Project 12 – Design Review 5

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1.0 EXECUTIVE SUMMARY

The Anatomic Pathology department at the University of Michigan Hospital has requested an automated sorting system for anatomic pathology sample blocks. The pathology department processes each sample into several block containers and each block container has several corresponding slides. The block container's dimensions are 1 1/8" x 1 3/4" x 1/4" (width x length x height). These block containers and slides must sorted and filed in numerical order so they can be located and retrieved at a later date. The pathology department has reported errors in the sorting and filing of the blocks due to the fatigue and monotony of manual sorting. These filing errors can lead to misdiagnosis of a patient, which can be at the very least costly and at the very most fatal. The goal of this project is to automate the process of block sorting and increase the accuracy of block filing.

Benchmarking for a similar automated sorting system proved to be difficult. A comparable system has not been created according to our research and project sponsor, Dr. Balis. The hand sorting process will be used as a benchmark for our system. Several other technologies, systems, and patents were researched including mail sorting systems, pick and place machines, and XZ tables.

After observation and documentation of the current process of block sorting, the customer requirements were defined and discussed with our project sponsor. The primary customer requirements are traceability of the blocks, accuracy in sorting, and the ability for the system to fit on the countertop workspace. These corresponded with the most significant engineering specifications for our design: dispensing and loading mechanisms and the ability for the design to store at least the capacity of two filing drawers.

We developed several concepts for block sorting machines. All of these concepts have two common characteristics. First, each concept has a method for taking blocks out of their initial transport bins, scanning them, and placing them into an internal storage unit. Second, each concept has the ability to accept an empty drawer from the user and load the proper blocks into it. Additionally, we developed several concepts for our subsystems, such as various gripper designs and a modular storage concept for the internal storage unit.

Using selection criteria based on our engineering specifications and customer requirements we selected one of these concepts to analyze in detail. This selected concept was then further refined and the process for manufacturing a prototype of this concept was developed. The design has a 600 block vertical storage shelf for internal storage. To fill the shelf, a gripper is attached to a linearly actuated X-Z Cartesian system. To unload a transport bin the gripper grabs a block from the bin, scans their barcode and documents their location in the shelf. To load a drawer, the gripper locates the blocks assigned to that drawer and places them in the rows of the drawer.

The focus of the following report is to document the description, analysis and manufacturing process of our final design into a prototype, discuss engineering change notices, critique our design, and give recommendations to our sponsor.

2.0 INTRODUCTION AND PROBLEM DESCRIPTION

The University of Michigan Hospital’s Anatomic Pathology Department wants to implement an automated sorting system for blocks containing anatomical pathology samples. This department receives biological tissue samples that must be examined by pathologists and other doctors for diagnosis. These samples are processed into paraffin-filled block containers and slides. Currently, after the block containers and slides are processed, they are sorted and filed according to an identification number. The pathology department will be implementing a system that uses 2-D barcodes to identify the blocks and slides. They would also like to implement an opto-mechatronic system that reads these 2-D barcodes and automates the sorting and filing of these blocks and slides. The goal of an automated sorting system is to increase accuracy and reduce filing errors associated with manual sorting. Manual sorting is a tedious and monotonous task and misplacement can occur due to human error. Misplacement or misfiling of a patient’s sample can cause misdiagnosis for the patient. Misdiagnosis can be very costly or fatal. This project will focus on the design of an automated system for sorting the block containers. The current process of handling blocks and slides in the anatomic pathology department is summarized in Figure 1.

The patient’s tissue sample is first catalogued and given an ID number by a prosector in the grossing station (1). A sample is sectioned into several parts with each part receiving a block container with a printed ID number. When the 2-D barcode system is implemented, the prosector will have printed the barcodes on each block container. The block’s dimensions are 1 1/8” x 1 3/4” x 3/16” (width x length x height). The blocks then go to the processor station (2). The processor dehydrates the sample and sanitizes the sections of the sample. This process usually takes 24 hours. In the embedding station (3) the block is used as a holder while the tissue sample is surrounded by paraffin wax. A worker must orient the sample on the block so it can be easily cut and cross-sectioned in the cutting station (4). At the cutting station the sample is cut into thin ribbons and placed on slides. After cutting, the blocks are placed into a transport container, shown in Figure 2. The transport container is sectioned into five rows, with each row holding 27 to 30 blocks. Figure 2 also shows the dimensions of the transport containers. The blocks are then taken from the transport containers and sorted by hand into drawers (5). The blocks are sorted into sequential order and multiple blocks for each sample are grouped together. The drawers are taken to the storage room (6). After cutting, the slides are dyed and sorted into trays for review by pathologists. Eventually, the slides are sorted into drawers in the same storage room as the blocks. Sometimes, a block that has been filed into a drawer must be retrieved for further review by a doctor. This usually occurs within 24 hours of being initially filed. This project focuses on the process for blocks as highlighted in red in Figure 1.

This project will focus on Step 5 of the current process. The goal is to eliminate manual sorting of the blocks into the drawers. The sorting process usually takes place in the morning and takes two to three hours. An inventory of 12 to 15 transport containers (Figure 2) must be sorted into corresponding drawers. These drawers are held at the sorting station and hold the most recent blocks. The worker first opens one of the transport containers and groups the blocks which belong to a sample and sorts within this group. The worker then pulls out the corresponding drawer and sorts and places this group of blocks into the drawer. After completing this procedure for all blocks in the transport container, the worker repeats the process for the remaining containers. The transport trays are on average 75% full and it takes the worker two to three hours to sort 12 to 15 transport trays. This corresponds to a manual sorting rate of approximately 7.5 blocks per minute. Manual sorting can lead to inaccuracies and misplacement due to human error. By implementing an automated sorting system, the accuracy of sorting can be increased. It will also eliminate the need for manual sorting, thereby increasing resources available for other tasks. Also, an automated sorting system may decrease block processing time by reducing sorting time.

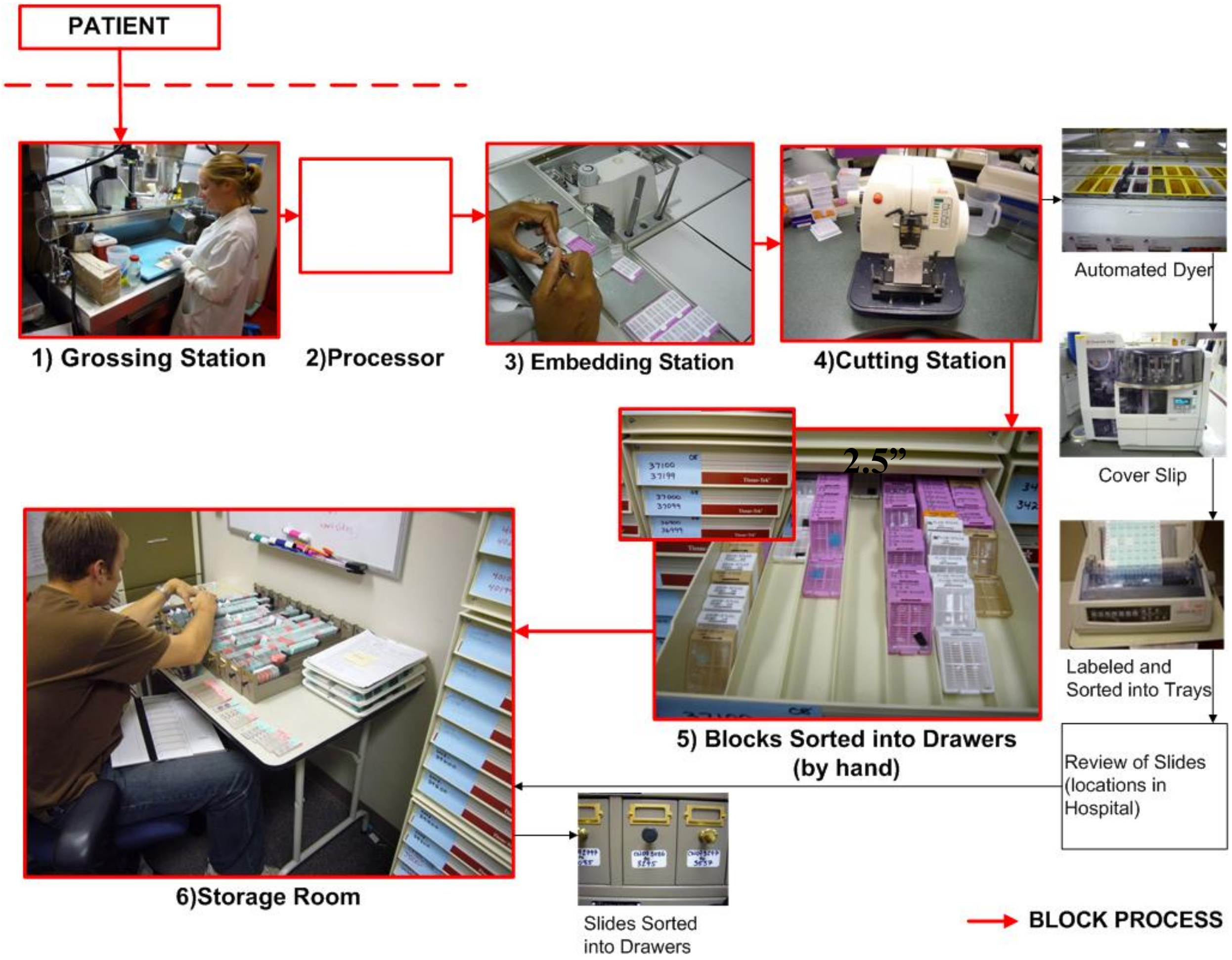

Figure 1: Process flow diagram for anatomic pathology blocks and slides

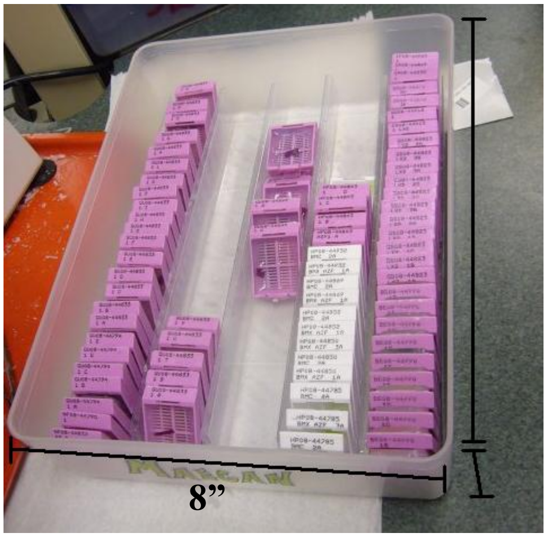

Figure 2: Transport Tray

3.0 CUSTOMER REQUIREMENTS and ENGINEERING SPECIFICATIONS

3.1 Customer Requirements

The seven customer requirements found include (1) traceability and (2) accurately sorting the blocks, (3) depositing the blocks into drawers, having a machine that can (4) handle different size blocks, having a mechanism that can (5) maintain throughput, have an (6) internal storage area for blocks waiting to be sorted, (7) a design compatible with existing file drawers, and finally one that is able to (8) fit in the counter top work space. These customer requirements are shown in the quality function diagram (QFD) in APPENDIX A – CONCEPT GENERATION

Since the goal of this project is to reduce human error in sorting and storing of the blocks, the device must be able to sort and scan the blocks. Having automated sorting instead of manual sorting will not only reduce error, but may also reduce sorting time. Tracing the block's location will be imperative so each block can be properly identified and filed in the correct location for later retrieval. Since sorting and traceability of the blocks is the main function of the machine, both have received a weighted importance of ten. Due to space limitations, the need to fit on a countertop has also received a ten. During the sorting process, blocks that belong in different drawers are received at different times. For this reason, Dr. Balis has asked that the design have an internal storage capacity of 600 blocks. Internal storage of the blocks has received a ten. To prevent restructuring of the entire storage system and facilities, our machine should be able to use the existing filing drawers and be integrated into the process. Replacing all the existing file drawers in not only the pathology lab, but the offsite storage facilities has received an importance rating of nine. A design that is able to handle multiple block sizes is also important to the customer. Since each block's thickness can vary due to variable sample sizes and amounts of paraffin wax, this has received an importance of eight. The machine should also be able to dispense the blocks into the filing drawers. This will reduce the amount of human interaction with the blocks, decreasing the possibility of human error, and has received a weighted importance of six. Although the machine's ability to maintain throughput is important to prevent creating a bottle neck at the sorting process, it has received a score of four since the machine can run for many hours with limited manual labor, decreasing the need for rapid sorting.

3.2 Engineering Specifications

To determine engineering specifications, each customer requirement had to be considered individually. The engineering specifications are: (1) block thickness, (2) 2-D barcode, (3) must be less than 6' wide, 19" long, (4) dispensing capabilities of at least two blocks/minute, (5) loading mechanism that can accept at least two blocks/minute, (6) an efficient sorting algorithm capable of sorting 2 blocks/minute, (7) able to store 600 blocks, (8) and a budget of $10,000.

The three highest ranked engineering specifications are (1) internal storage of 600 blocks, (2) a loading mechanism, and (3) a dispensing mechanism.

Since manual sorting is the current process, it was used as the benchmark for our design. On average there is 12 to 15 While human sorting meets most of the customer requirements, errors still occur, leading to the misdiagnosis of multiple patients. As accuracy in diagnosis is the most important concern of the pathology lab, a more accurate sorting process is needed. With the introduction of an automated system for sorting blocks, mistakes due to human error and fatigue will be eliminated.

4.0 CONCEPT GENERATION

Several initial concepts were generated for the block sorting machine. The concepts described in this section were developed after Design Review One. After Design Review 1, the scope of the project became more defined, and the concepts described in this section reflect these changes. The scope of the project dictates that the machine should have: 1.) a method of taking blocks out of transport bins, 2.) the ability to store a large number of blocks in a compact way, and 3.) the ability to sort the blocks into drawers. For concepts developed before Design Review 1, please see APPENDIX A – CONCEPT GENERATION.

The concepts in this section were developed with mutual understanding about how the product would be used in a pathology lab. The product will be used as follows: First, when employees are done working with a set of blocks, they will take the blocks in a transport bin to the machine. Second, the machine should automatically unload the blocks from the transport bin, scan them, record block information in a database, and place them into an internal storage area. Third, a user should then be able to place an empty drawer into the machine and the machine should automatically load the correct blocks into the drawer by taking them from its internal storage area and placing them into the drawer, in the proper order.

4.1 Window Concept

The Window concept has three main subsystems: the XZ table, the storage area, and the gripper. A concept sketch is shown in Figure 3. The XZ table is a motor controlled mechanism that translates on two axes (the horizontal axis, X, and the vertical axis, Z). It can be programmed to move to any position on an XZ grid. Next, the storage area is a shelf with hundreds of small slots in it. The slots are large enough for a block to fit into, with room on either side so the block may be easily grabbed and removed from the slot. Within the storage area is an empty rectangular area referred to as a window. A vertically standing transport bin or filing drawer can be placed in the window. Finally, the gripper subsystem is mounted to the XZ table. It contains a mechanism for grabbing and holding the blocks. It also contains the bar code scanner for identifying the blocks.

This concept has two modes: one is to load blocks from a full transport bin into the storage shelf, the other is to unload blocks from the storage shelf and place them into an empty drawer. To load blocks from a transport bin into the storage shelf, the transport bin is placed in the window standing vertically. The XZ table navigates to the first block in the transport bin, grabs it, and scans it. The XZ table then navigates to an available slot in the storage area and places the block in the slot. The machine records in the database the block ID and the slot location of that block. This process repeats until every block in the transport bin has been loaded into a slot in the storage area.

To take blocks from the storage area and place them in a drawer, the user first inserts an empty drawer into the window standing vertically. The machine must determine which blocks belong in that drawer, what order they belong in, and then scan its database to determine how many of those blocks it has in storage and where they are located. The machine then navigates to the slot location of the first block, grabs it, and navigates to the drawer. The machine places the block into the drawer. Then, the machine navigates to the location of the next block and the process repeats, creating a stack of blocks in each column of the drawer. When all the blocks from the storage area that belong in the drawer have been placed in it, the user can take the drawer out of the window.

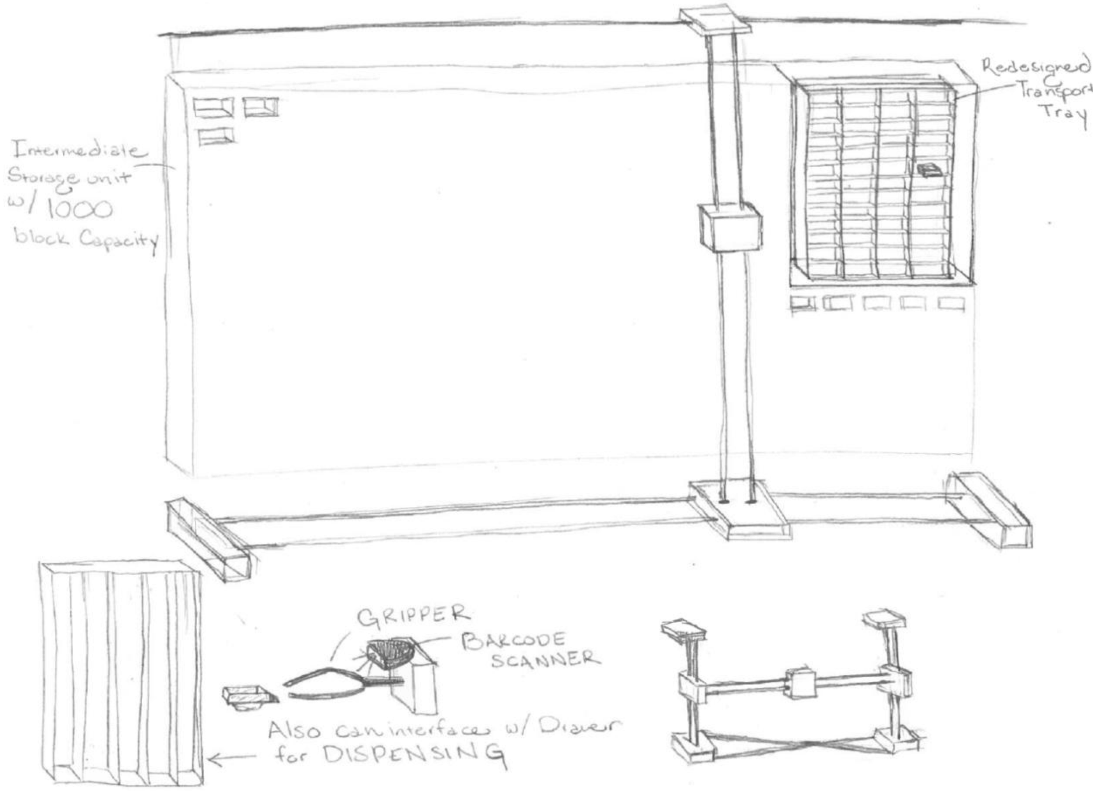

Figure 3: Window concept

4.2 Bottom Slider Concept

The Bottom Slider concept is very similar to the Window concept. The method for getting the blocks from the transport bins to internal storage is the same for both methods. The only difference is how the blocks are placed into the drawers. To place blocks into a drawer, the drawer is placed on a table below the XZ table. This table translates along one axis, perpendicular to the XZ plane. The XZ table navigates to the proper slot location, the gripper grabs the block and then rotates 90 degrees downward. The XZ table then moves over the drawer and drops the block into the proper drawer column. As the column is filled, the table translates so the next block to be loaded can be placed in front of the previous loaded block. This concept is shown in Figure 4.

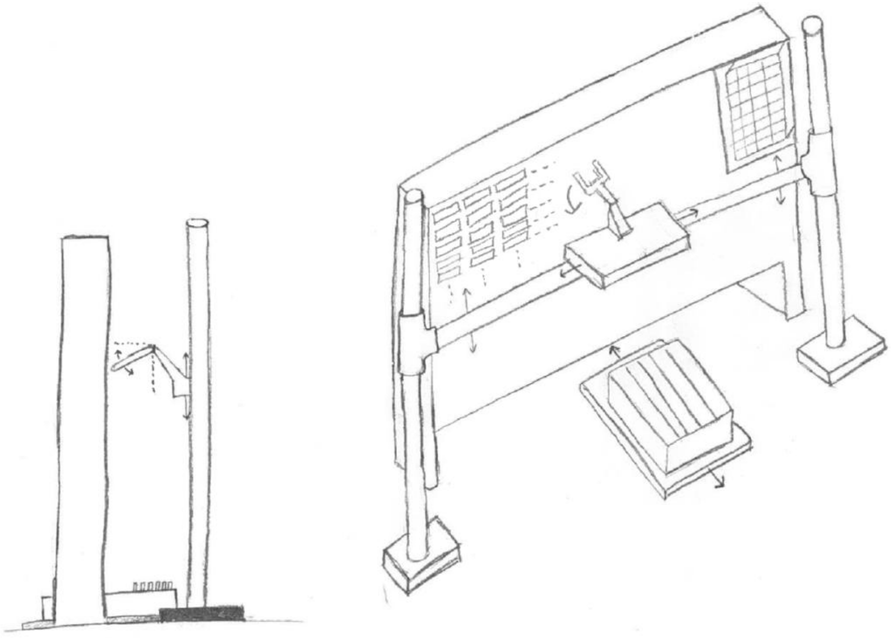

Figure 4: Bottom slider concept

4.3 Magazine Concept

The Magazine concept is very similar to the Window concept. The method for getting the blocks from the transport bins to internal storage is the same for both methods. The only difference is how the blocks are placed into the drawers. The XZ table navigates to the location of the first block, grabs it, and then rotates 180 degrees. The block is then pushed into a magazine which accepts the block and pushes it up in the magazine to make room for the next block. This process is repeated until the entire magazine if full. The magazine holds the same number of blocks as a drawer does per column. A drawer will be placed at the foot of the XZ table. When the magazine is full, the XZ table translates so that it is over the proper column of the drawer. The entire magazine then rotates 90 degrees so it is parallel with the drawer. When it is parallel to the drawer, the side of the magazine that is facing the drawer opens, and the entire set of blocks is placed into a drawer column. This concept is shown in Figure 5.

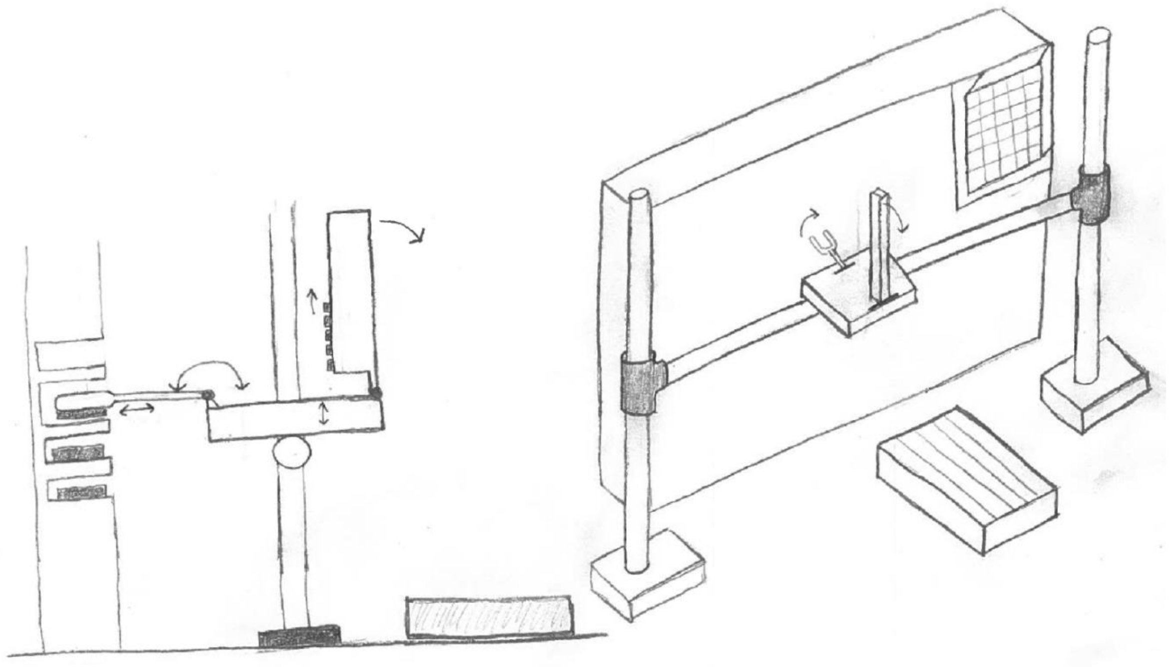

Figure 5: Magazine concept

4.4 L-Slider Concept

The L-Slider concept has a rectangular block storage area, similar to the first three concepts presented. It also uses an XZ table to place and remove blocks from the storage area. However, the vertical travel path does not stay purely vertical. Once it moves above the top of the storage area, the axis bends 90 degrees and becomes parallel to the floor (following an L- shaped path). This allows the gripper to navigate over the top of the storage area. Drawers and transport bins can be placed on top of the storage area, and the gripper can grab or place blocks by going to the top of the storage area. The blocks are loaded and unloaded into internal storage in the same way as the first three concepts of this section. This concept is shown in Figure 6.

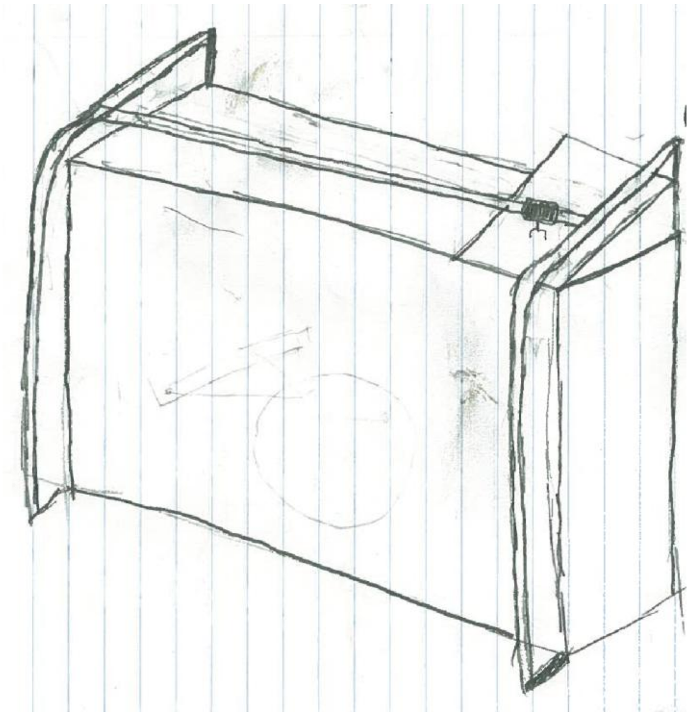

Figure 6: The L-slider concept

4.5 Rotating Storage Concept

The Rotating Storage concept uses a rotating cylinder for the internal storage area. The cylinder has slots in it large enough to accommodate a block. The cylinder is placed next to a z-axis translating mechanism (i.e. an elevator) with a gripper mounted on it. A drawer or transport bin is placed at the foot of the elevator. To load blocks from a transport bin into internal storage, the elevator goes to the bottom, the gripper rotates 90 degrees downward and grabs a block out of the transport bin. The gripper flips back to its original horizontal position and places the block into an empty slot in the storage cylinder. To load blocks from storage into a drawer, the cylinder rotates and the elevator adjusts so the gripper is in front of the slot of the block it wants. The gripper grabs the block, flips 90 degrees downward, and the elevator lowers so the block can be placed in the drawer at the foot of the elevator. This concept is shown in Figure 7.

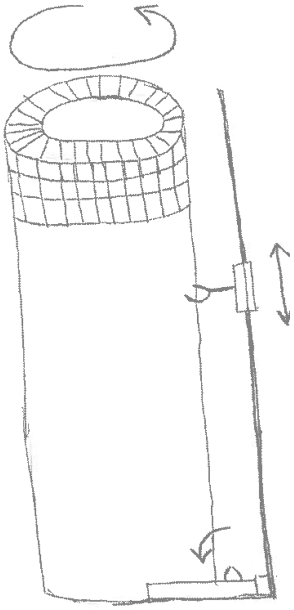

Figure 7: Rotating storage concept

5.0 CONCEPT SELECTION

A weighted Pugh chart was used to select a final concept for development. Each concept was ranked on a scale of 1-5 for each of eight selection criteria. The selection criteria were: the ease of unloading blocks from bins, ease of loading blocks into drawers, number of different movements required and their difficulty, placement and orientation of the transport bin, placement and orientation of the drawer, stability of overall system and subsystems, space efficiency, and amount of travel required to process a single block. The weighted Pugh chart is shown in **Error! Reference source not found.**

Table 1: A weighted Pugh chart was used to choose the concept for development.

		CONCEPTS									
		Window		**Bottom Slider**		**Magazine**		**Rotating Storage**		**L-Slider**	
SELECTION CRITERIA	**Weight**	**Rating**	**Weighted Score**	**Rating**	**Weighted Score**	**Rating**	**Weighted Score**	**Rating**	**Weighted Score**	**Rating**	**Weighted Score**
Unloading from bins	25	5	1.25	5	1.25	5	1.25	4	1	4	1
Loading to drawers	25	5	1.25	4	1	3	0.75	4	1	4	1
Movements	15	5	0.75	4	0.6	2	0.3	5	0.75	3	0.45
Bin placement	5	3	0.15	3	0.15	3	0.15	1	0.05	3	0.15
Drawer placement	5	1	0.05	4	0.2	5	0.25	4	0.2	4	0.2
Stability	10	1	0.1	4	0.4	4	0.4	4	0.4	4	0.4
Space efficient	5	4	0.2	4	0.2	3	0.15	1	0.05	3	0.15
Travel distance	10	3	0.3	3	0.3	4	0.4	3	0.3	3	0.3
TOTAL SCORE		4.05		4.10		3.65		3.75		3.65	
RANK		2		1		4		3		5	
CONTINUE?		No		Yes		No		No		No	

5.1 Window Concept

The main advantage of the Window concept is that the number of movements is minimized because several functions are performed in the same way. The method of unloading the transport bins is identical to the method of loading drawers. This simplifies the design, requires fewer parts, and requires fewer degrees of freedom. The main disadvantage of the Window concept is that placing the drawers vertically makes them very unstable. There is potential that the blocks could spill out of the drawer, which would then require resorting the blocks.

5.2 Bottom Slider Concept

The main advantage of the Bottom Slider concept is that it corrects the drawer instability problem of the Window concept. Its main disadvantage is that it requires two additional degrees of freedom to do so; the gripper must rotate 90 degrees and the drawer must be placed on a table that translates.

This concept was chosen for further development because we believe it is technically feasible and satisfies all the selection criteria. While it does require two more degrees of freedom than the Window concept, they are both simple movements: linear translation and 90 degree rotation. Additionally, the drawer is held in a stable position, so there is no concern about drawers spilling their contents. This design is also versatile enough to allow for design changes at a later date.

5.3 Magazine Concept

The main advantage of the Magazine concept is that it does not have to travel to the drawer to unload each block it grabs; it grabs a block, loads it into a magazine, and immediately can grab the next block. This minimizes the total distance the machine must travel. Also, the ability to load an entire column of blocks into a drawer simultaneously means that the drawer can remain stationary and doesn't have to move, as in the Bottom Slider concept. However, the main disadvantage of the Magazine concept is the added complexity. There are at three new movements that have to be implemented: loading blocks into the magazine, rotating the magazine, and opening the side of the magazine to unload the column.

5.4 Rotating Storage Concept

The main advantage of the Rotating Storage concept is that rotational motion may be easier to achieve than linear motion. However, this concept has several disadvantages. It is not space efficient, it requires additional movements, and retrieving blocks from the transport bins takes longer and is more complicated than in the other concepts.

5.5 L-Slider Concept

The main advantage of the L-Slider concept is that the drawer is able to be placed flat (for stability) but there are no new movements or mechanisms are required. The main disadvantage is the technical challenge of building an XZ table with L-shaped bends at the top of the vertical bars. Achieving the precise motion and positioning of an XZ table would be complicated if the system had to travel along a curved track. It is also very difficult to find a commercially available product with this feature.

6.0 CONCEPT DESCRIPTION

Our design has four subsystems: the XZ Cartesian system, a gripper, a storage shelf and a bottom translating platform. This is a modified version of the Bottom Slider concept (Section 4.2). These modifications are presented in this section along with a detailed overview of the design.

The design is essentially the same as the Bottom Slider concept with two changes. First, the window has been eliminated and blocks are now loaded into the storage area by placing a transport bin on the translating platform. Thus, the process of unloading a transport bin is the same as the process of loading a drawer, except in reverse. This simplifies the design by eliminating an additional feature (the window). The second change is that this translating platform is now tilted at an angle which helps the blocks stay in an upright orientation.

This design has six degrees of freedom: translation along both the X-axis and the Z-axis by the XZ table, extension of the gripper, rotation of the gripper, pinching motion of the gripper, and translation of the drawer or transport bin. A CAD model of our final concept is shown in Figure 8.

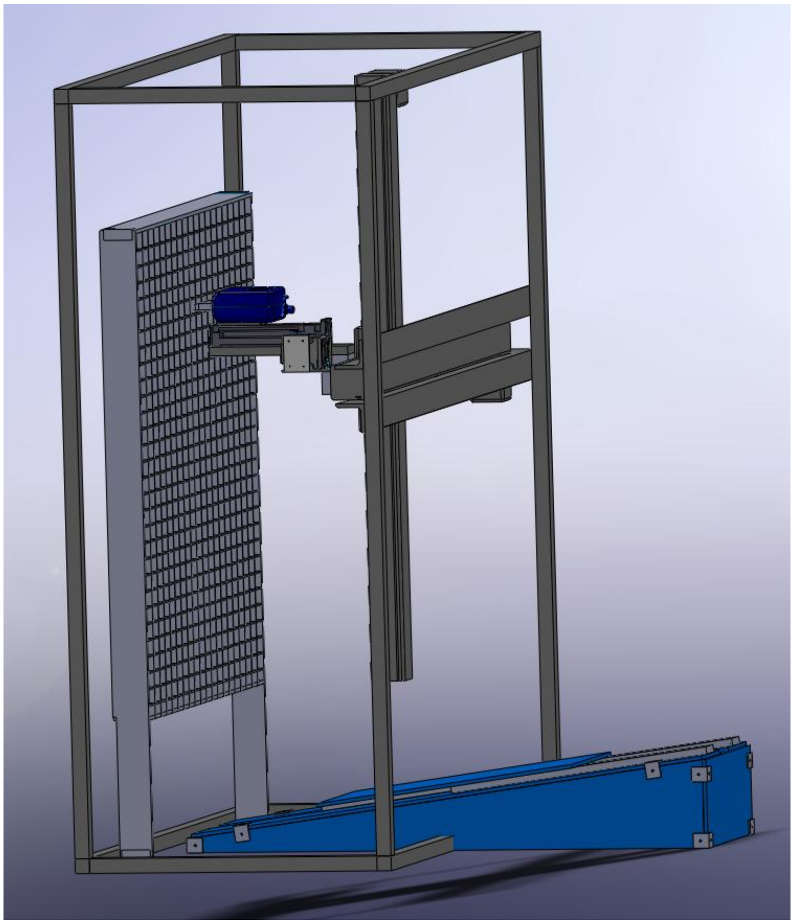

Figure 8: CAD Model of entire system

The system has two modes: one to unload the blocks from the storage bin and place them into the shelf, and one to retrieve scanned blocks from the shelf and load them into empty drawers. A flow chart for both the unloading process and the loading process is shown in Figure 9 and Figure 10.

To unload a transport bin the user places the transport bin on the translating platform. The platform moves to a position so that the gripper pointing downwards can pick up one of the blocks. The gripper grips the block and scans the block's barcode, finding the information on the barcode in the database. The linear actuators of the XZ Cartesian system move the gripper to a location in the shelf. As the gripper moves it rotates to its horizontal position. At the shelf position the gripper releases the block and places it in the shelf. The computer program files the block's position in a database for later retrieval. This process is repeated with the translating platform moving towards the shelf to allow access to sequential blocks in the transport bin.

To load a drawer the process is very similar to unloading a transport bin. An empty drawer is placed onto the translating platform. The platform moves to align the gripper at its downward position and the inside front of the drawer. The computer program retrieves a block's position from the internal database. The XZ system translates to the position in the shelf and the gripper grips the block. The XZ system then moves to the center and downward to align itself with the drawer and platform. The gripper rotates downwards 90 degrees and releases the block into the drawer. This process is repeated with the translating platform moving to align the drawer for space for new blocks, until all blocks are sequentially aligned in the drawer.

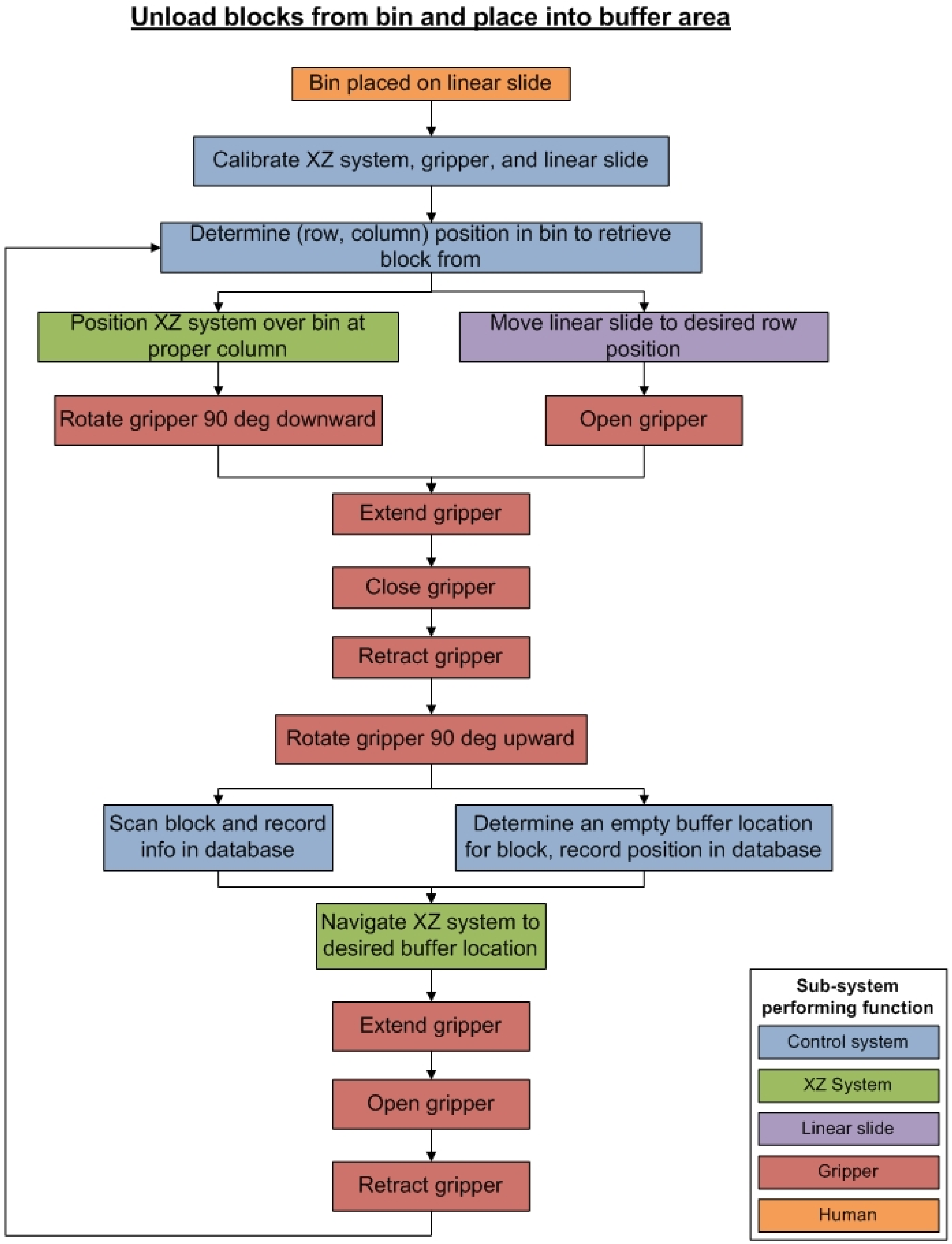

Figure 9: Flow chart for unloading process

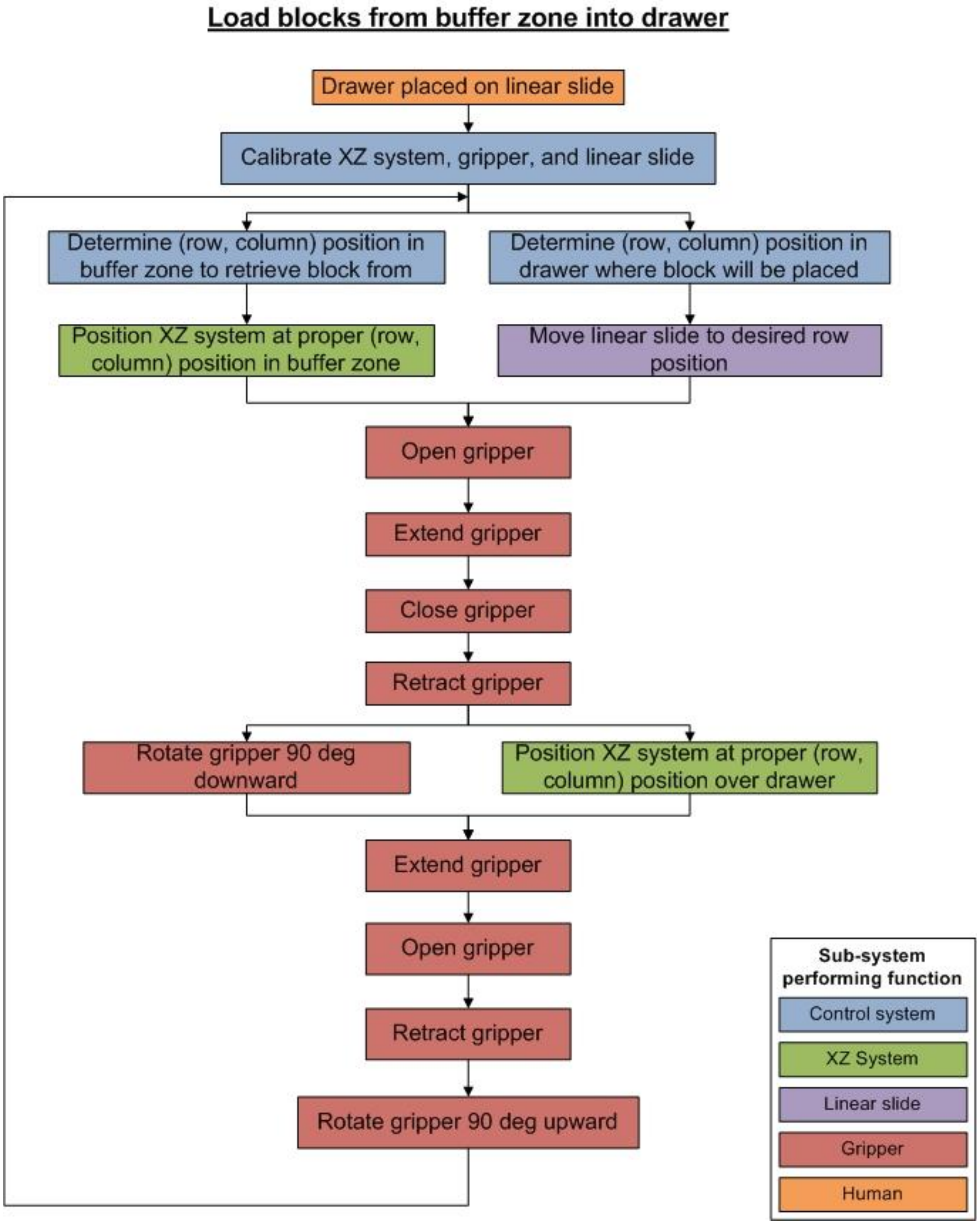

Figure 10: Flow chart for loading process

6.1 Subsystem: XZ Cartesian System Design

Figure 11 shows a model of the final design for the XZ Cartesian system. The x-axis is mounted to a rigid frame, and the z-axis is mounted to the carriage of the x-axis. Therefore, the z-axis will be moved horizontally by the x-axis. The z-axis's carriage will move vertically and will carry the gripper mechanism. This allows the gripper to be navigated to any XZ coordinate specified.

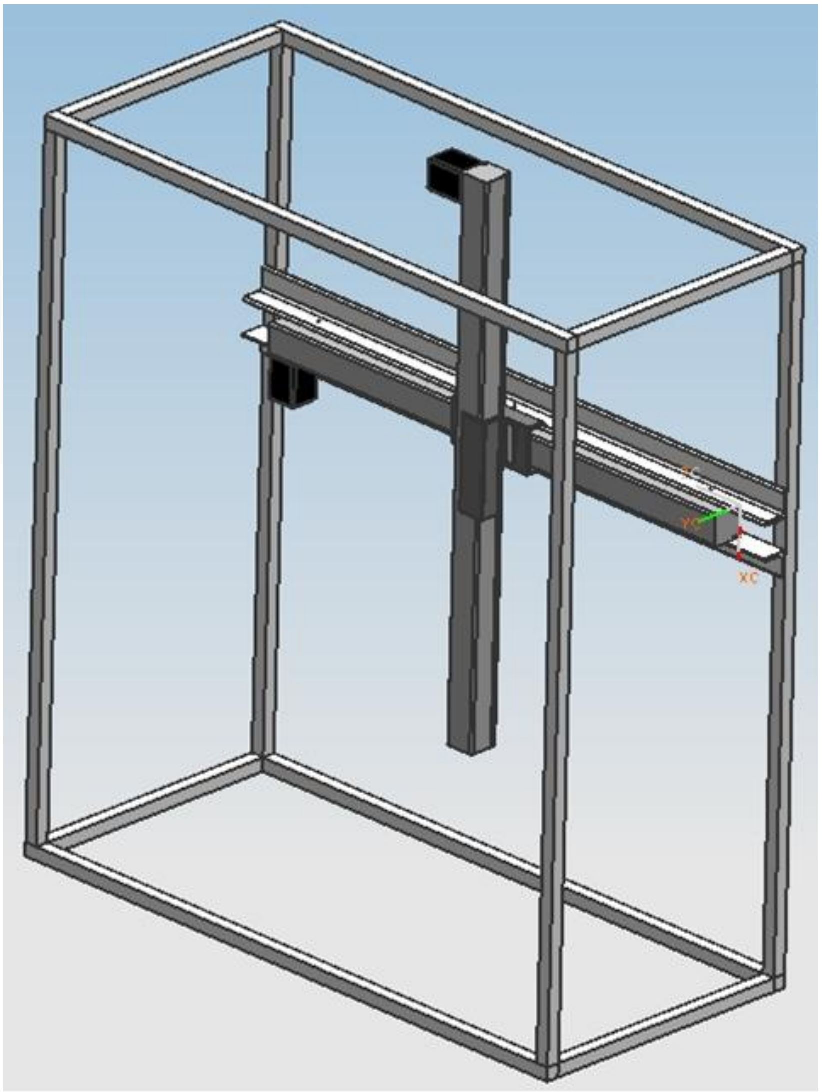

Figure 11: The XZ Cartesian system mounted in the system frame

6.2 Subsystem: Gripper Design

The gripper can retrieve blocks from and place blocks into both the shelf and the transport bins. The gripper mechanism has six parts; the 1) Smart Gripper 2.0, 2) THK VLA ST-45 linear actuator, 3) Animatics SM 2315DT, 4) bracket that connects to the XZ table, 5) rotating base on which the actuator and linear gripper is connected to, and a 6) counter weight to minimize torque on the motor.

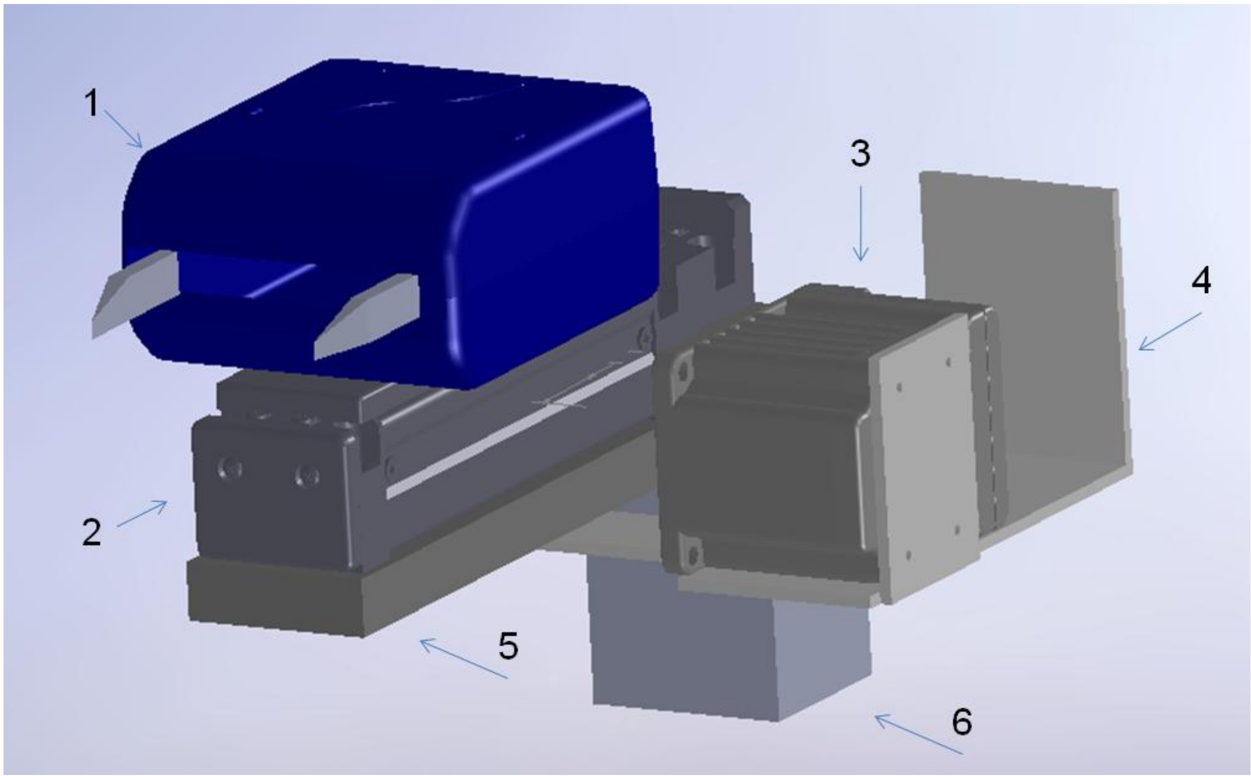

Figure 12: Gripper Mechanism

The bracket is connected to the XZ Cartesian system with four 20 mm M4 screws. The mounting region of the bracket that is fastened to the XZ table is bent at a 90 degree angle. The Animatics SM 2315DT motor is also mounted onto this bracket. The motor has holes for screws on the bottom while the rotating shaft is on the opposite side. The motor is placed on its side so the shaft of the motor is available to mount the rotating base. Another region of the bracket is bent 90 degrees to provide a mounting position for the motor. The bracket has a third 90 degree bend, with a ¼'' hole located concentrically to the shaft. An axel made of Multipurpose Aluminum (Alloy 6061) is placed in the through hole and is mounted at a position to relieve the motor's shaft of most of the axial force. A counterweight is attached to the rotating base on the reverse side of the gripper. The counter weight will be mounted on the bottom of the base to allow for counter weight in both the horizontal and vertical positions. The bracket will be made out of a 12''x12''x1/8'' sheet of Multipurpose Aluminum (Alloy 6061).

The motor will be capable of rotating the shaft and rotating base in both the clockwise and counter clockwise position, while in the horizontal position the gripper will be able to place and retrieve blocks from the shelf. When the base rotates 90 degrees to the vertical position, the gripper will be able to either place or pick up pathology blocks from the translating bin. Located on the rotating base will be the THK VLA linear actuator, which will be mounted, using four 10 mm M3 screws, screwed into the bottom of the base into the actuator. The actuator will have a stroke length of 4.5 cm allowing the gripper to place and pick up blocks from either the shelf or transport bins. An Applied Robotics Smart Gripper 2.0 is mounted on the linear actuator. The Smart Gripper will provide the actual "gripping" of the gripper mechanism, procuring the blocks when in the closed position and releasing them when in the open position. The rotating base is made out of a 12''x 2''x 5/8'' sheet of Multipurpose Aluminum (Alloy 6061).

The linear guides are drawer slides made by Liberty. They are made of steel with ball bearings for a small coefficient of friction and a stroke length of 18”. A set of these drawer slides has a 100 lb capacity, more than sufficient for the maximum 10lb force of the drawer.

6.3 Subsystem: Shelf Design

The storage shelf will have a 600-block capacity and will be made entirely of aluminum and acrylic stock. It will serve as a buffer zone for the sorting of the blocks. The gripper will pick up a block from a storage bin full of unsorted blocks, scan it, then place it in an empty slot in the storage shelf, or it will take a block already placed in the storage shelf and place it in an empty drawer. The blocks will always be scanned before being placed into the storage shelf.

The outer frame of the shelf will be made from the acrylic and will be held together by aluminum L-brackets. There will be 600 individual compartments, and the compartmental grid of the shelf will be machined from 1/16” aluminum sheets.

We have purchased a tissue file case from Electron Microscopy Sciences that has a cardboard insert with 100 individual compartments. The insert can be taken apart into slotted strips of cardboard that are arranged vertically and horizontally to form the 100-compartment grid. This insert has been used to develop the CAD model shown in APPENDIX C – CAD MODELS AND ENGINEERING DRAWINGS, which will be used to machine the same shape out of the aluminum stock. In this way, a 600-block grid will be made from the aluminum, and press-fit into the acrylic frame. Acrylic was chosen for the frame of the shelf for the same reason as explained in Section 8.2 for the translating table.

6.4 Subsystem: Translating Platform Design

A translating table is located at the base of the XZ system and storage shelf. It translates linearly and perpendicular to the storage shelf, as can be seen in Figure 13. The translating table consists of five main components: 1) translating platform 2) inclined ramp 3) rack and pinion 4) motor and 5) linear guides. Detailed CAD models and drawing for each of these components are shown in APPENDIX C – CAD MODELS AND ENGINEERING DRAWINGS.

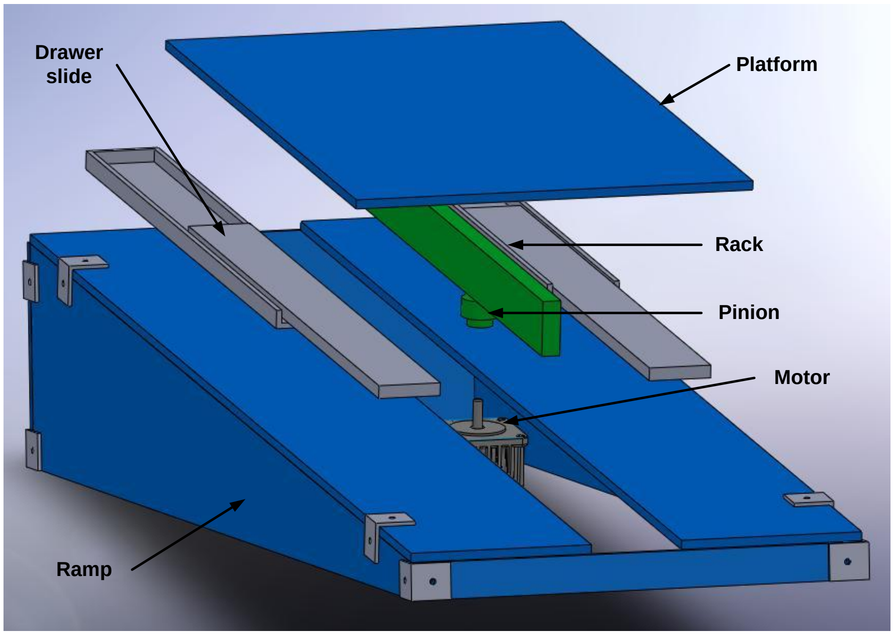

Figure 13: Linear translating table

The inclined ramp will also be made of six pieces of acrylic stock mounted together with aluminum brackets. The material choice for the inclined ramp follows the same analysis for the translating platform. Using the same material will increase aesthetic appeal, reduce cost and manufacturing time.

A rack and pinion made of C1018 steel with a face width of ½" will be used to create the linear motion of the platform. This face width and material will easily bear the maximum10 lb force of the drawer. The SM2315D motor created by Animatics will be used as to rotate the pinion. This motor has a continuous torque of 1.69 lb-in and therefore can be used to rotate the pinion.

7.0 PARAMATER ANALYSIS

This section describes the analysis for every engineering decision made for each subsystem, as well as an environmental analysis for our system.

7.1 Subsystem: XZ Cartesian System Analysis

XZ System

To create the XZ Cartesian system, we decided to purchase linear actuators from OEM Dynamics (www.oemdynamics.com). These linear actuators were chosen because of the competitive price and because they are designed specifically to work Animatics Smartmotors – the type of motor we were initially supplied with for this project. The major parameters we had to define for these linear actuators were the type of linear actuator, the stroke length, the number of support rails, and displacement per revolution. Figure 14 shows a concept drawing of what the layout of the XZ Cartesian system looks like. The x-axis is mounted to a rigid system frame and the z-axis mounts onto the carriage of the x-axis.

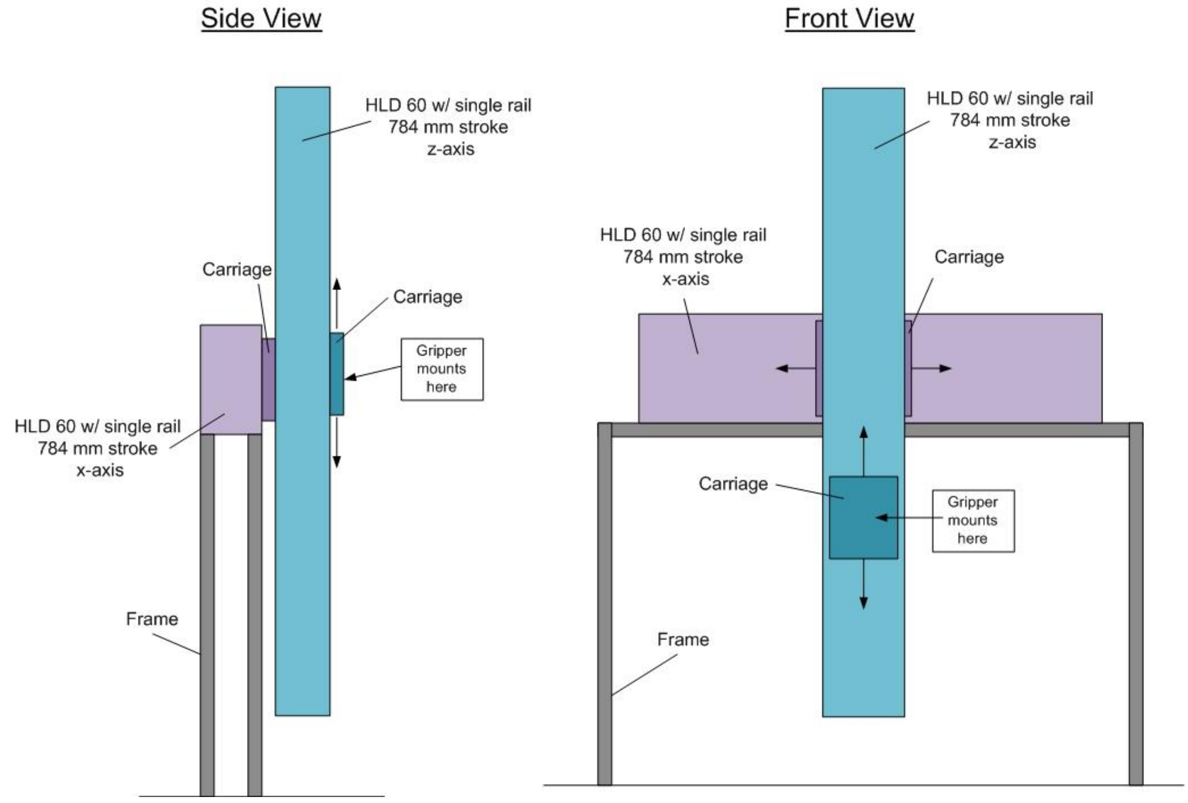

Figure 14: Concept drawing of XZ Cartesian system

OEM Dynamics manufactures several different lines of linear actuators, both ball screw driven and belt driven. Our first step was to select the type of linear actuator. The ball screw actuators were more expensive than belt drive ones, and had a maximum stroke length of only 700 mm. Our design required stroke lengths longer than this, so we had to consider belt driven actuators. We decided to go with OEM's Harmonic Linear Drive (HLD) line of belt driven actuators. The HLD linear actuators come in stroke lengths of up to 3.3 meters, and unlike most other belt drive systems, they are highly resistant to back-driving due to internal gear reduction within the actuator. According to an OEM Dynamics sales engineer, the HLD linear actuators can support a load of up to 70 lbf before back-driving. Additionally, the HLD line of linear actuators is one of OEM's lowest cost systems. Figure 15 shows one of these HLD linear actuators.

Figure 15: An HLD linear actuator from OEM Dynamics

The next step was to determine the stroke lengths of two linear actuators that will make up the XZ Cartesian systems. We calculated our desired stroke length of 800 mm based on the dimensions of the internal storage area and based on the requirement that the system should take up no more than approximately 1 linear meter of lab counter space. The total length of a linear actuator with 800 mm stroke is 1084 mm. This size fit within the approximate space constraint, and maximizes the size of the storage area the system is capable of interfacing with. However, these products typically have a lead time of 3-4 weeks. Because our project development time was limited, we wanted to order linear actuators with stroke lengths that would be easier for OEM to produce quickly and ship to us. Representatives from OEM told us stroke lengths of 784 mm would be the easiest for them to prepare in a short time. This stroke length is satisfactory to meet our space and dimensional constraints. So, each axis of the Cartesian system has a stroke length of 784 mm and a total length of 1068 mm.

The next step was to determine the number of support rails we wanted our actuators to have. The HLD liner actuators come with three different options for this: no rails (internal rollers only), single rail, or dual rail. We determined that the x-axis of the system should be a dual rail actuator and the z-axis should be a single rail actuator. The more rails an actuator has, the more capable the system is of supporting a greater loads and carriage moments. However, cost increases with the number of rails. An HLD linear actuator with 784 mm stroke length costs $2580 without any rails, $3275 with a single rail, and $3820 with dual rails. Figure 16 shows a moment and loading diagram for the actuators, and Table 2 shows the moment and load ratings for both dual and single rail actuators.

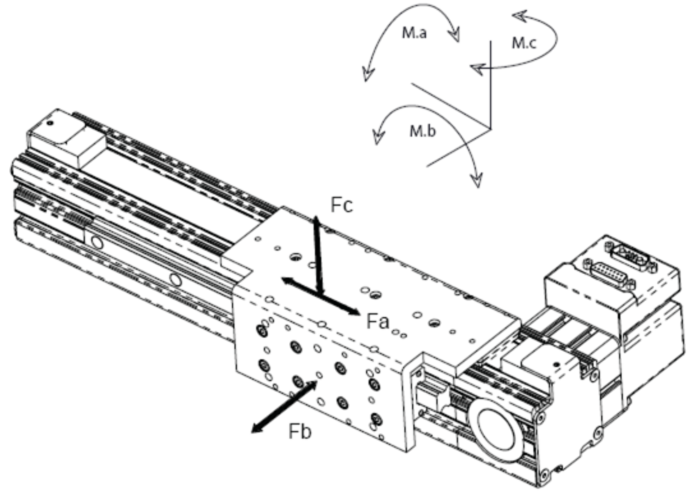

Figure 16: Force and moment diagram for HLD linear actuators

Table 2: Force and moment ratings for single and dual rail actuators

Spec.	Single rail, dynamic (static)	Dual rail, dynamic (static)	Unit
F_b	460 (1200)	3000 (3000)	N
F_c	460 (1200)	3000 (3000)	N
M_a	12 (24)	114 (200)	Nm
M_b	45 (200)	89 (200)	Nm
M_c	45 (150)	89 (200)	Nm

APPENDIX B- ENGINEERING ANALYSIS and CALCULATIONS shows the calculations we used to determine the actuator moment requirements. We assumed a maximum gripper mass of 9 kg and performed moment calculations to determine how far the gripper center of mass could be from the face of each carriage. We determined that the center of mass of a 9 kg gripper could be a maximum distance of 510 mm from the z-axis. This gives us plenty of room to tweak the design (both mass and length) of the gripper. If we had used a single rail actuator on the x-axis, this distance would have been 90 mm, which we decided did not give us enough flexibility in our gripper design.

We also had to verify that the chosen actuators would be able to support the load we were putting on them. The x-axis must support the mass of the z-axis and the mass of the gripper (6.8 kg + 9 kg = 15.81 kg, or 155 N). A dual rail actuator can support a load of 3000 N in this direction, so a dual rail actuator is more than capable of supporting the load. The z-axis must support the mass of the gripper (9 kg, or 88.29 N). A single rail actuator is capable of supplying a thrust of 185 N (determined by Figure 17), so a single rail actuator is more than capable of supporting its required load.

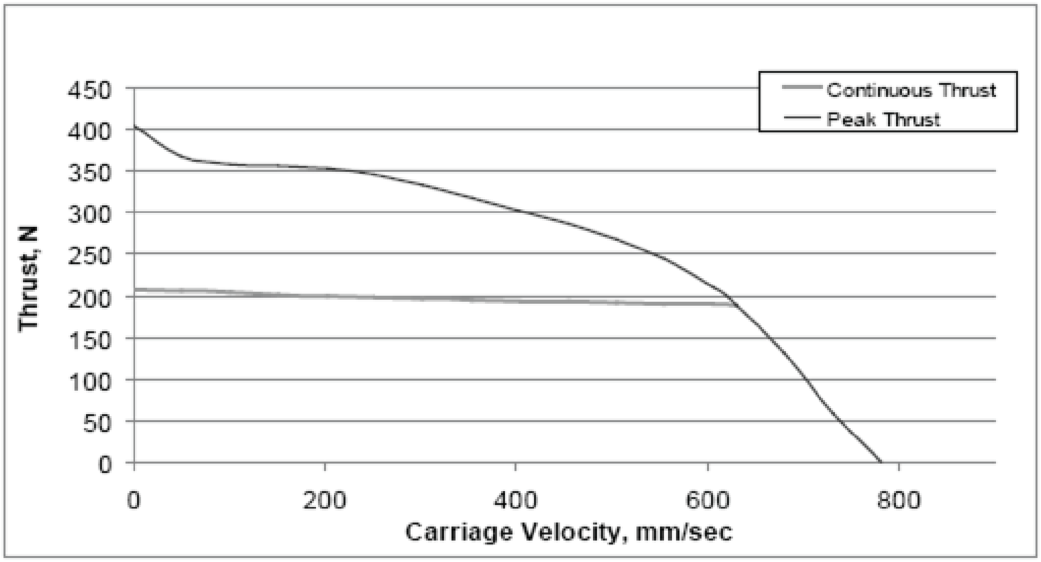

Figure 17: Thrust curve for single rail HLD at 10 mm/rev displacement

Finally, we had to determine the displacement per revolution of the linear actuators. The HLD linear actuators come with four different options for this: 2.5, 5, 10, and 12.5 mm/rev. The greater the displacement per revolution, the faster the system can move. However, as displacement per revolution increases, thrust and the payload mass limitation both decrease. For our linear actuators, we determined that a displacement of 10 mm/rev was preferred. This will allow the system to travel at a maximum speed of 700 mm/s while still providing 185 N of thrust.

To verify if our chosen displacement was sufficient, we calculated the cycle time of the XZ Cartesian system. We assumed a trapezoidal velocity profile, as shown in Figure 18, with one third of the time for acceleration, one third for constant velocity, and one third for deceleration. This means the average velocity is 2/3 of the travel velocity. If an actuator with this displacement is capable of traveling at up to 700 mm/s, we could set the desired travel velocity to 500 mm/s for a safety factor of 1.4. So the average velocity would be 333 mm/s. The average travel distance for one of these actuators will be half its stroke length, or 392 mm. Since both axes travel simultaneously, we can just calculate the cycle time of a single actuator. We obtain the average time of one-way travel to be 1.18 s. So, the average round-trip time for the XZ system will be 2.35 s. This time does not include the time required for other tasks, such as gripping, scanning, and placing blocks.

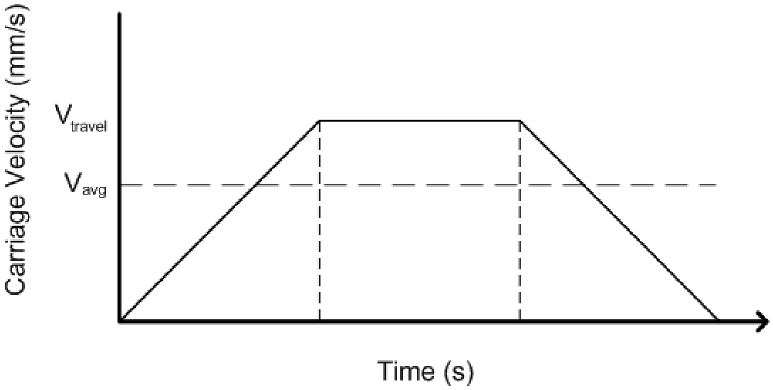

Figure 18: Trapezoidal velocity profile for linear actuators

This analysis was sufficient to allow us to order linear actuators for the Cartesian system that will meet system requirements. We have calculated the stroke, speed, loads, moments, times, and other parameters to determine how our system will behave. We believe we applied the appropriate level of analysis and can state with confidence that these actuators will satisfy the design requirements.

Design for Manufacturability

The XZ system is easy to assemble. The actuators can be purchased with custom t-slot mounting fixtures called toe clamps. A picture of these is shown in Figure 19. These toe clamps slide into the t-slot on the actuator. The hole pattern on these fixtures matches the hole pattern on the carriage of the actuators. This allows for the z-axis actuator to be mounted to the carriage of the x-axis actuator.

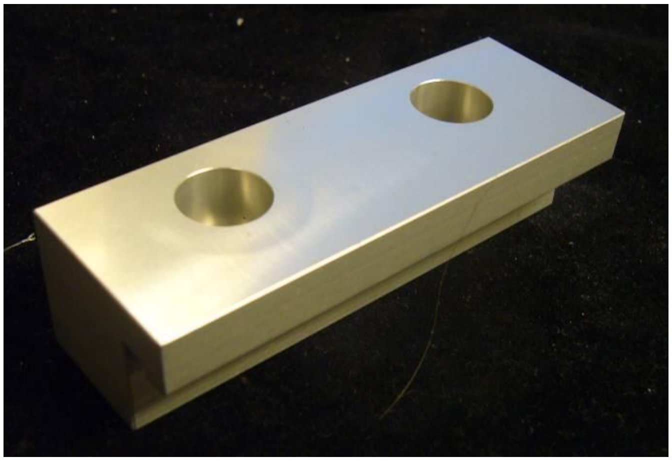

Figure 19: Toe clamp for mounting z-axis to carriage of x-axis

Failure and Safety

We have taken several actions to ensure that the system will remain safe in the event of failure or misuse. First of all, the actuators will have limit switches installed on them. These limit switches are sensors that will detect when the carriage of the actuator is getting near the end of its travel length and automatically stop movement if the carriage crosses a certain point. This ensures that the motor will not drive the carriage into the end of the actuator and possibly damage the system. Additionally, we have ordered all of our Animatics Smartmotors with the drive enable feature. This feature allows the controller and encoder to be powered separately from the motor. Thus, if the motor exceeds its current limit and trips out a power supply, the motor controller will not lose any data. This will allow the system to “remember” critical data so when the motors are powered back on they take the correct course of action.

Additionally, we have considered the possibility of failure by overloading the actuators. In the Parameter Analysis section, we determined that the actuators could support the load we are subjecting them to. The primary concern was whether or not the actuators could support the moment we would subject them to. We performed an analysis (see Section 7.0 and APPENDIX B- ENGINEERING ANALYSIS and CALCULATIONS) and determined that the actuators could handle the moment load if the gripper mass is no more than 9 kg and the gripper center of mass is no more than 585 mm from the face of the x-axis.

System Frame

A large rectangular frame surrounds the system and is used for mounting all subsystems. This system uses 1.5 x 1.5 in. “lite” t-slot aluminum extrusions for its frame; these are shown in Figure 20. We chose 1.5 in 2 extrusions over the less expensive 1 in 2 extrusions because of concerns about the ability of the 1 in 2 extrusions to support loads at lengths greater than 50 in. Our system uses 3 different lengths of t-slot extrusion: 40, 48, and 60 in. The system is 40 in. long internally because it needs to contain the translating table, which is 40 in. long. The system is 48 in. wide internally because it needs to contain the x-axis actuator, which is 42 in long. This gives an extra 3 inches on each side of the actuator to use as a safety buffer and to route cables and wires. The system is 60 in tall because it needs to contain a 42 in. actuator and be 12 in. off the ground to allow for the drawer to translate beneath it. At the time of the frame's design, the dimensions of the gripper remained uncertain. If the gripper were to be longer than expected, the actuator may have had to be mounted even higher off the ground. Thus, we designed the frame to be extra tall because the final gripper design was uncertain at the time.

Figure 20: T-slot aluminum extrusions for system frame

7.2 Subsystem: Gripper Analysis

The analysis for the components of this subsystem is summarized below and calculations can be found in Appendix E. Once deciding that our design would use all electrical powered components, each specific component specification was found and a final product was chosen. Due to the weight constraints of the XZ table (Section 10.1) the maximum mass of the design was found to be 11.2 kg. No force calculations were done for any screw fasteners due to the negligible force in relation to yield strength.

Gripping mechanism

The minimum grip strength required to carry a block is .232 newtons. The Smart Gripper has a maximum grip strength of 13.3 Newtons, as seen on the smart gripper data sheet in Appendix E. Calculations for the grip strength of the gripper can be found in Appendix E. The grip strength required is very small due to the light weight of the blocks, so most grippers met the required grip force.

Linear Actuator

The analysis of the THX VLA linear actuator is based off the datasheet in Appendix E. The maximum center of mass of the gripper at 9 kilograms was found to be over 500 millimeters based on moment analysis of the XZ table. As the final gripper mechanism has a maximum length of 280 millimeters, the stroke of the linear actuator does not matter. The linear actuator must also be able to handle the weight of the gripper, which was placed at a one kilogram maximum.

Motor analysis

A servomotor is needed to the gripper and actuator. An analysis of the amount of torque needed can be found in Appendix E. The torque depends on the forces needed to overcome the weight of the gripper, linear actuator, and platform for continuous torque. The continuous torque needed was found to be at least .32 Newton-meters. The Animatics SM 2316 DT has a maximum continuous torque of .4 Newton meters. Using the Animatics SM 2316 DT peak torque of .79 newton-meters as a bench mark the maximum angular velocity was calculated. The maximum angular momentum found is at 12.4 rad/s.

Bracket

The bracket is manufactured out of aluminum weighing only .15 kg and providing sufficient strength.

Design for manufacturability

The redesigned gripper mainly emphasized assembly as many of the components were purchased from third party sources. Fasteners and U-Bolts were used for easy mounting that can be assembled and disassembled easily. The manufacturing and fabrication involved in our gripper was minimal as the band saw and drill press. Since our gripper is one-of-a-kind, each reproduction of the gripper will have to be redesigned to fit the specific application.

Failure and Safety

The principle failure modes for the gripper are the risk of the gripper being disconnected from the XZ table and the risk of dropping the blocks. To reduce the risk of the gripper being disconnected from the XZ table, 3 ¼-20 bolts were used to secure the gripper to the XZ table. Due to the relatively low weight of the gripper three 1/4-20 bolts ensure a high safety factor. The risk of blocks being dropped was addressed by finding a gripper with sufficient gripping force. The current gripper has a factor of safety of 4 which was determined experimentally. In the occurrence of a power outage the gripper is secured into place and will maintain the gripping force, even with no power supplied.

7.3 Subsystem: Shelf Analysis

The design parameter analysis for the storage shelf is summarized in the sections below. The dimensions of the frame and the compartments were chosen based on the tissue file case purchased from Electron Microscopy Sciences. We decided not to use the inserts that came with the cases themselves because they were made of cardboard, a material not rigid enough for our application. Also, since minimal forces will be exerted on the frame and the compartments, no stress analysis was done on it.

Compartment dimensions

The storage shelf will accommodate 600 blocks, each block having its own compartment. The compartments must be large enough to hold one block with additional room for the end-defector of the gripper to extend inside the compartment and grab the block. The blocks are each 1.125” wide, 1.75” length, and have variable thickness, with the maximum thickness being 0.5”. The compartments in the tissue file cases we have purchased have dimensions 1.5”x 1” x 2.25” (width x height x depth), which allows enough space for one block. To make room for the gripper, we have increased the width of the compartments to 1.8”.

Frame material and dimension analysis

The frame for the storage shelf will consist of ¼” acrylic sheets, 1/16” thick aluminum L-brackets and steel fasteners. The dimensions that need to be determined for the frame are the height, width, and depth. Since the shelf will be designed to accommodate 600 blocks, each with their own compartment, the dimensions of the frame will depend on the dimensions of each individual compartment. The arrangement of the compartments will be in 20 columns and 30 rows. This means that both the height and the width of the frame must be at least 30 inches. The height of the frame must also include a clearance for the translating table to be placed beneath it. This clearance was chosen at 10 inches, because it accommodates the height of the translating table plus the height of a transport bin or storage drawer. The thickness of the aluminum sheets used to make the individual compartments will also add to the height and width of the frame. The aluminum sheets have a thickness of 1/4”. Based on these constraints, the height of the frame was chosen to be 43 inches, the width 32 inches, and the depth 2.25 inches.

Acrylic was chosen for the frame instead of any other plastic, metal, or wood because it was readily available, the least expensive, and aesthetically pleasing. Aluminum brackets were chosen to connect the pieces for the frame because it is one of the lightest metals and has a yield strength of about 7-11 MPa [2], which is strong enough to support the load of the frame. Aluminum was also chosen for the compartments for the same reason, and because it is strong enough to support the load of the blocks. All materials for the storage shelf were purchased at Home Depot in Ann Arbor because they were easily accessible there and reduced the overall manufacturing time, which would not be possible if we had ordered the materials from a supplier. A complete bill of materials for the storage shelf can be seen in APPENDIX E- BILL OF MATERIALS.

Design for manufacturability

As explained in the previous section, we purchased the materials for the storage shelf as they were easily accessible and reduced the total lead time in acquiring all materials for each subsystem. The materials used for the storage shelf are easily machined because neither the acrylic nor the aluminum exceeded a thickness of ¼“.

Since the whole sorting system is not designed to be mass produced, the storage shelf is also designed to be a customized, proof-of-concept prototype. Therefore, once the storage shelf has been manufactured, it is not intended to be disassembled and reassembled afterwards.

Failure and safety

The principle failure modes that we are concerned with for the storage shelf are the possibility of the shelf tipping over or collapsing under the load of the blocks. Since the yield strength of the aluminum and acrylic are high enough to withstand the load of 600 blocks, collapsing under their load is not an issue. However, since the shelf is high but not very deep, there is a chance it can become top-heavy and tip over. To address this issue, we have designed the shelf to be rigidly fixed to the ground so that it cannot tip over.

The prototype is expected to last at least several years, since it is not expected to be removed from the pathology lab or disassembled once it has been manufactured.

7.4 Subsystem: Translating Platform Analysis

The analysis for the components of this subsystem is summarized below, and calculations can be found in APPENDIX B- ENGINEERING ANALYSIS and CALCULATIONS. After deciding on the linear motion system of a rack and pinion the placement of the rack on the platform was analyzed. Placement of the rack on the center axis of the platform along the line of motion minimizes the torque applied on the linear guides.

Translating platform material and size analysis

The translating platform needs to be created from a light weight material with moderate compressive yield strength since it needs to bear the weight of a full transport bin or drawer which will not exceed 10 lbs. The drawer has a base of 9”x16”. Therefore the platform dimensions will be 11”x18”x1/4” to allow for tolerance and placement guides for the base of the bin and drawer.

The translating platform material is acrylic. Several materials were considered including plastics such as Delrin® or PVC, wood and acrylic. Since all of these materials can be easily manufactured into an 11”x18”x1/4” platform and can withstand a weight of 10lbs, other factors such as lead time and aesthetic appeal were considered. To order plastic Delrin® stock from an online vendor there is a lead time of a one to two weeks and costs more than $50 per ¼”thick square foot. Wood was also considered as a cheaper alternative but the finishing, sanding and painting is additional manufacturing time. Acrylic was finally chosen as it has a compression yield strength of 5300 - 18000 psi [1], can be bought at a local vendor thus no lead time and costs around $4 per ¼” thick square foot.

Inclined ramp angle analysis

The inclination angle for the ramp is based on a moment analysis (APPENDIX B- ENGINEERING ANALYSIS and CALCULATIONS) of the blocks. The translating platform needs to be at a slight angle to ensure that the blocks stay vertical when the drawer is accelerating up and down the ramp. An angle of 10° was found to be sufficient for the low acceleration speeds of the drawer.

Linear motion system analysis

Several types of linear motion systems were considered. A rack and pinion was chosen as the most cost effective system for this application. A pneumatic actuator is undesirable because of its noisiness and lack of supplied air in the pathology lab. A linear actuator with an attached servomotor, similar to that of the XZ Cartesian system has very high precision which unnecessary for this motion and has a significant cost increase.

Motor analysis

A servomotor is needed to rotate the pinion. An analysis of the amount of torque needed can be found in APPENDIX B- ENGINEERING ANALYSIS and CALCULATIONS. The torque depends on the forces needed to overcome the weight of the platform and drawer and the friction forces of the linear slides.

Linear guide analysis

Linear guides are needed to reduce the coefficient of friction between the platform and ramp which will minimize the torque needed by the motor. The analysis for this coefficient of friction can be seen in APPENDIX B- ENGINEERING ANALYSIS and CALCULATIONS. The platform is 18” and needs to move the full 18” therefore the linear guides must have a stroke length of 18”.

Design for manufacturability

The translating platform can be easily manufactured using a band saw, lathe, mill and drill press. The materials can all be purchased at a local hardware store except for the motor, rack and pinion. By using consistently the same size bolt holes for all brackets and attachments (for drawer slides) this eases the assembly process.

Failure and safety

The main failure mode for the translating platform subsystem is the pinion and rack becoming misaligned. If the rack and pinion do not function then the platform will not translate, thus the drawer or transport bin cannot move. Another failure is the possibility of the motor's power being shut off. This would result in the shaft being able to move freely and the platform would be pulled down by gravity and would fall to its bottom most position. This has few consequences, though, because of the small inclination angle allows the platform to move downwards at a slow rate. Safety is an issue because of the sharp edges of the acrylic. The motor, pinion and rack are enclosed in the ramp therefore reducing the danger of the moving parts.

7.5 Design for the environment

The design has a minimal environmental impact, and many of the materials chosen have a lower carbon footprint than the alternatives. The first materials compared were Aluminum (6060) which was used for many of the structural components of our design to Stainless steel. Aluminum has a lower Eco-Score of 2.91pt compared to the stainless steel Eco-Score of 3.24 pt. This is seen in APPENDIX E – DESIGN FOR THE ENVIRONMENT. The second material compared was the PlexiGlass used on the shelving unit and ramp. This was compared to polycarbonate. As seen in Appendix E, the PlexiGlass received an

Eco-Score of 234 mpt while the polycarbonate received an Eco-Score of 296 mpt. Since the rest of our components could not be replaced using different materials, no further environment analysis was done.

8.0 FINAL DESIGN

This section outlines our final design and the major changes between this design and our manufactured prototype. Our finished prototype is shown in the figure below.

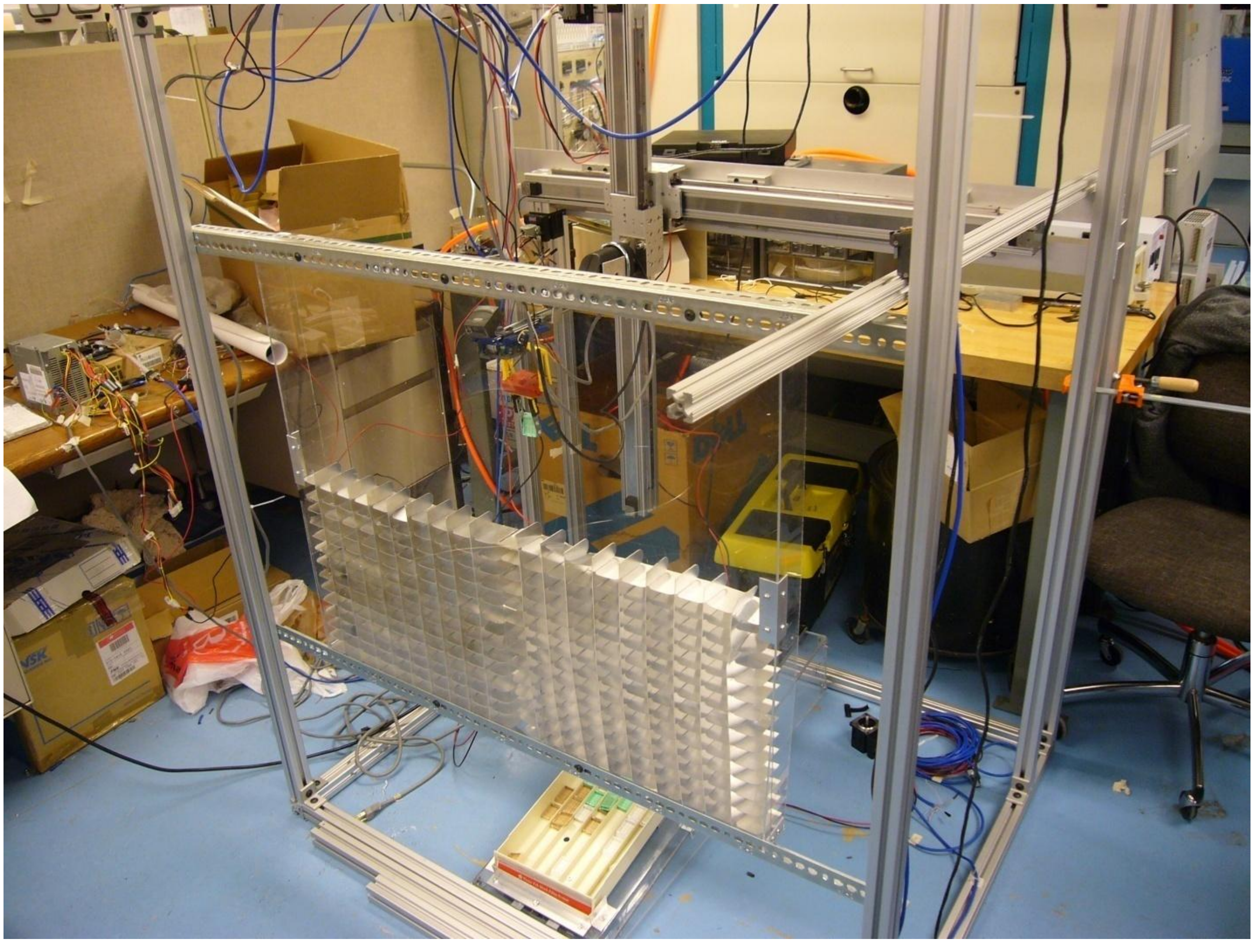

Figure 21: Final design

8.1 Subsystem: XZ Cartesian System Design

XZ System

Figure 22 shows a model of the final design for the XZ Cartesian system. The x-axis is mounted to a rigid frame, and the z-axis is mounted to the carriage of the x-axis. The z-axis will be moved horizontally by the x-axis. The z-axis's carriage will move vertically and will carry the gripper mechanism. This allows the gripper to be navigated to any XZ coordinate specified.

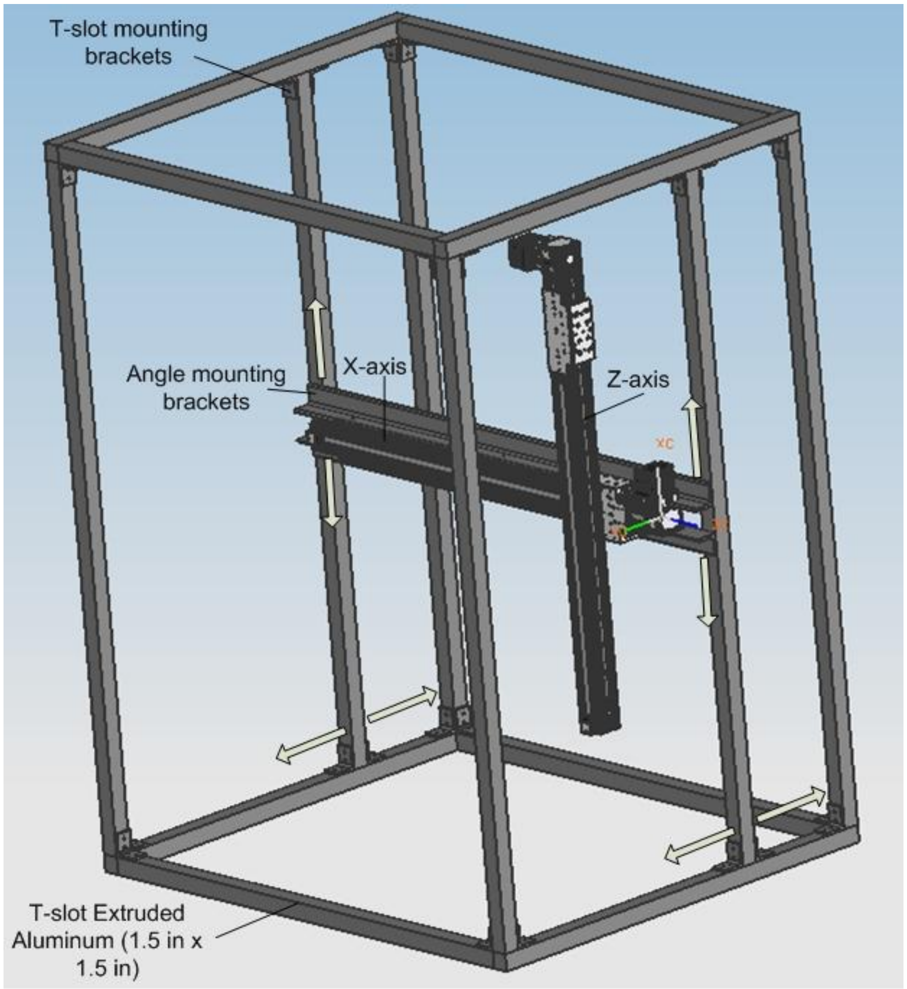

Figure 22: The XZ Cartesian system mounted in the system frame

Toe clamps will be used to attach the x-axis to the rigid system frame, as shown in Figure 23. The base of the linear actuators is made out of t-slot aluminum. The toe clamps will slide into these t-slots allowing the actuator to be held securely in place. The toe clamps will fasten to one of two pieces of angle aluminum bracket. These pieces of angle aluminum connect to the system frame, as shown in Figure 23.

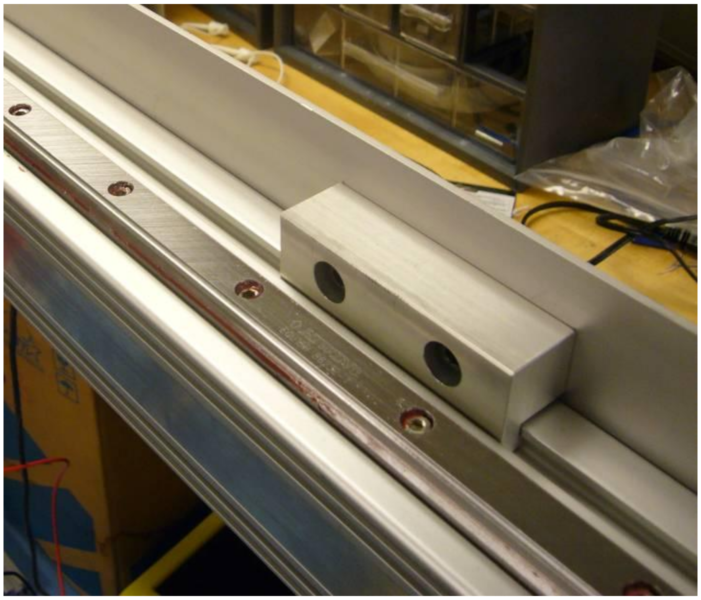

Figure 23: Toe clamps attach the x-axis to the system frame via two aluminum angle brackets

Toe clamps are also used to attach the z-axis to the carriage of the x-axis, as shown in Figure 24. The base of the linear actuators is made out of t-slot aluminum. The toe clamps will slide into these t-slots allowing the actuator to be fastened in place. The hole pattern in the toe clamps matches the hole pattern on the carriage of the x-axis. This allows for the toe clamps to be fastened directly to the carriage of the x-axis with no custom machining required.

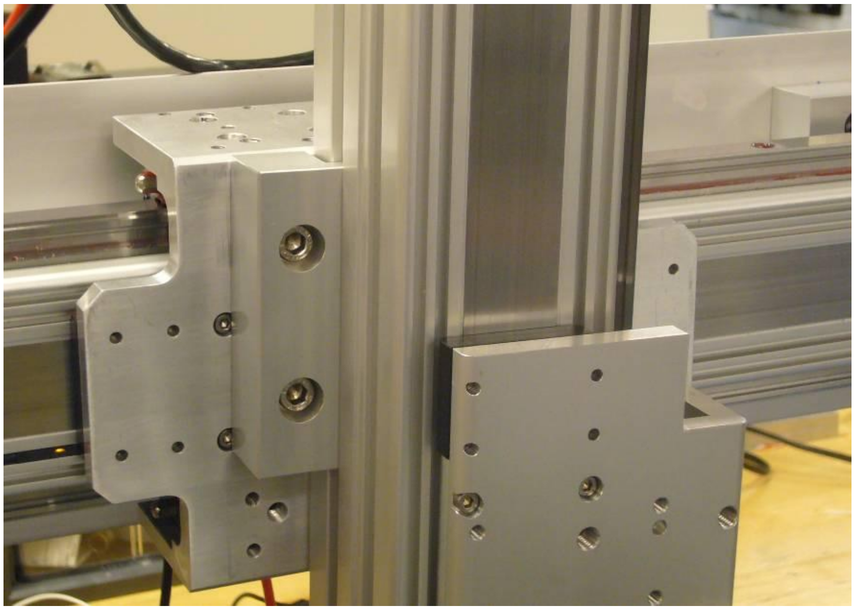

Figure 24: Toe clamps connect the z-axis to the frame of the x-axis

The Animatics Smartmotors used in this design receive commands via a computer's RS-232 port. By specifying a position, velocity, and acceleration for each motor and echoing those values to the computer's serial (RS-232) port, the motor can be completely controlled. The Animatics Smartmotors in the XZ Cartesian system, along with the Smartmotor for the translating table, are daisy chained together allowing them to connect to a single serial port. A wiring diagram for the daisy chain is shown in

APPENDIX C – CAD MODELS AND ENGINEERING DRAWINGS. This diagram describes how the the power and signal wires to each motor in the daisy chain.

System Frame

The system frame is a rectangular structure with outer dimensions of 40 × 51 × 63 in and internal dimensions of 37 × 48 × 60 in. The system frame has two vertical beams that support the aluminum angle brackets that mount the actuators. These were included in the design because, at the time of the frame's design, the dimensions of the gripper were not finalized. Thus, the distance the Cartesian system had to be mounted from the frame was unknown. These brackets can be translated within the frame, as shown in Figure 25, by simply loosening the fasteners and sliding the beams forward or back. This allows the Cartesian system to be placed the correct distance from the storage shelf.

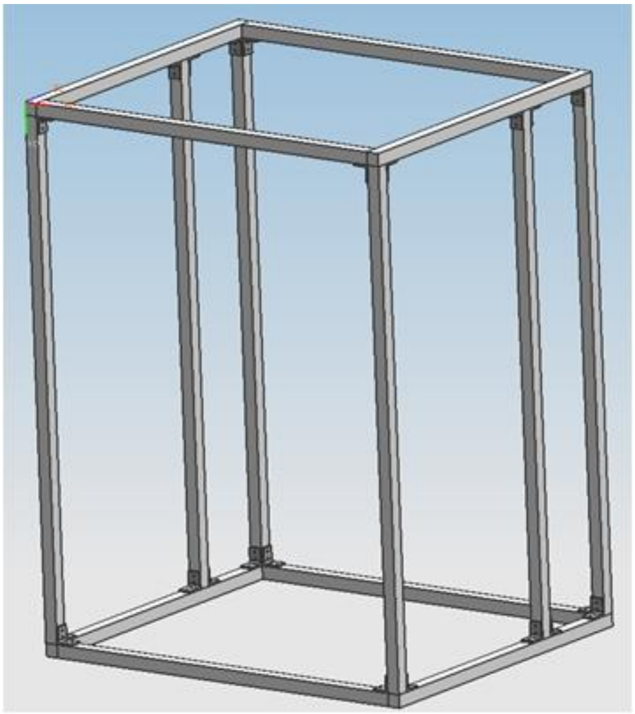

Figure 25: CAD model of system frame

8.2 Subsystem: Gripper Design

Many changes were made to the gripper between DR 3 and the prototype design. These include a change in the final linear actuator chosen, a change in the final gripper chosen, and a redesign of the rotating function of the gripper, a redesign of the final bracket and the addition of a slider for structural integrity. These changes are detailed in Section 12.0.

8.3 Subsystem: Shelf design

The storage should have a 600-block capacity and will be made entirely of aluminum and acrylic stock. It will serve as a buffer zone for the sorting of the blocks. The gripper will pick up a block from a storage bin full of unsorted blocks, scan it, then place it in an empty slot in the storage shelf, or it will take a block already placed in the storage shelf and place it in an empty drawer. The blocks will always be scanned before being placed into the storage shelf.

The outer frame of the shelf will be made from the acrylic and will be held together by aluminum L-brackets, as shown in Figure 26. There should be 600 individual compartments, and the compartmental grid of the shelf will be machined from 1/16" aluminum sheets.

We have purchased a tissue file case from Electron Microscopy Sciences that has a cardboard insert with 100 individual compartments. The insert can be taken apart into slotted strips of cardboard that are arranged vertically and horizontally to form the 100-compartment grid. This insert has been used to develop the drawings shown in Figure 42 and Figure 43, which will be used to machine the same shape out of the aluminum stock. In this way, a 600-block grid will be made from the aluminum, and press-fit into the acrylic frame. Acrylic was chosen for the frame of the shelf for the same reason as explained in Section 8.2 for the translating table.

A 3D model and 2D drawings for the storage shelf are shown below. Our final prototype is shown in Figure 26 while the original design is shown in Figure 26. While the shelf should have a 600-block capacity, our prototype only has a 300-block capacity. This is because we did not have enough time or resources to machine enough of the aluminum grid that formed all 600 compartments. Also, instead of being rigidly fixed to the ground, the shelf has been mounted to the aluminum frame that surrounds the entire system, using steel angle brackets. The reason for mounting the shelf to the frame using steel angle brackets is that it made the system more mechanically sound, while allowing the shelf to be adjusted in height. To adjust the height, the user can simply loosen the fasteners for the t-slot aluminum and slide the shelf up or down before tightening the fasteners again. The fasteners for the t-slot aluminum are placed through the holes shown in the horizontal steel brackets shown in Figure 27.

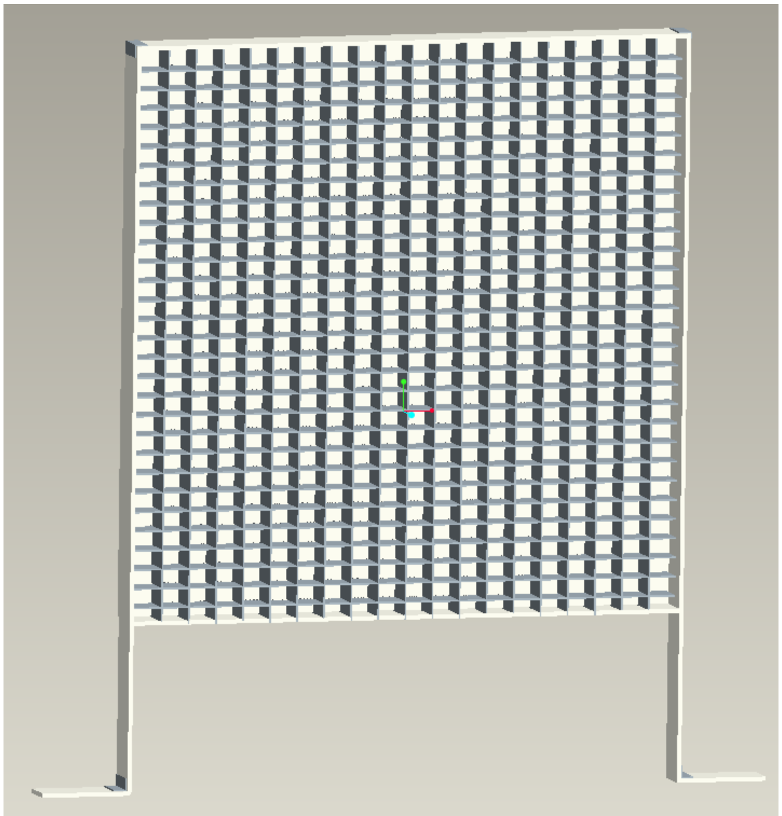

Figure 26: CAD model for final design of storage shelf

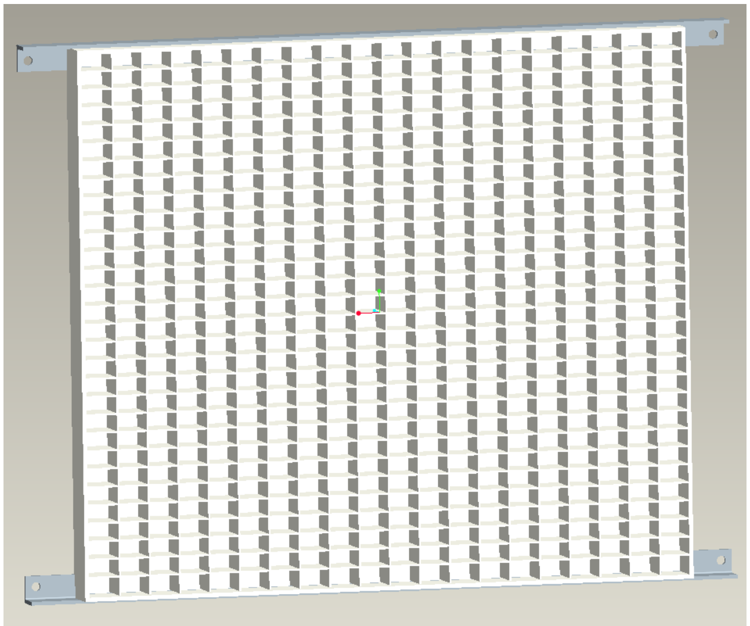

Figure 27: CAD model of prototype for storage shelf

To validate our assumptions about the strength of the materials, we purchased extra aluminum and acrylic stock and fabricated a miniature grid. We made sure the compartments were large enough to fit the end defectors of the gripper, and then fabricated the full size prototype shown above.

8.4 Subsystem: Translating Platform

The final design, (Figure 28) for the translating platform differed very little from the concept design. The only changes made were the addition of a few brackets and drawer guides, the attachment of the motor ramp to the ramp (Figure 29), and modification to the assembly of the pinion and motor shaft. These changes are discussed in detail in Section 12.0.

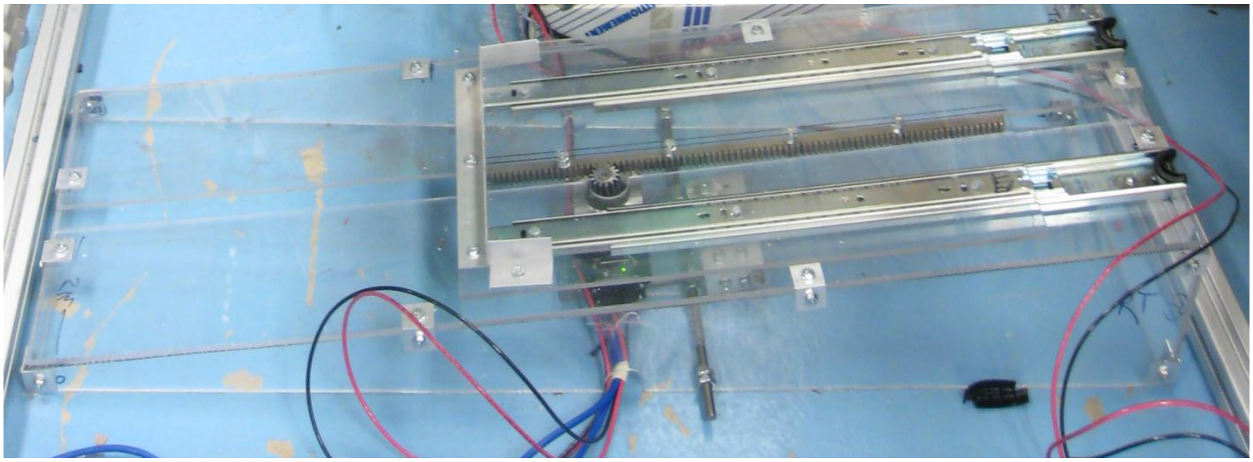

Figure 28: Final Design of Translating Platform

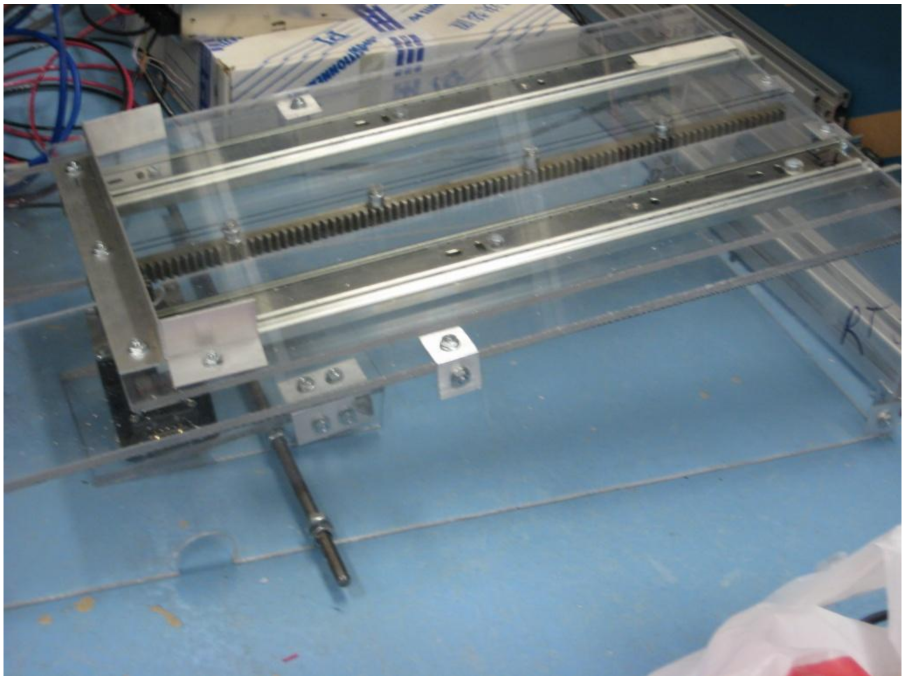
Figure 29: Motor Ramp and Ramp connection

9.0 MANUFACTURING PLAN

9.1 Subsystem: XZ Cartesian System Plan

XZ system

The XZ subsystem requires very little manufacturing. Two angle aluminum brackets (each 48 in. long, 0.125 in. thick, 1.5 in. wide) connect the x-axis to the frame. The toe clamps attach to the x-axis and are bolted through the aluminum angle bracket. Thus, the hole pattern on the aluminum angle brackets matches the hole pattern of the toe clamps. A total of 6 toe clamps are used to attach the x-axis to the aluminum angle brackets, 3 on the top bracket and 3 on the bottom. This means that each bracket has 6 holes drilled in it (because each toe clamp has two mounting holes.) A drawing of these brackets and their hole pattern is shown in. To drill the holes in these brackets, a drill press with a standard F size APPENDIX B- ENGINEERING ANALYSIS and CALCULATIONS (0.257 in.) drill bit is required. These holes will accommodate ¼-20 fasteners used for fastening the toe clamps to the brackets. Only an Allen Wrench, ¼-20 lock nuts, and a wrench are required to assemble the angle brackets to the actuator. A picture of the brackets is shown in Figure 30.

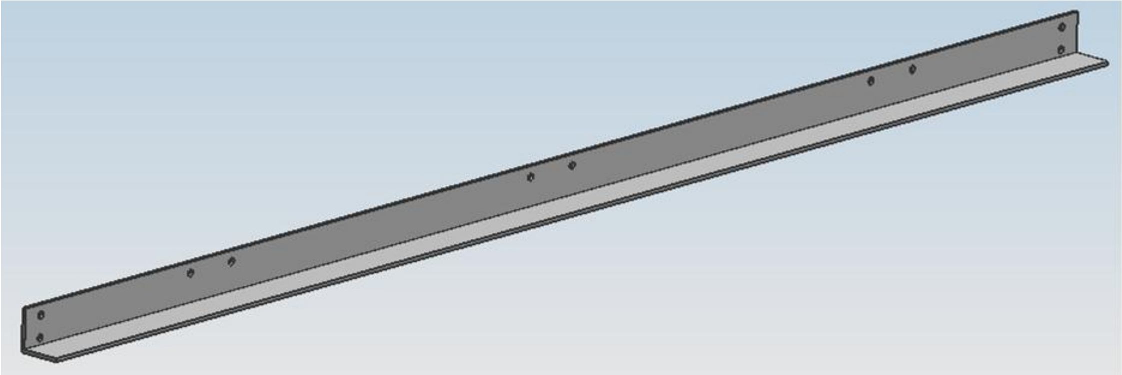

Figure 30: Angle bracket for mounting x-axis actuator to frame

System Frame

Table 3 summarizes the parts required to assemble the system frame. The slot aluminum extrusions are connected to each other using the mounting brackets shown in Figure 31. The extruded aluminum, mounting brackets, t-nuts, and fasteners were all supplied by T-slots supplier HH Barnum Co. The extruded aluminum is cut to the proper lengths using a horizontal band saw. To assemble the pieces together, all that is required is an Allen wrench. The corners of the system frame should appear as shown in Figure 32.

Table 3: Parts required for system frame

Part	Quantity
Extruded aluminum beam, 60 in.	6
Extruded aluminum beam, 48 in.	4
Extruded aluminum beam, 40 in.	4
Mounting bracket	24
Economy t-nut	48
Fastener: 5/16-18 x 5/8"	48

Figure 31: T-slot mounting brackets for system frame

Figure 32: Corner interface of the system frame

9.2 Subsystem: Gripper Plan

Changes in the fabrication and assembly were extensive due to significant changes from the final design to the prototype gripper. These changes include the fabrication of the bracket, modifications made to the slider, modifications made to the Rokenbok RC TransGripper, mounting of the gripper to the slider, mounting the linear actuator to the bracket, and connecting the linear actuator to the slider.

Initially the bracket was going to be milled using a CNC machine, with a 1/4’’ drill bit. After the redesign of the bracket this was unnecessary, as many of the complex features of the bracket were taken out. Instead the bracket was cut from a 12’’ x 12’’ x 1/8’’ sheet of multi-purpose aluminum using a band saw at 300 RPM. Once the general shape of the bracket was cut from the plate, the aluminum was annealed at 475 degrees Celsius to prevent fracture during bending. Then, the aluminum was bent at into two angles at a little less than 90^o. From here the bracket was bent into a complete right angle using a ball pin hammer and an anvil. This was done by aligning one face of the bracket on the side of the anvil and hitting close to the corner of the right angle with the hammer. Once bent, the face that was hit with the hammer was placed in a vice to flatten the face out. This was done for both right angles. Three holes to mount the bracket to the XZ table were made using a 1/4’’ drill bit and a drill press. A 1/8’’ hole to mount the slider was also made using a 1/8’’ drill bit and a drill press.

Modifications to the slider include removing the first stage of the slider, shortening stages two and three, and drilling holes to mount the slider to the bracket, the gripper to the slider, and the L-bracket that leads to the linear actuator. To remove the first stage of the slider, the first stage was placed on top of a vice in such a way that the walls of the slider would catch on the vice and deform allowing stages two and three to fall out. A diagram of this process can be seen in Figure 33.

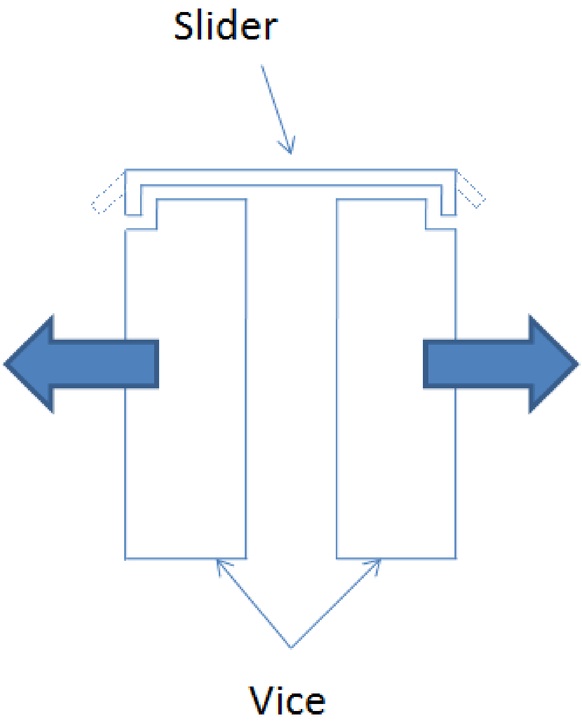

Figure 33: Diagram of slider modifications

Stages two and three were longer than required for our gripper, so they were shortened to save space using a band saw at 100 RPM. All three holes were drilled at 1/8'' diameter using a drill press to ensure accuracy located at the center of the slider. One hole was made to mount the gripper to the slider 6.5 cm from the end of the third stage of the slider. One to mount the L-bracket that connects the slider to the linear actuator was drilled 9 cm from the end of the third stage of the slider. The final hole to connect the slider to the bracket was drilled on the second stage of the gripper 3 cm from the opposite end that the gripper is closest to. Locations of the holes can be seen in Figure 34.

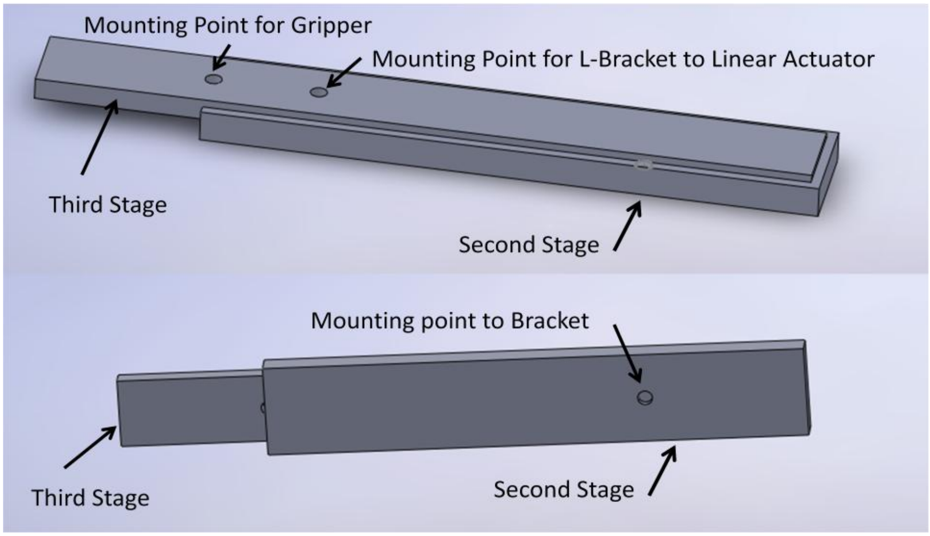

Figure 34: Mounting for linear actuator

The L-bracket was manufactured by cutting a one inch piece from 2’’ angled aluminum. A 1/8’’ hole was then drilled in the center of one face to mount to the slider with nuts and bolts. Another ¼’’ hole was drilled on the other face to mount to the linear actuator as seen in Figure 35.

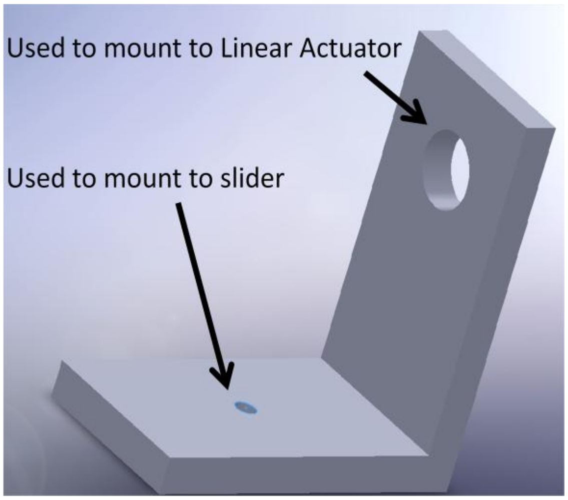

Figure 35: L-Bracket for Gripper

To modify the Rokenbok RC TransGripper for the final design, the bottom wheel portion of the gripper was removed, along with the encasing covering the DC motor and wires. The circuit board to control the Rokenbok RC TransGripper was removed. Limit switches were mounted on the body of the TransGripper using cyanoacrylate (super glue). A 1/8’’ hole was drilled through the gripper using a hand drill to mount the gripper to the slider. This was drilled at 2 ½ in. from the opposite end of the gripping mechanism and 1 3/8 in. from the side of our gripper. End defectors for the gripper are manufactured by cutting a ½’’ x 3’’ rectangle from 1/8’’ aluminum plate. This is then attached with cyanoacrylate to the gripper fingers, to extend the reach. The end defectors can be seen in Figure 36.

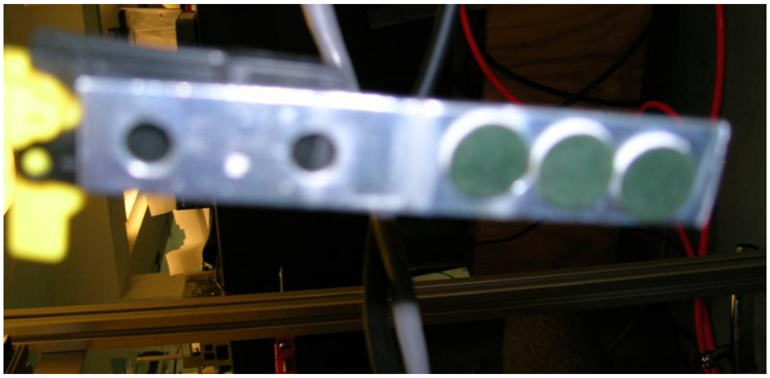

Figure 36: End defectors for gripper

For assembly the slide was attached to the bracket, L-Bracket, and gripper to the slider with 6-32 rounded machine screws. The slider was mounted to the bracket upside down, and the gripper was mounted to the slider upside down. The linear actuator was attached to the bracket using a 5/16" x 2.5" x 5.19" U-Bolt and a 3/8" x 3" x 6" Sq. U-Bolt. The metal bracket that attaches both sides of the U-bolt is also used to hold the slider in place. This can be seen in Figure 38. The linear actuator is attached to the L-bracket by a ¼’’ threaded lamp post pipe. Locknuts are placed at both sides of the actuator and back side of the L-Bracket. This configuration can be seen in

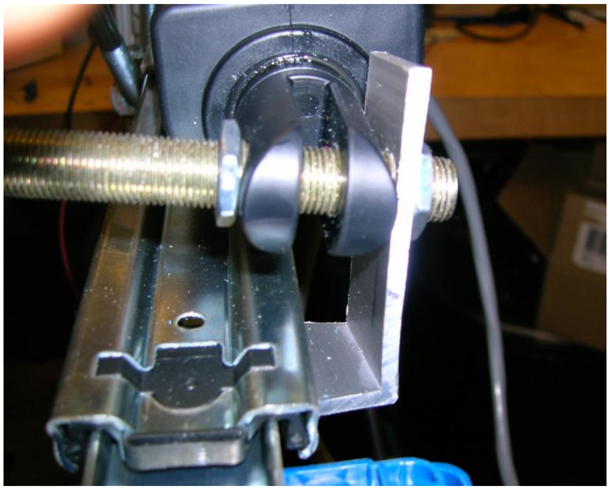

Figure 37: U-bolt configuration (front view)

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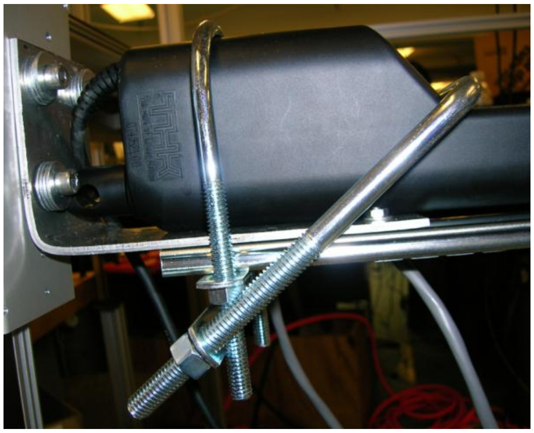

Figure 38: U-bolt configuration (side view)

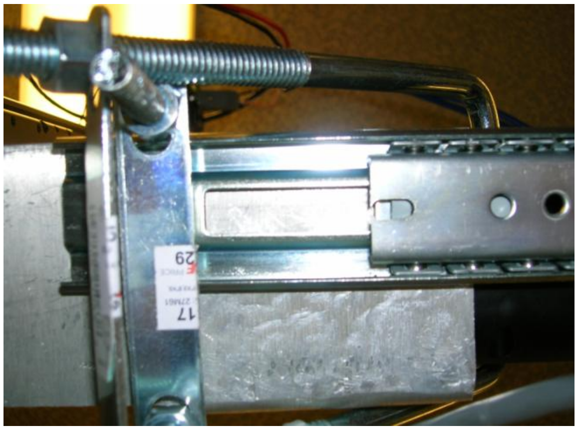

Figure 39: U-bolt configuration (bottom view)

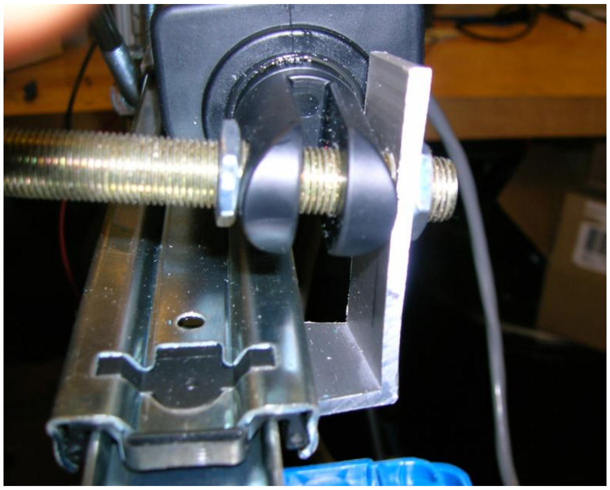

Figure 40: Fastening of linear actuator to slider

Wiring for the gripper can be seen in APPENDIX C – CAD MODELS AND ENGINEERING DRAWINGS.

9.3 Subsystem: Shelf Plan

The processes used to build the storage shelf will are drilling, sawing, and cutting. The materials used are 0.02” thick aluminum stock, 0.118” acrylic stock, aluminum L-brackets and steel fasteners. First, the acrylic stock is cut into five pieces using a band saw: back piece measuring 36”x30.5”, two side pieces measuring 30.5”x2.25” and two pieces for the top and bottom measuring 36”x2.25”. Next, the aluminum L-brackets are cut into four 2” pieces and four 3” pieces also using a band saw. A drill press with a number 19 standard drill bit is used to machine 4 clearance holes for the bolts in each L-bracket. On the 2” brackets, the holes are spaced 0.6” apart and 0.6” from either edge. On the 3” brackets, 4 clearance holes are drilled 1” apart from each other and from each edge. A model of one of these brackets is shown in Figure 41. Corresponding clearance holes are then drilled into the acrylic pieces. These cut brackets and acrylic pieces are then fixed together using #8-32, ¼” bolts and corresponding washers and nuts.

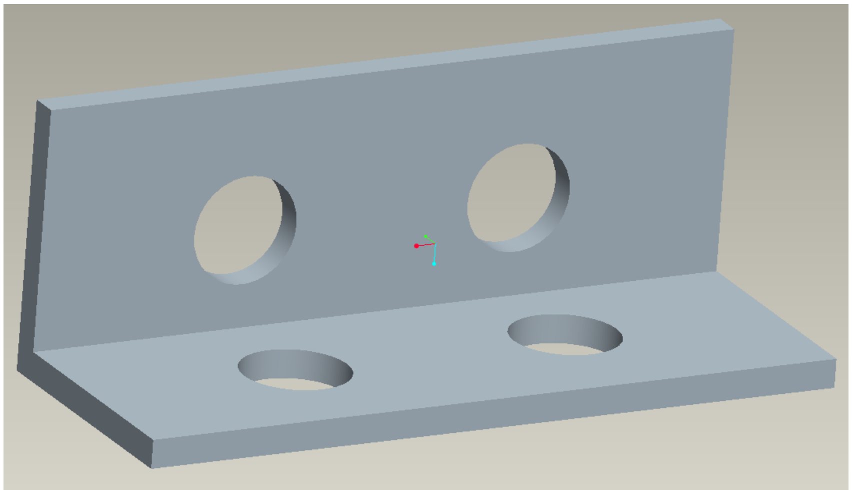

Figure 41: Aluminum L-bracket used to join acrylic frame

Next, for the aluminum grid forming individual compartments for the blocks, the aluminum stock is cut into 19 strips measuring 2.25”x15”, and 29 strips measuring 2.25”x18”, shown in Figure 42and Figure 43below. The strips are cut using a water jet cutter. These strips have slits in them so that they can be fitted together to form the grid shown in Figure 44.

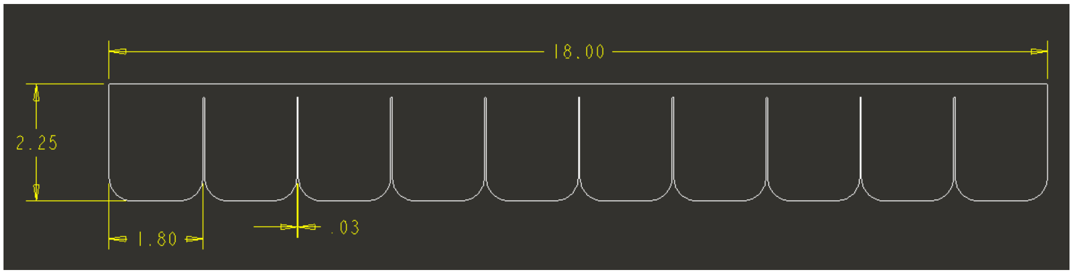

Figure 42: 2D dimensioned drawing of horizontal aluminum strip

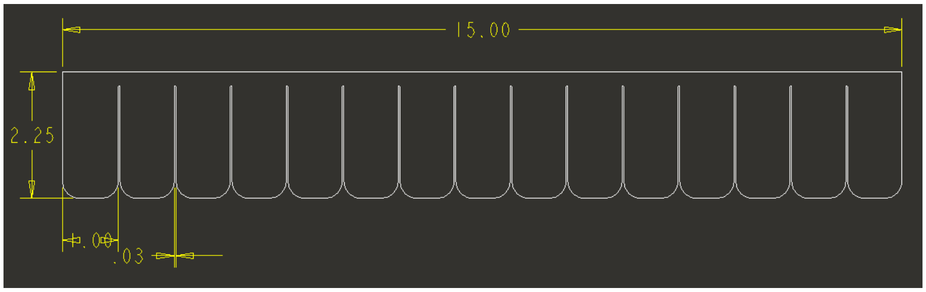

Figure 43: 2D dimensioned drawing of vertical aluminum strip

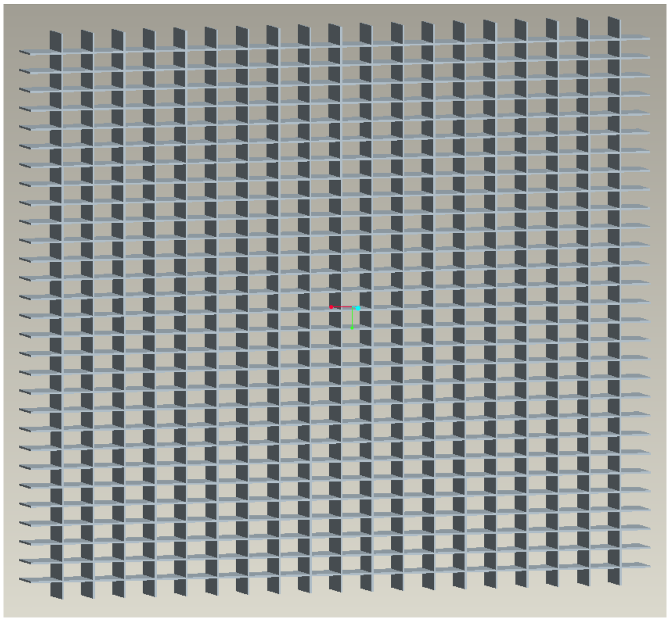

Figure 44: Aluminum grid used for individual block storage

The tools used to build the storage shelf will be a drill press, a band saw, and a water jet cutter. The drill press will be used to drill holes in the acrylic L-brackets so that the fasteners can fit through them. The band saw will be used to cut the acrylic into strips, and the water jet cutter will be used to cut out the aluminum inserts from the stock.

We planned to assemble the storage shelf in the following steps. First, after all the holes for the fasteners have been drilled, the side panels, top and bottom panels, and back panels of the acrylic frame will be fastened together by placing the aluminum L-brackets along each edge and placing the steel fasteners through them. The fasteners will be tightened using a wrench. Then, once the aluminum grid for the individual block compartments has been machined, we will place the grid into the acrylic frame. The acrylic frame will have a small enough tolerance such that the aluminum grid can be press-fit into the frame. Finally, the acrylic frame with the aluminum grid will be bolted to the counter or floor in our testing lab.

The manufacturing plan for our final design described above was followed for our prototype except for minor changes. Instead of using the drill press for drilling holes in the acrylic, we used a hand drill in order to prevent spider-cracking in the acrylic. As mentioned before, the storage shelf was mounted onto the T-slot aluminum frame for the whole system instead of being fixed to the ground. To do this, we used steel angle brackets that were cut to the horizontal width of the aluminum frame. The angle brackets were cut using a horizontal band saw. For our prototype, we mounted the acrylic frame with the aluminum grid onto two steel angle brackets – one at the top of the shelf and one on the bottom of the shelf. This shelf-steel bracket assembly was then mounted onto the T-slot aluminum frame for the whole system. The steel brackets act as cross bars for the shelf to be mounted on the system frame. The storage shelf was assembled by hand. Two people were needed to mount the shelf onto the steel angle brackets and to fasten these brackets onto the T-slot aluminum frame.

9.4 Subsystem: Translating Platform Plan

The ramp’s, motor ramp’s, and sliding platform sides and top shapes were cut with a band saw, dimensioned drawings can be seen in APPENDIX C – CAD MODELS AND ENGINEERING DRAWINGS. A semicircular cut out for the pinion was created using a hand drill in one of the ramp’s top pieces.16 aluminum brackets and drawer guide were also cut from the aluminum angle stock. Using a drill press size 19-drill bit holes were drilled into the center of each aluminum bracket's sides, Figure 45. The steel rack was cut to its specified length and width (18") using a band saw. Using a mill four, size19-drill bit holes were drilled at the specified locations. A lathe was used to create a 1" aluminum tube that could be press fit into the pinion and over the motor's shaft.

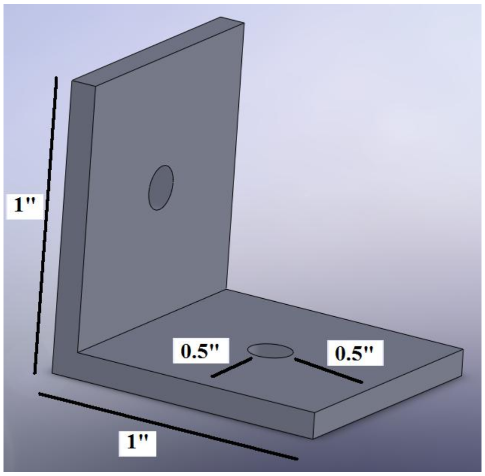

Figure 45: Brackets used to assemble Ramp and Motor Ramp

The ramp's sides, back and front were assembled first using eight of the aluminum brackets and size #8-32, ½ " bolts, Figure 46. Using a hand drill and marking the bolt holes, bolt holes were created in the acrylic. Using the same procedure the two top pieces of the ramp were assembled. This same method of using a hand drill and two aluminum brackets was used to assemble the motor ramp. Bolt holes for the linear slides were also created using a hand drill. The linear slides, drawer guides, and rack were attached to the sliding platform using bolts and a hand drill. The sliding platform, linear slides and rack were attached to the top of the platform. The bolts for the rack and linear slides were cut so they would not hinder movement of the slides. The pinion was attached to the motor's shaft using a setscrew and the 1"of aluminum tubing. The motor was attached to the motor ramp using four #10-32 3"bolts. The motor ramp was then aligned inside the ramp so that the pinion was aligned with the end of the rack when the platform is at its topmost position. Using a hand drill, a 5/16" threaded steel rod and eight nuts were threaded through the sides of the ramp and motor ramp.

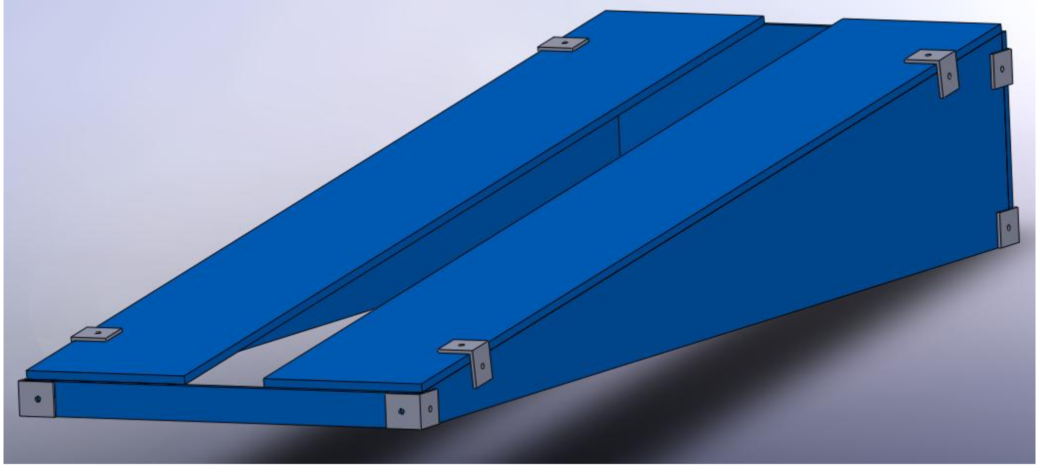

Figure 46: Assembly of ramp

10.0 VALIDATION PLAN

We developed a validation plan to verify that our system meets the engineering specifications. This validation plan can be used upon completion of the project by future teams. For the first semester of the project, the tests we ran to verify the suitability of our prototype are different from the tests mentioned in this validation plan. For information on verification of the prototype, please see the Section 11.0.

The initial engineering specifications for our system were as follows: (1) must be able to handle blocks from ¼ to ¾ inch thickness, (2) compatible with 2-D barcode system, (3) less than 4 × 2 × 5 feet (length × width × height), (4) dispense at least two blocks per minute, (5) load at least two blocks per minute, (6) sort at least two blocks per minute, (7) store at least 600 blocks, and (8) budget of $10,000.

As the project evolved throughout the semester, so did the engineering specifications. Most notably, less emphasis was placed on obtaining specific dimensions of 4 × 2 × 5 ft. Instead, it was decided that placing the machine on the floor would be acceptable and thus size became less important. We revised our goal for the outer dimensions of the system such that the machine should be less than 6 ft long and high and no more than 4 ft. wide. Also, our budget was expanded to be a total of $30,000 between our team (Team 12) and Team 11. Thus, our budget increased from $10,000 to approximately $15,000.

To test the ability of our system to handle blocks of thicknesses between ¼ and ¾ in. thickness, we will get a sample of 20 blocks that fit within this thickness constraint. We will test our machine to see if it is capable of sorting and filing all of these blocks. If the machine cannot handle certain blocks, we will see if the machine is more prone to failing with thick blocks or thin blocks, or if thickness isn’t a factor. We will also investigate what other factors besides thickness may cause the machine to fail to handle a block. For example, this failure may be a function of block orientation and not thickness. We will use trial and error, as well as single variable process of elimination to determine what factors cause the machine to fail to handle a block.

To test the compatibility of our system with the 2-D barcode system, we will scan a set of barcoded blocks, holding them in the exact position the gripper will hold them and the exact distance from the scanner they will be in the machine. We will place the barcodes in a variety of orientations, as well as attempt to obscure the barcode by placing paraffin wax over it, getting pen or marker ink on it, and tearing off a small piece of it. We will design our system to return to the user all blocks it cannot identify. This way, no block will be sorted incorrectly. All blocks that are not barcoded so they can be read by the machine will be ejected so they can be fixed before being filed.

To test whether the machine can process at least 2 blocks per minute (either unloading them from internal storage to drawers, or loading them from transport bin to internal storage), we will run a series of timed tests in both load and unload mode. Both machine modes can be broken down into several different parts. For loading mode, the machine must navigate to the XZ position of the block, extend the gripper, grab the block, retract the gripper, navigate to the drawer, rotate gripper, extend gripper, and release gripper. For unloading mode, the machine must navigate over the drawer, rotate down, extend, grab the block, retract, rotate upward, navigate to the proper XZ position, extend, then release the gripper. Each of these steps can be broken down into individual times. If the machine is unable to meet the total time requirement, we will see which step of the process is taking the longest and which step needs the most improvement. By focusing on the time required for each individual step, we will be able to reduce the total time required for the system to process blocks.

Certain engineering specifications cannot be tested. The dimensions of the system are a constraint that will be satisfied based on the design of the storage unit and XZ Cartesian system (see Section 7.0). The ability to store at least 600 blocks is a constraint that will be satisfied based on the design of the storage unit (see Section 7.0). Finally, the cost constraint is measured based on the information provided in our bill of materials for each subsystem.

11.0 TEST RESULTS

We evaluated the functionality of our design by testing each moving component of our system individually. After we had verified the functionality of each individual component, we tested the system as a whole to evaluate its functionality. Through this system evaluation, we were able to show proof of concept. Our system is capable of navigating to a specific XZ position and picking up a block. Our translating table is capable of translating and we can control its motor position, velocity, and acceleration. This shows that, with additional development, the system will be fully capable of performing to the customer's requirements.

To test the XZ system, we first tested the operation of both actuators by themselves by connecting their motor to Smartmotor Interface software. This software allows Animatics Smartmotors to be controlled through a graphical user interface in Windows. Using this software, we verified that each actuator was functional and could respond to commands. Next, we verified we could control the actuators by echoing commands to them through a computer's serial port through command line prompts in Linux. We were able to specify a position, velocity, and acceleration for the motor and the actuator would respond accordingly and accurately.

To test the translating table, we connected the translating table's Smartmotor to the Smartmotor Interface software and verified that the motor was functional. We then connected it to a PC running Linux and verified that the motor could respond to commands echoed to the serial port. Finally, when the translating table subsystem was assembled, we verified that the table could translate to a specific position by running the same command and return command several times in a row and observed that the table always returned to the same position.

We verified the performance of each of the gripper's 3 motors: the linear actuator for extension, the rotate motor, and the grip motor. We did this by powering up each motor and running it through its full range of motion several times in a row. In each instance, the motors were able to go through their full range of motion in both directions.

Finally, we tested the entire subsystem as a whole. With the help of programmer extraordinaire Dr. Grant Kruger, we created a program that performs the basic operation of navigating the XZ system to a specific position and picking up a block. First, when the system is powered up, the motors home to a position determined by the limit switches on the linear actuator. Next, the actuators each move to a predetermined XZ position. Then, the linear actuator on the gripper extends into a slot in the storage area. The gripper then opens, and the actuator lowers the gripper so it is positioned around the block. The gripper then closes, grabbing the block. The linear actuator retracts with the block being held in the gripper. Then, the XZ system navigates upward and the gripper arm rotates the block downward. We were able to successfully program this sequence of events. This represents all the fundamental movements associated with our machine. Based on this test, we have shown that our system can perform all essential functions required to grab and place a block. The system needs continued development to be fully functional. For a description of this, please see the Discussion and Recommendation Section 13.0 and 14.0.

12.0 ENGINEERING CHANGES NOTICE

This section discusses in detail all the changes made between our final design and our manufactured prototype.

12.1 Subsystem: XZ Cartesian System

There are no engineering changes for this subsystem that took place between Design Reviews (DR) 3 and 5. The method of mounting the actuators (i.e. using toe clamps) is the same as DR 3. Also, all of the actuator engineering parameters described in the Parameter Analysis section have not changed because once we placed the actuator order with the manufacturer, making changes was not an option.

For the system frame, no engineering changes place between DR 3 and 5. The initial concept called for a rectangular frame made out of 12 pieces of t-slot aluminum. During Design Review 3, we added two additional support bars to the frame for a total of 14 pieces. The lengths of the t-slot pieces and the method for attaching them have remained consistent since Design Review 3.

12.2 Subsystem: Gripper Changes

Many changes were made to the gripper between DR 3 and the prototype. These include a change in the final linear actuator chosen, a change in the final gripper chosen, and a redesign of the rotating function of the gripper, a redesign of the final bracket and the addition of a slider for structural integrity. All of these changes drawings can be seen in APPENDIX D – ECN DIAGRAMS.

Linear Actuator

The change from the THK VLA ST-45 linear actuator to the THK CRES200-100-12 linear actuator was due to price consideration and lead time. Due to the precision and rarity of the THK VLA ST-45, the linear actuator had to be ordered from Japan with a 4 week shipping time. Since the THK CRES200-100-12 was accurate, inexpensive and had a short lead time it was chosen over the THK VLA ST-45.

Gripper

Initially the Smart Gripper 2.0 from Applied Robotics was chosen. Due to the large size, programming, and end defector fabrication, a different gripper was chosen. The gripper portion of the Rokenbok RC TransGripper provided enough grip force to secure a pathology block while weighing considerably less than the Smart Gripper 2.0. With the addition of a limit switch the gripper could be easily controlled and provided enough robustness.

Rotation of the Gripper

The gripper initially was going to be rotated by connecting a base (which the linear actuator and gripper was connected to) and connecting it to the shaft of an Animatics Smart Motor. This design was made significantly less complex by transforming the Rokenbok RC TransGrippers lifting function to a rotation function. This was accomplished by detaching the third and forth link that keeps the gripper from rotating. With this change, the addition of two limit switches (one for the vertical and one for the horizontal position), and the addition of an H-bridge circuit to allow for a change in polarity of voltage applied to allow the gripper to rotate both clockwise and counter-clockwise, the new rotation feature accomplished all the functions originally intended for the prototype.

Final Bracket

Due to the change of components, some features on the bracket were unnecessary. These changes are best seen in.

Slider

The slider was added due after changing the linear actuator. A slider component was part of the THK VLA ST-45 linear actuator while the THK CRES200-100-12 had only an actuating arm. Since the THK CRES200-100-12 did not have a slider built in, a slider relieving this stress was added. The length of the slider was determined by the stroke length of the linear actuator while still providing enough room for the gripper to be mounted.

12.3 Subsystem: Shelf Changes

The changes made between our final design and our actual prototype for the storage shelf includes the storage capacity, the design of the aluminum grid, and the way the shelf was mounted. The initial storage capacity for our shelf was 600 blocks, but when we manufactured the shelf, we did not have enough resources to finish machining the aluminum grid for all 600 compartments. Instead, our prototype has room for 300 blocks at most. For the grid, our initial plan was to machine aluminum strips that spanned the entire length and height of the acrylic frame and was not intended to be modular. However, the maximum stroke length of the water jet cutter was not long enough to cut strips of this length. Therefore, we cut the length of the strips in half, and machined the vertical strips to measure 15” instead of 30” and the horizontal strips to measure 17” instead of 36”. The final change in design relates to the mounting. Instead of bolting the shelf to the floor, we used 2 steel angle brackets that acted as cross bars to hold the shelf fixed to the aluminum frame built for the whole system. These brackets are shown in Figure 41.

12.4 Subsystem: Translating Table Changes

Four assembly changes were made to the final design in DR 3 to result in the actual prototype’s translating platform subsystem.

Drawer Guides

The drawer guides made out of the aluminum bracket stocker were added to secure and designate the placement of the drawer on the platform.

Pinion mount on Motor Shaft

Aluminum tubing was milled and used to press fit the pinion onto the shaft before using a setscrew to secure it. This was necessary because the pinion’s inner diameter was much larger than the motor shaft.

Ramp and Motor Ramp

The motor ramp and ramp were attached using a threaded steel rod to allow for continuity of the entire system.

Additional Brackets

An additional bracket was used at the top and bottom of each of the ramp’s top pieces to secure them to the back and front of the ramp.

13.0 DISCUSSION

13.1 Subsystem: XZ Cartesian System Discussion

XZ system

The main strength of the XZ system is that it is very robust. The decision to order the x-axis actuator as a dual rail and the z-axis actuator as a single rail was a good one (see Section 7.0 for more information). This system should be able to adequately support the loads we subject it to. Additionally, the choice of gear ratio for the actuator’s internal belt drive (10 mm per revolution) was a good engineering decision. The system hasn’t had trouble moving the loads we’ve subjected it to, and speed was a priority for this system. This gear ratio allows us to achieve fast speeds without us having to worry about the motors being overloaded.

A weakness of this design is the issues we have with the system not being square and level. Currently, the z-axis is not perfectly perpendicular to the floor; it is inclined at an angle in two planes as shown in Figure 47. This is due to two factors: the moment the z-axis subjects on the x-axis, and the hole pattern on the x-axis carriage. To correct the first problem we could add a support rail for the z-axis to translate on so it does not deflect in one place. To correct the second problem, we will have to work with the manufacturer to correct the hole misalignment on the x-axis carriage.

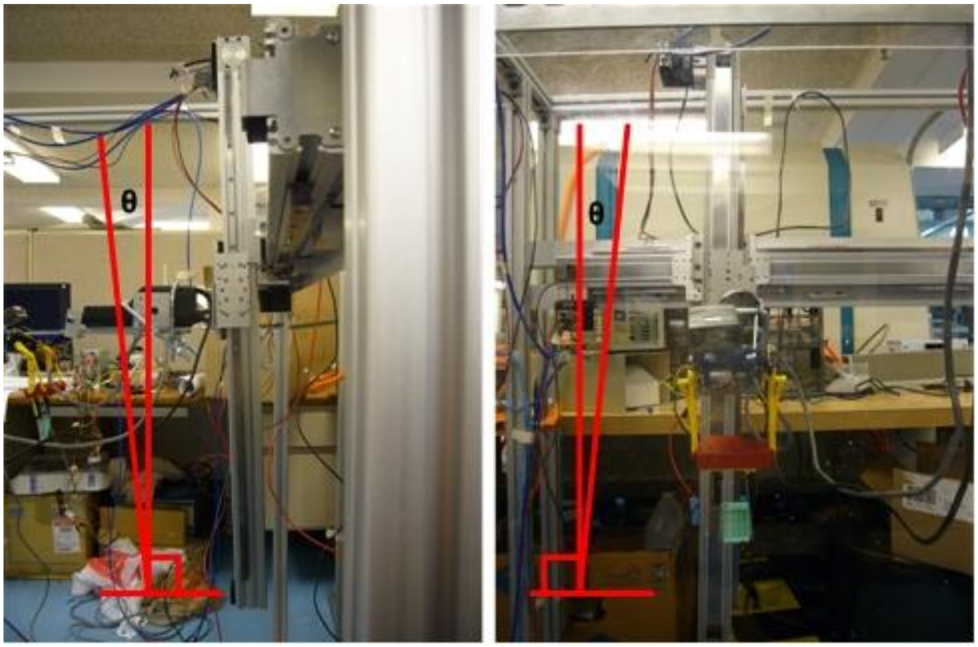

Figure 47: Z-axis is misaligned in two planes

System Frame

The main strengths of the system frame are that it is strong, sturdy, and versatile. The frame can adequately support loads that it is subjected to and remains rigid. Also, because it is constructed out of t-slot products, it is easy to take apart, adjust, and assemble. Putting pieces together involves only tightening and loosening bolts. Additionally, the frame has fully adjustable mounting bars for the x-axis. This is a very convenient feature which allows the Cartesian system to be adjusted so it is the proper distance from the storage area.

A weakness of the system frame is that it vibrates and shakes when the actuators move. There are 3 key ways this can be addressed. First, currently the corners of the system frame only have 2 mounting brackets holding them together, as shown in Figure 48. Adding a third bracket to each corner will help improve the stability and rigidity of the frame. Second, additional cross bracing can be added to the frame. For example, when we added cross beams to the system to mount the storage area, the overall stability of the system increased considerably. This is shown in Figure 49. Cross bracing can take the form of either cover panels for the sides of the machine, or additional support beams. This will make the frame more stable and rigid. Third, the system frame could be fixed to the wall and floor. Anchoring two sides of the system like this will improve stability. During testing, we attached one side of the machine to a rigid table, and it drastically reduced the vibrations the system experienced when the actuators moved (shown in Figure 50). Fixing the frame to both a rigid wall and floor will improve the stability even more.

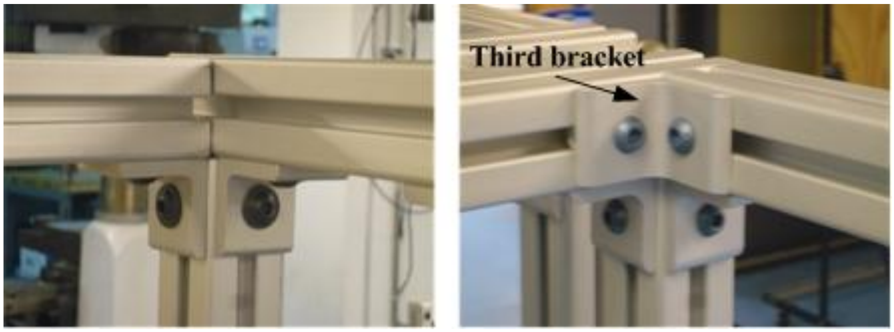

Figure 48: Frame stability can be improved by putting 3 brackets in each corner

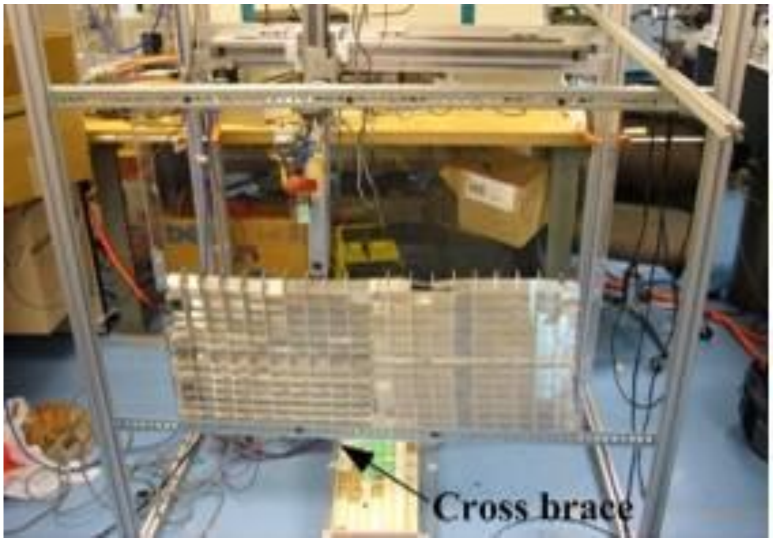

Figure 49: Cross bracing can make system more stable and rigid

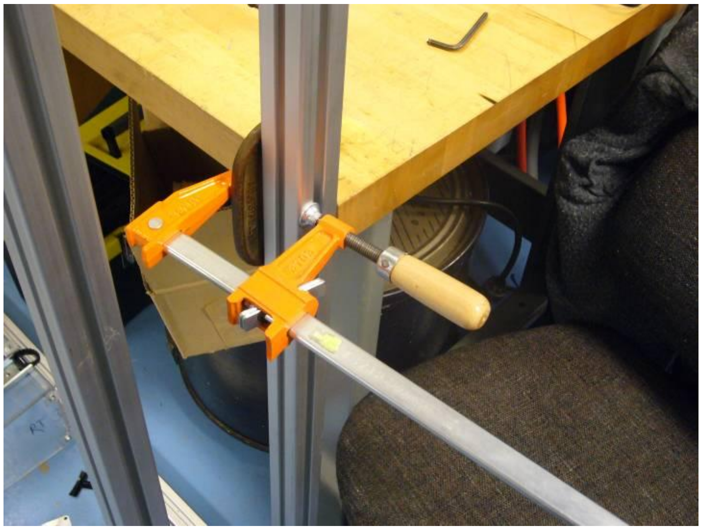

Figure 50: Anchoring system to floor and wall will improve stability and reduce vibrations

13.2 Subsystem: Gripper Discussion

Strengths

All motions needed for the gripper are obtained using light and inexpensive parts. Due to the small DC motor and the use of plastic gears, the gripper mechanism is relatively light compared to other grippers, which mainly use metal parts and heavier servo motors. Considering the degrees of freedom and the amount of control available to the user, the gripper is inexpensive compared to the alternatives. Electrical grippers and linear actuators alone can total in the thousands, while the prototype costs less than 500 dollars.

Weaknesses

The gripper can be improved in various ways, including improving the speed of each cycle, decreasing vibrations after the XZ Cartesian system translates and stops, increasing the accuracy of the gripper, and fastening the components better.

Speed of the Gripper Cycle

The speed of the gripper, in particular the rotating motion, is below the needed speed to obtain the requested cycle time. The DC motor is attached to various gears and has a low gear ratio. While this provides the gripper with plenty of torque to rotate while a block is located in the gripper, it is at a slower velocity. Due to the current rating on the gripper, supplying a higher voltage is not an option, as this will burn out the motor. This can be improved by replacing the current DC motor with a motor that can handle a higher current.

Vibrations

The vibrations at the end of the gripper decreases cycle time and can damage the integrity of the gripper components. Before an action can be executed the gripper must wait for the vibrations to cease, or risk large errors in the final actuated location of the end defectors on the gripper. This could cause damage to the buffer zone if the gripper misses a compartment and contacts the aluminum mesh instead. The vibrations can also cause bolts to unscrew and adds fatigue to the gripper components decreasing the total life of the gripper. To decrease the vibrations dampeners can be added between the XZ Cartesian system and the connecting bracket, while adding a cross bar on the frame of our prototype will provided added stability.

Accuracy

Due to the plastic gears, there are considerably high tolerances when the motor stops. While the motor and gears lock into place, the gears are not perfectly interlocked, and provide room for small rotation after the motor is stopped. While this is not a huge case in the horizontal position of the gripper, as the force of gravity forces the gripper into a consistent position, when in the vertical position the rotation error can be seen when the XZ Cartesian system moves. This could be improved by making the gears out of a more rigid material than plastic. As this would require extensive machining, a hard stop when the gripper is vertical would make the gripper more rigid when in the vertical position.

Fastening

Currently due to time constraints some components are connected to the gripper through adhesives. To improve the integrity and the reconfigurability of these components these components should be mounted on using fasteners.

13.3 Subsystem: Shelf Discussion

The prototype of our storage shelf is generally mechanically sound and did not fail when we tested it. However, there are several things we would have done differently if we were to redesign the shelf and produce a second prototype. One of the weaknesses of the design is that the acrylic sheets are not very rigid. Instead of using the acrylic sheets, we would use a stiffer, thicker material like wood or some other metal alloy. This would eliminate the need for brackets to hold the pieces of the frame together.

Another weakness of the design is that there are many sharp edges, especially on the aluminum grid. To remedy this, we would file the edges, or put a protective acrylic (plexiglass) cover on the entire system. To eliminate the sharp edges on the acrylic frame, we would file the edges, or use a different material as mentioned above.

One of the strengths of this design however, is the way it is mounted directly onto the aluminum frame for the system. The aluminum angle brackets shown in the model in Figure 26 act as crossbars and hold the frame rigidly in place. An advantage of this design that we did not have in our previous design is that the shelf can be adjusted in height. The user would only need to loosen the fasteners and T-nuts holding the shelf in place, slide the shelf up or down as needed, and tighten the fasteners again.

13.4 Subsystem: Translating Platform Discussion

The top pieces of the ramp should have been cut longer than 36” to allow for tolerance and to make the edges of the ramp cleaner and more aligned. The pinion should have been ordered with a smaller inner diameter to eliminate the use of the aluminum tubing.

One of the strengths of this design is the adjustable location of the pinion to the rack. By using a threaded rod to connect the motor ramp and ramp allows the pinion’s location to be calibrated easily. Another strength is the angle of the ramp. This angle allows gravity to aid in maintaining the upright orientation of the blocks.

A weakness of this design is the long assembly time. 16 brackets are used and the precision of the bolt holes was a difficult task. To eliminate this weakness a mold of the ramp could be created which would make the ramp a continuous piece and eliminate the need for brackets. Another weakness is the permanent placement of the drawer guide. If the drawer shape or another type of tray is used the platform is useless. By creating adjustable guides this problem would be eliminated.

14.0 RECOMMENDATIONS

We recommend that programming for the system be improved upon. All mechanical parts of each subsystem have been manufactured. Also all six movements (gripping, rotation and extension of gripper, linear motion in the X and Z directions, and the translating platform) have been programmed and can be computer controlled. These movements are currently not synchronized. Preliminary programs for gripping a block out of the shelf have been completed but the additional steps and calibration need to be enhanced. Specific recommendations for each of the subsystems are discussed in the following sections.

14.1 Subsystem: XZ Cartesian System

Due to the misalignment of the z-axis (i.e. it is not perpendicular to the floor) it is recommended that the actuators are returned to the manufacturer so the carriage can be replaced with one with correctly drilled hole patterns. Also, it is recommended that a support rail for the z-axis is developed. This would run parallel to the x-axis and help support the bottom of the z-axis when it translates. This will prevent it from deflecting in one plane and correct alignment issues.

14.2 Subsystem: Gripper Recommendations

The gripper can be made more accurate and structurally sound. To address these issues, numerous changes can be made. More fastening points on the gripper to the slider and the slider to the bracket would further increase stability, while connecting the linear actuator to the bracket without U-bolts would increase the repeatability of assembly. Shorter bolts should be used to mount the bracket to the XZ table as the current bolts were too long, and 4 washers were used to fill the gap between the XZ table and the bracket that was left. One of the biggest improvements that can be made to our gripper is the addition of an additional arm to the XZ table, effectively giving it 3 ranges of motion. This will reduce the bulkiness of the project and allow for larger, more accurate components to be used for rotation and gripping. The current rotation method is very slow, and should be replaced with an Animatics SmartMotor as it would not only increase control but the time it takes to run each cycle. The gripper is also not very accurate and lacks a control mechanism to tell the gripper to stop opening. With the addition of a limit switch the control aspect of the problem could be solved. The accuracy portion could be solved by either reinforcing the existing gripper in with L brackets particularly on the fingers of the grippers, or finding a new gripper entirely. With the speed and accuracy of the gripper being a problem it is recommended that the Rokenboks RC TransGripper be replaced by the SmartGripper 2.0 for gripping and an Animatics SmartMotor that has a rotating base connected to its shaft that is connected to the SmartGripper 2.0. This mechanism could be attached to the Y arm of the XYZ table and would provide a very precise, accurate, and stable alternative to our current design.

14.3 Subsystem: Shelf Recommendations

For Dr. Balis and future teams that may further develop this design, we would recommend the following for the storage shelf. First, the material for the frame should be thicker and stiffer than acrylic. Wood is a better choice, since it is much more rigid and the shelf can be made to stand on its own if the legs are bolted to some surface. If the thickness of the wood is large enough, one would only need bolts to fasten the sides of the wood together and no L-brackets are needed. Also, it is easier to machine slots in the wood so that the edges of the aluminum grid can be press-fit inside the frame.

Second, as per our original engineering specification, the storage shelf should have a capacity of 1000 blocks. Due to time and machining constraints, we were only able to build a shelf with a 300-block capacity. Also, the aluminum strips cut to form the grid are not long enough to span the entire width and height of the shelf since the water jet cutter was not large enough to cut strips that long. Therefore, the grid in our prototype is modular and has two smaller grids. For an improved design, we would recommend machining the strips using a water jet large enough to cut strips that can form a grid with 1000 compartments of the same dimensions as our prototype. An alternative suggestion to machine the grid is to use injection molding and machine the entire grid in one operation with a plastic or polymer. Making the grid out of a polymer would also eliminate the sharp edges produced by the cuts on the aluminum strips.

Finally, we would recommend keeping the same mounting method, so that the shelf can be adjusted in height. If future designs require the shelf to be a standalone part from the XZ system and aluminum frame, then the shelf should be bolted to a counter surface, wall, or floor. If the shelf is not fixed to some surface, it may tip over.

14.4 Subsystem: Translating Platform Recommendations

I would recommend designing an adjustable drawer guide, which will allow other sizes of drawers or input trays to be used. This will increase the versatility of the machine. Also redesigning the way the motor ramp is attached to the ramp. It is a strength that it is adjustable in one direction but I would recommend designing an easier, user-friendly way of adjustment. Also being able to adjust it in the length wise direction would make calibration of the pinion's position easier.

15.0 CONCLUSIONS

A computer-controlled system for sorting of pathology block samples would ensure accuracy in diagnosis of disease and provide reliable placement of block samples for later retrieval. Drs. Ulysses Balis and Jeff Meyer from the University of Michigan Pathology Department have sponsored our team to design and fabricate such a system to ensure the highest precision in diagnosis.

After several discussions with Dr. Balis and interviewing lab technicians, customer requirements were found. Through analysis of the customer requirements and rigorous literature research, we developed engineering specifications. Problem analysis was done to find design difficulties and some of the problems anticipated in later design stages. To remain on schedule and develop proper pacing between design reviews a Gantt chart was developed.

Many designs were developed from the customer requirements and engineering specifications, while also considering the problem analysis (Shown in APPENDIX B- ENGINEERING ANALYSIS and CALCULATIONS) Based on how each design met the weighted customer requirements and the ease of fabrication, the final design was chosen. The final design is shown Figure 8. It has an XZ system built using two HLD linear actuators purchased from OEM Dyanmics and a rotatable gripper to store and place blocks within both a storage shelf and drawers. Our design also includes an angled, translating table beneath the storage shelf that will be automated with the XZ system so that blocks can be gripped and placed accurately. Our concept met all customer requirements, but our biggest challenge was to ensure that our prototype met customer requirements as well as engineering specifications.

We have successfully built a mechanical system that meets most customer requirements and engineering specifications. Our system can also be mechanically implemented in the pathology lab. However, the storage shelf does not have a 1000 block capacity, and the automation for the system is not complete. The system can pick and place a block, but it cannot complete a cycle of scanning and placing or retrieving a block without individual commands from the user. Complete automation can be achieved with our design, however, this will require more time and programming, possibly with future design teams.

16.0 ACKNOWLEDGEMENTS

Our team would like to acknowledge those who helped us immensely in the machine shop: Bob Coury and Marv Cressey. We would also like to thank the people that helped us with the water jet cutter in the Wu Manufacturing Research Center: Steve Erskine, Andrew Jessop, and Kevin Hulett. We thank Professor Albert Shih and Dr. Grant Kruger for taking the time to help us finish our prototype, and Tom Kunkel from Animatics Corporation for helping us in our decision to purchase linear actuators for the XZ system. Finally, we want to thank Dr. Ulysses Balis and Dr. Jeff Meyer for sponsoring our project and meeting with us regularly to discuss our progress.

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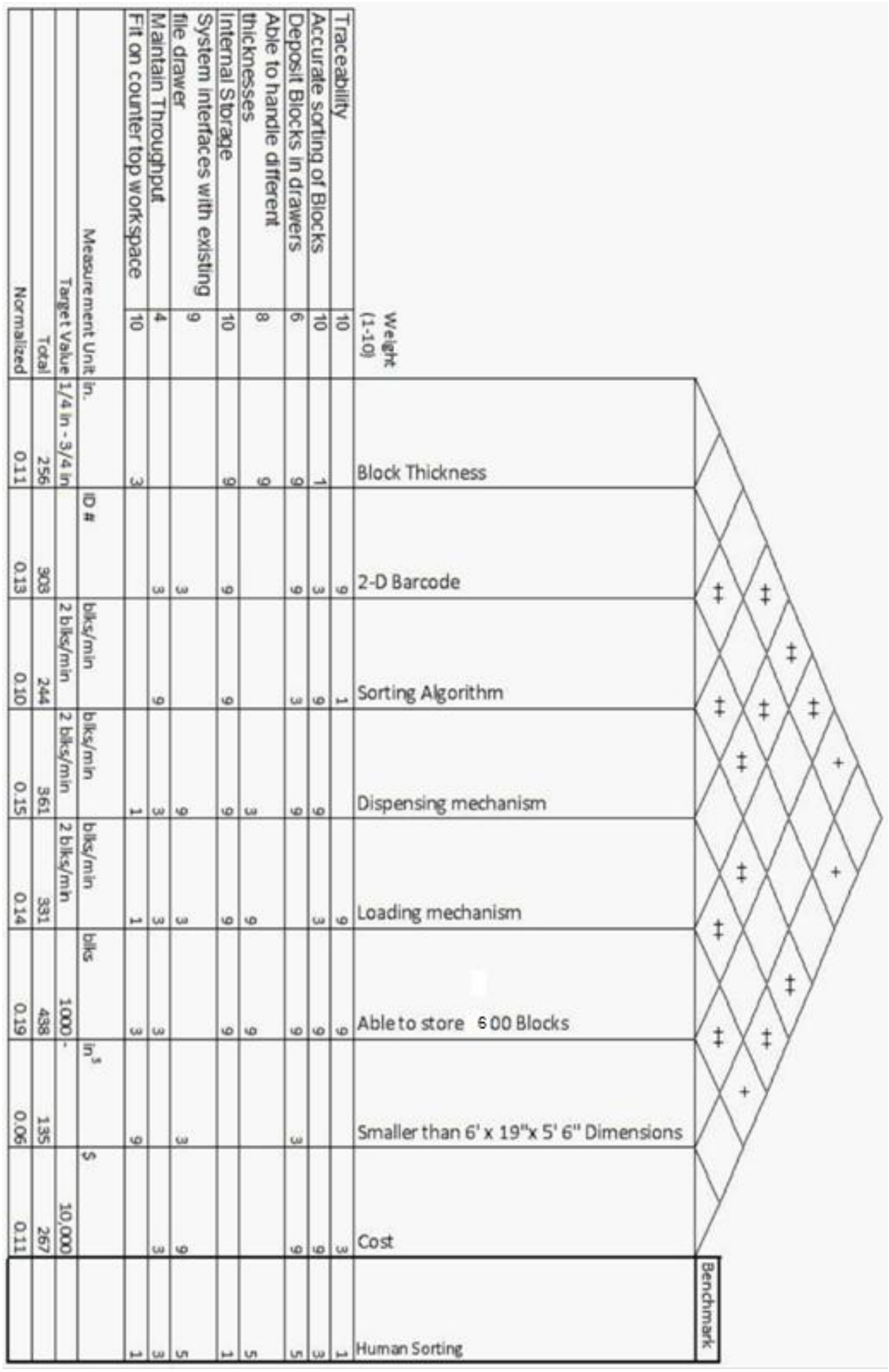
APPENDIX A – CONCEPT GENERATION

QFD



	Weight (1-10)	Block Thickness	2-D Barcode	Sorting Algorithm	Dispensing mechanism	Loading mechanism	Able to store 600 Blocks	Smaller than 6' x 19"x 5' 6" Dimensions	Cost	Benchmark Human Sorting
Traceability	10		9	1		9	9		3	1
Accurate sorting of Blocks	10	1	3	9	9	3	9		9	3
Deposit Blocks in drawers	6	9	9	3	9		9	3	9	5
Able to handle different thicknesses	8	9			3	9	9			5
Internal Storage	10	9	9	9	9	9	9			1
System interfaces with existing file drawer	9		3		9	3		3	9	5
Maintain Throughput	4		3	9	3	3	3		3	3
Fit on counter top workspace	10	3			1	1	3	9		1
Measurement Unit		in.	ID #	blks/min	blks/min	blks/min	blks	in³	$	
Target Value		1/4 in - 3/4 in		2 blks/min	2 blks/min	2 blks/min	1000 -		10,000	
Total		256	308	244	361	331	438	135	267	
Normalized		0.11	0.13	0.10	0.15	0.14	0.19	0.06	0.11	

This appendix contains several additional concepts we developed for the block sorting machine. These were preliminary ideas for the machine developed for Design Review 1. The scope of the project changed drastically since then, and these concepts were no longer sufficient to meet the design requirements. Nonetheless, they have been included to provide complete documentation of the design process.

Carousel Concept

The carousel concept involves a rotating wheel with multiple slots to hold blocks. Incoming blocks would be scanned and the carousel would rotate to the proper position so a block can be loaded in the correct slot. Blocks would then be dispensed from the carousel into the drawer in the proper order. This concept is illustrated in Figure 51.

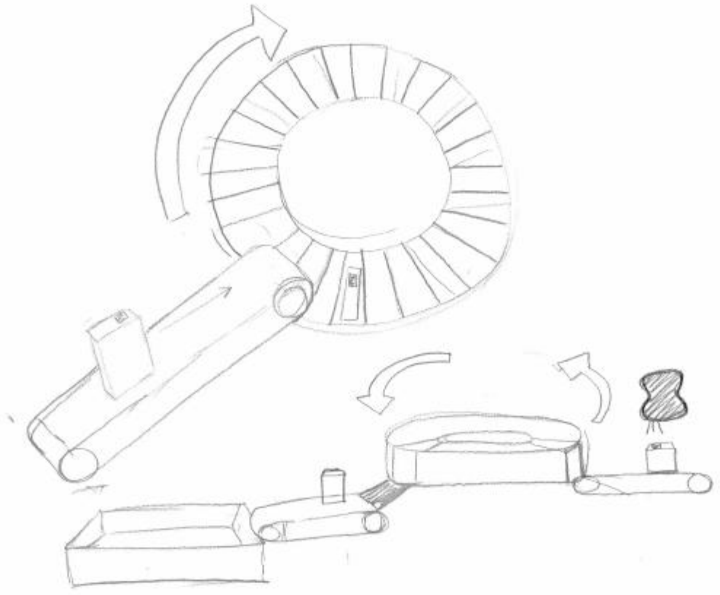


Figure 51: Carousel concept

Ferris Wheel Concept

The Ferris wheel concept has blocks that enter the machine on a conveyer belt. Blocks are scanned upon entering and sent to the proper location on the conveyer belt. Once in the proper location, the belt stops and the block is pushed into a vertical rotating wheel (i.e. a Ferris wheel). The Ferris wheel stores all the blocks that belong in a particular column of a drawer. The number of Ferris wheels is equal to the number of columns in a drawer. Once each Ferris wheel is full, or all the blocks have been input, all wheels rotate in sync to dispense the blocks to the drawer below it. The drawer translates along one axis so the blocks in each column are placed in the proper row. This concept is illustrated in Figure 52.

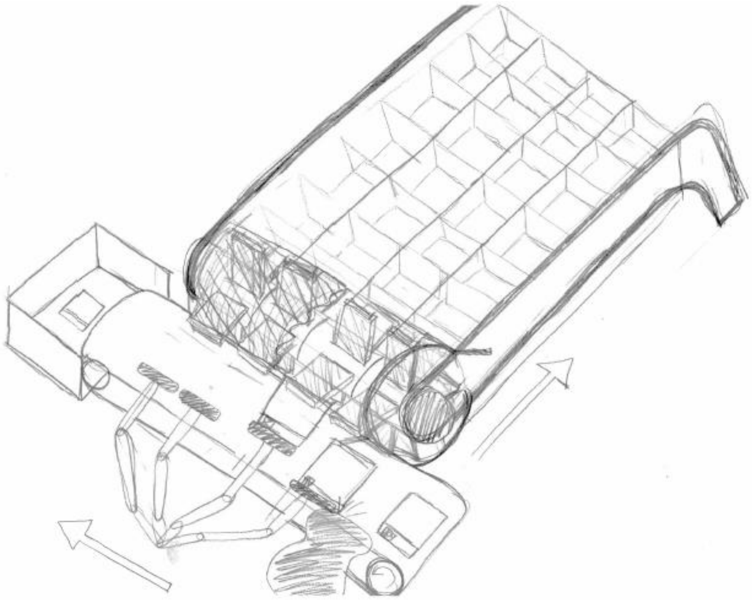


Figure 52: Ferris wheel concept

Drawer Insert Concept

There are several problems associated with automated filing of blocks into a drawer. Blocks are placed in a drawer's column in numerical order. If a block from a numbered set is missing, it is hard to "leave space" in the column for it so that the machine can file the missing block away later. Additionally, blocks within a column can "fall over" and take up too much space. To address these issues, the idea of a drawer insert is presented. The drawer insert would fit into the existing filing drawers and provide an individual space for each block. A device such as this would greatly simplify some of the problems associated with automated block sorting. This concept is illustrated in Figure 53.

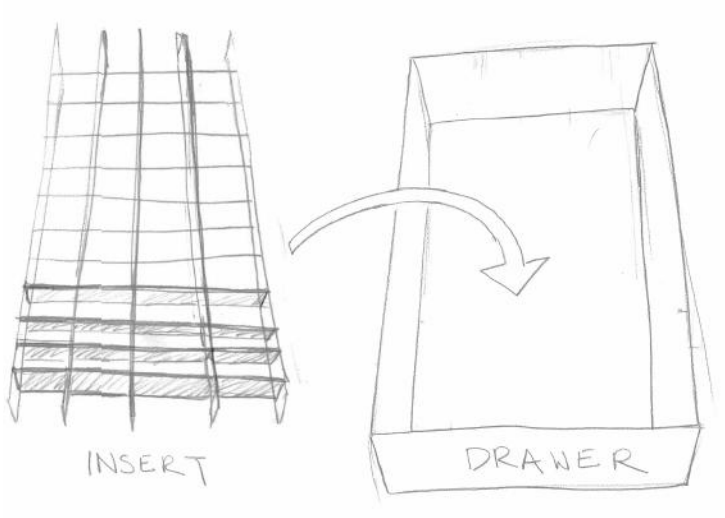


Figure 53: The drawer insert concept would provide an individual slot for each block.

Slot Sorter Concept

The slot sorter concept has the blocks inserted vertically through a chute. The blocks are dropped vertically onto a conveyer belt where they are scanned. As the blocks move along the conveyer belt, a port will open when the block is aligned over the proper drawer column. This will allow the block to fall through the conveyer belt into a bin. There are as many bins as there are drawer columns. The bins contain the same number of slots as there are rows in the drawer. These bins translate so that the blocks can fall into a specific slot. Each slot corresponds to a specific row of the drawer. Once all the blocks have been loaded into the bins, the bins align themselves over the drawer. The bottom of each bin then opens, allowing all the blocks to fall into their proper location in the drawer. This concept is illustrated in Figure 54.

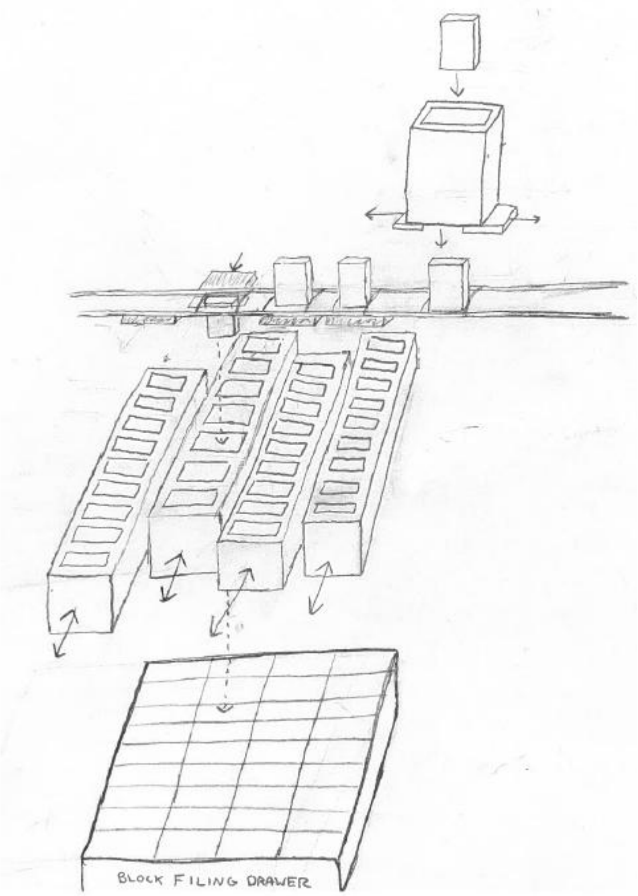


Figure 54: The slot sorter concept sorts blocks by column using a conveyer belt, and then by row using translating slotted bins.

X-Y Table Concept

The X-Y table concept allows the user to insert a large stack of blocks into the machine at once. A tall column of blocks is loaded into the machine. The bottom block is scanned and then rotated 90 degrees so that it is upright. The drawer is located on an X-Y table, which is a table that translates in both the X and Y directions. After the block is scanned, the table translates in both directions so that the column of blocks is directly over the correct drawer location (the proper row and column). After being rotated 90 degrees, the block drops into the drawer below in its proper location. This concept is illustrated in Figure 55.

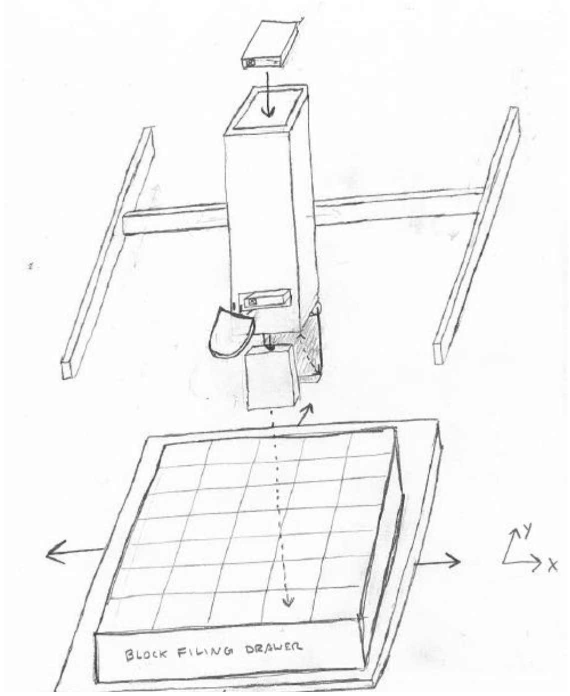


Figure 55: The X-Y table concept places the drawer on a translating X-Y table so that as blocks are scanned, the table moves the drawer so the block falls into the proper location.

APPENDIX B- ENGINEERING ANALYSIS and CALCULATIONS

This section details all calculations used to determine the design of each subsystem.

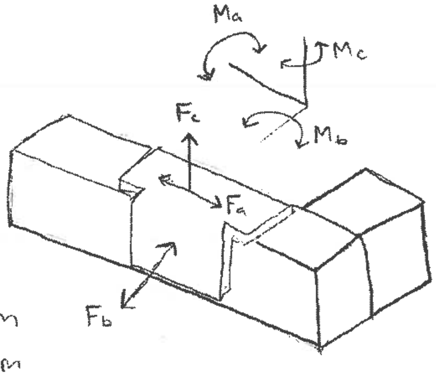
XZ Table Analysis

Moment Calculations

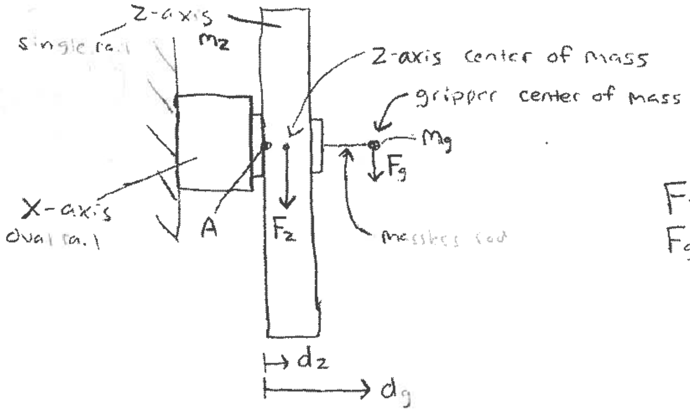
HLD 60 single / dual rail

10 mm/rev

Spec	Single rail Dynamic (static)	Dual rail dynamic (static)	
F_b =	460 (1200)	3000 (3000)	N
F_c =	460 (1200)	3000 (3000)	N
M_a =	12 (24)	114 (200)	Nm
M_b =	45 (200)	89 (200)	Nm
M_c =	45 (150)	89 (200)	Nm



Moment on x-axis, M_a:



$m_z = 6.8$ kg

$m_g = 9$ kg

$g = 9.81$ m/s²

$d_z = 38$ mm

$F_z = m_z g = (6.8)(9.81) \rightarrow F_z = 66.71$ N

$F_g = m_g g = (9)(9.81) \rightarrow F_g = 88.29$ N

$$\circlearrowright_+ \sum M_A = -F_z d_z - F_g d_g = M_a$$

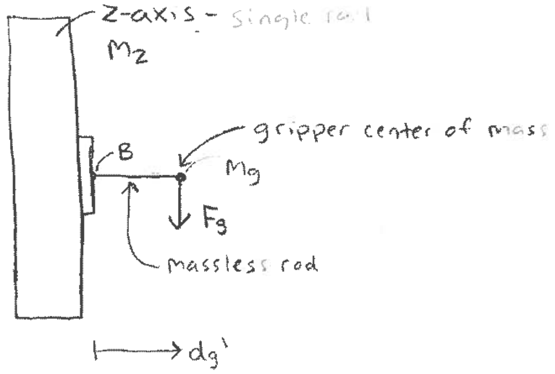
limitation on $M_a = 200$ Nm (Static), 114 Nm (dynamic)

$$\frac{M_a + F_z d_z}{F_g} = d_g = \frac{114 + 66.71(0.038)}{88.29}$$

$d_g = 1.320$ m

So, if gripper is 9 kg, the max distance the center of mass of the gripper can be from the face of the x-axis carriage is 1.320 m

Moment on Z-axis, M_b :



$d_g' = ?$

$M_z = 6.8 \text{ kg}$

$M_g = 9 \text{ kg}$

$F_g = M_g g = (9)(9.81) \rightarrow F_g = 88.29 \text{ N}$

$$\Sigma M_B = F_g d_g' = M_B$$

$$d_g' = \frac{M_B}{F_g}$$

limitation on M_b = 45 Nm (dynamic), 200 Nm (static)

$$d_g' = \frac{45}{88.29} \rightarrow d_g' = 0.510 \text{ m}$$

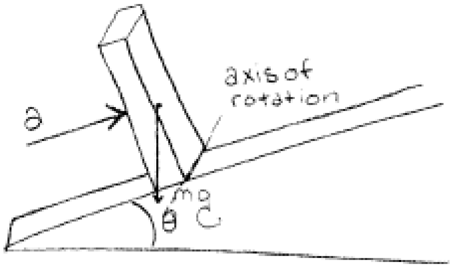
So, if a dual rail is used on the x-axis and a single rail is used on the z-axis, the max distance the center of mass of the gripper can be from the face of the z-axis is 510 mm. (d_g')

The max distance the center of mass of the gripper can be from the face of the x-axis is :

lever arm + thickness of z-axis

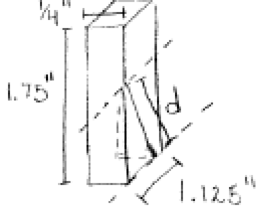
510 + 75 = 585 mm

Inclined Ramp Angle (Acceleration of Platform) Analysis



Moment of Inertia around axis of rotation:

$I_x = I_{CM} + md^2$



$d = \sqrt{(.5\cdot 1.75)^2 + (.5\cdot .25)^2}$

$d = .883883''$

$$I_x = \left(\frac{1.75^2 + .25^2}{12} + .883883^2\right) m$$

$I_x = 1.04167\cdot m$

$\Sigma\tau$:

$mg\cdot x = I_x\cdot\alpha$

$g = 386.4''/s^2$

$\alpha = \frac{a}{r} = \frac{a}{0.875''}$

$x = .875\tan\theta$

$$\cancel{m}\cdot 386.4\cdot .875\tan\theta = 1.04167\cdot\cancel{m}\cdot\frac{a}{0.875''}$$

$$a = \frac{386.4\cdot .875\cdot .875\tan\theta}{1.04167}$$

Our design:

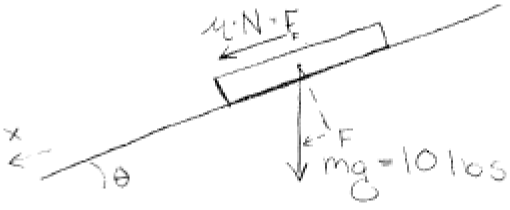
$\sin\theta = \frac{5''}{36''}$

$\tan\theta = .13889$

$a = 39.44''/s^2 \Rightarrow$ extremely high

needs to move only 3/4" in 1 cycle time

Translating Table Motor Analysis



$\sin\theta = \frac{5}{36}$

$\theta = 7.98^\circ$

$\sum F_x = F + F_F = \mu \cdot 10\cos\theta + 10\sin\theta$

$\tau = F_x \cdot r$ r = radius of pinion = .5"

Animatics SM2315D:

Continuous $\tau = 1.69$ in-lb

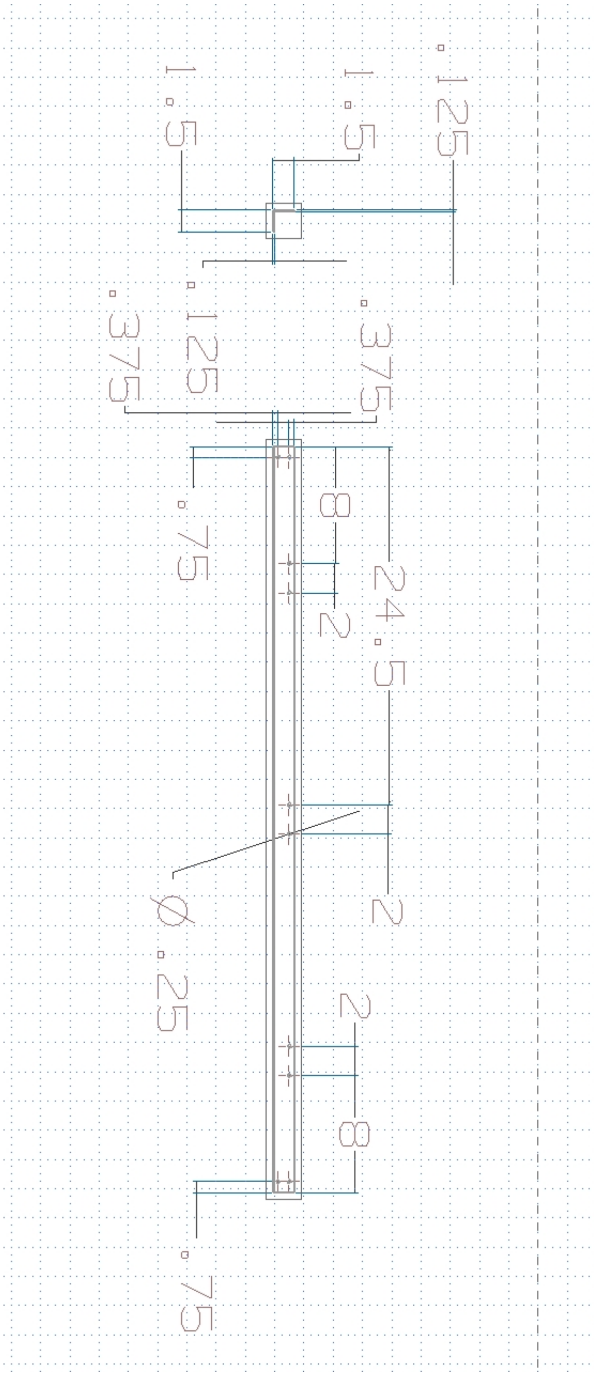
$1.69 = \mu \cdot 10(\cos 7.98^\circ + \sin 7.98^\circ)$

$\mu = \frac{1.69}{11.292} = 0.14966 \Rightarrow$ Large coefficient of friction; drawer slides less than this

APPENDIX C – CAD MODELS AND ENGINEERING DRAWINGS

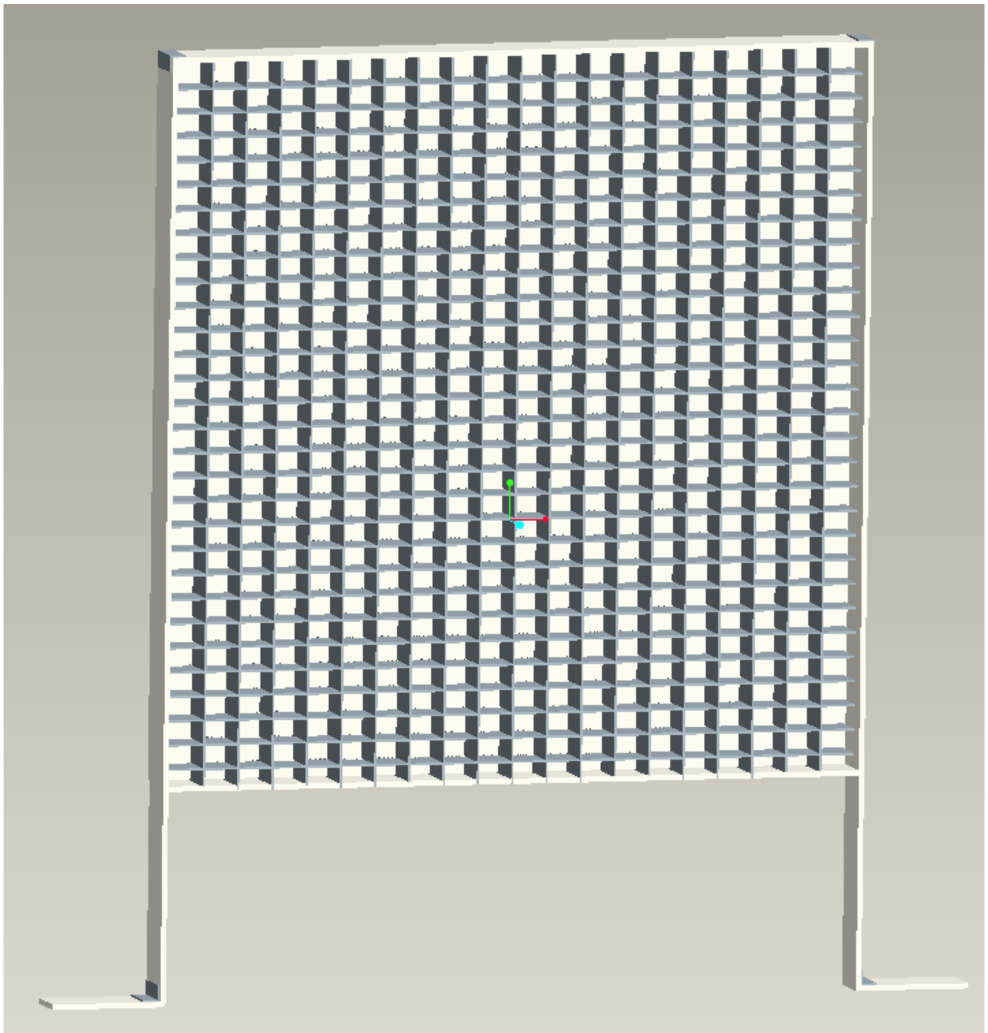
This section provides CAD models and 2D dimensioned drawings of each subsystem.

Drawing of x-axis actuator mounting bracket.

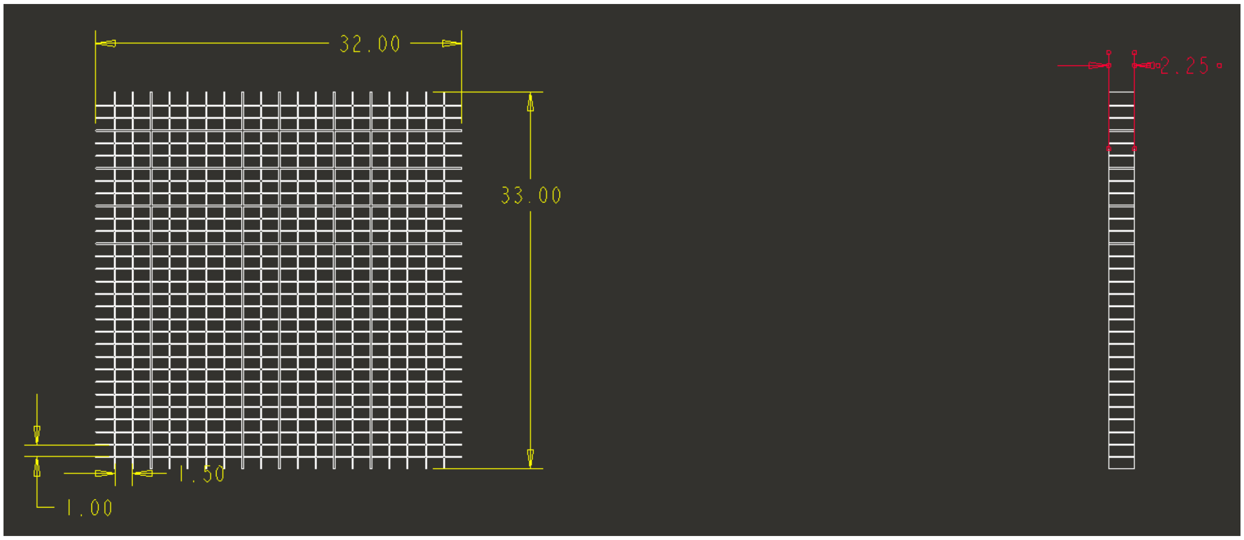


*Dimensions in inches

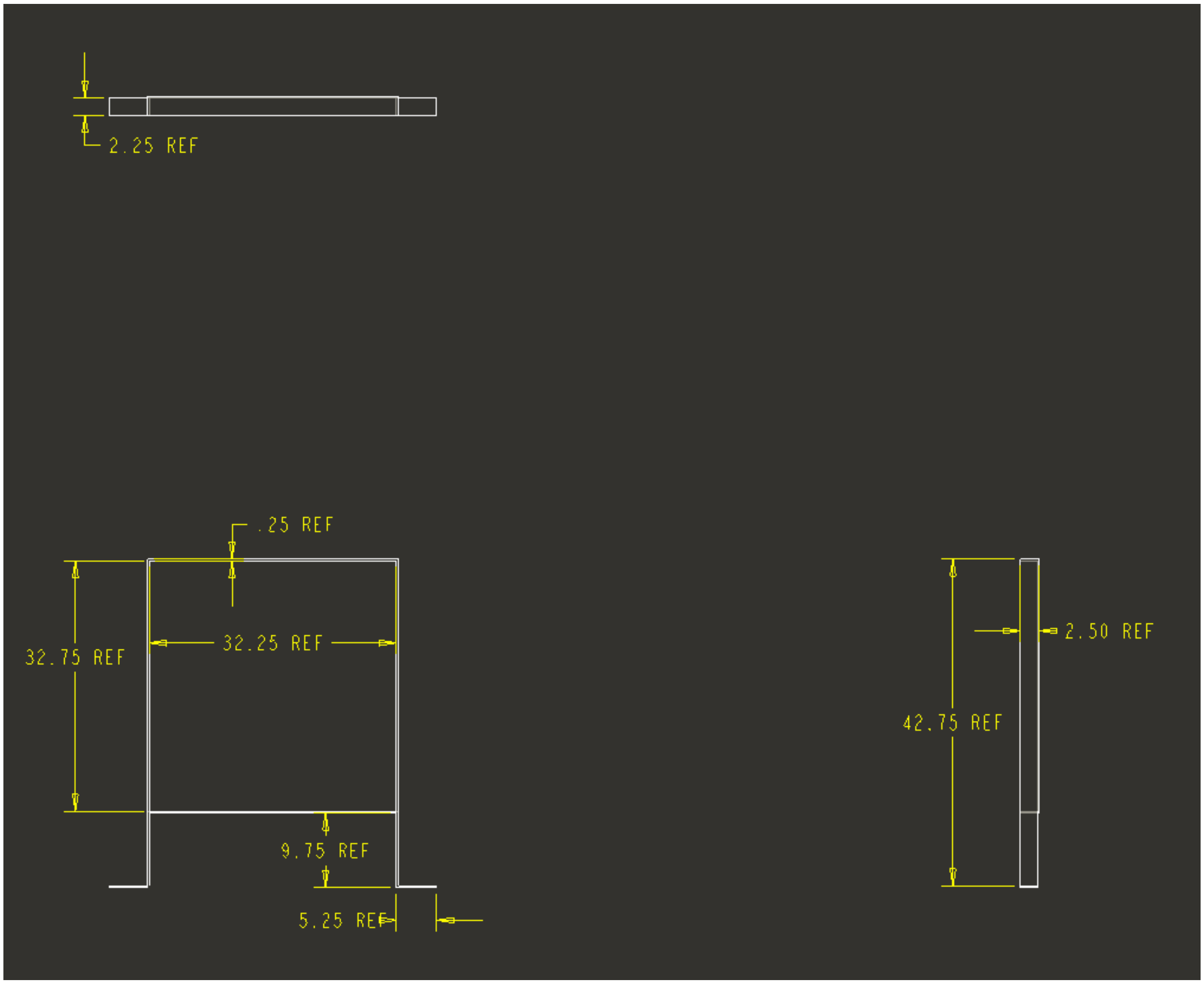
Storage Shelf



3D CAD Model of Storage Shelf

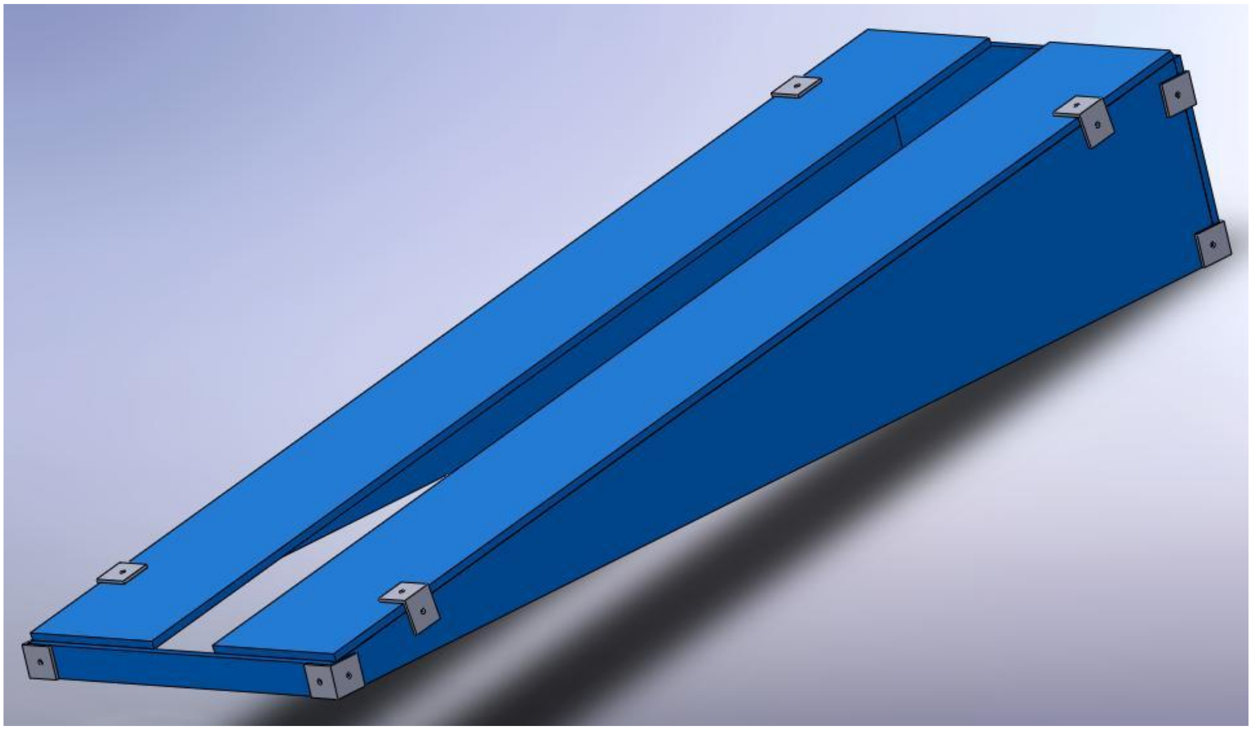


2D Dimensioned drawing o aluminum compartmentalized inserts

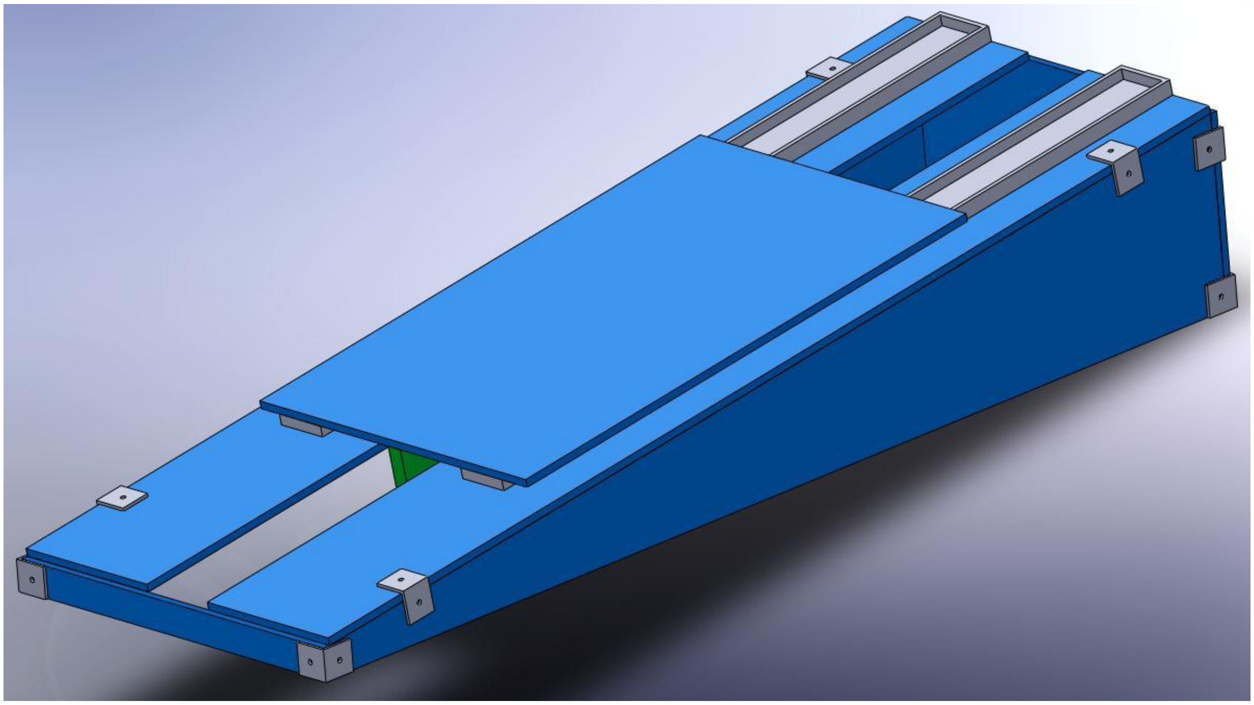


2D Dimensioned drawing of acrylic frame for storage shelf

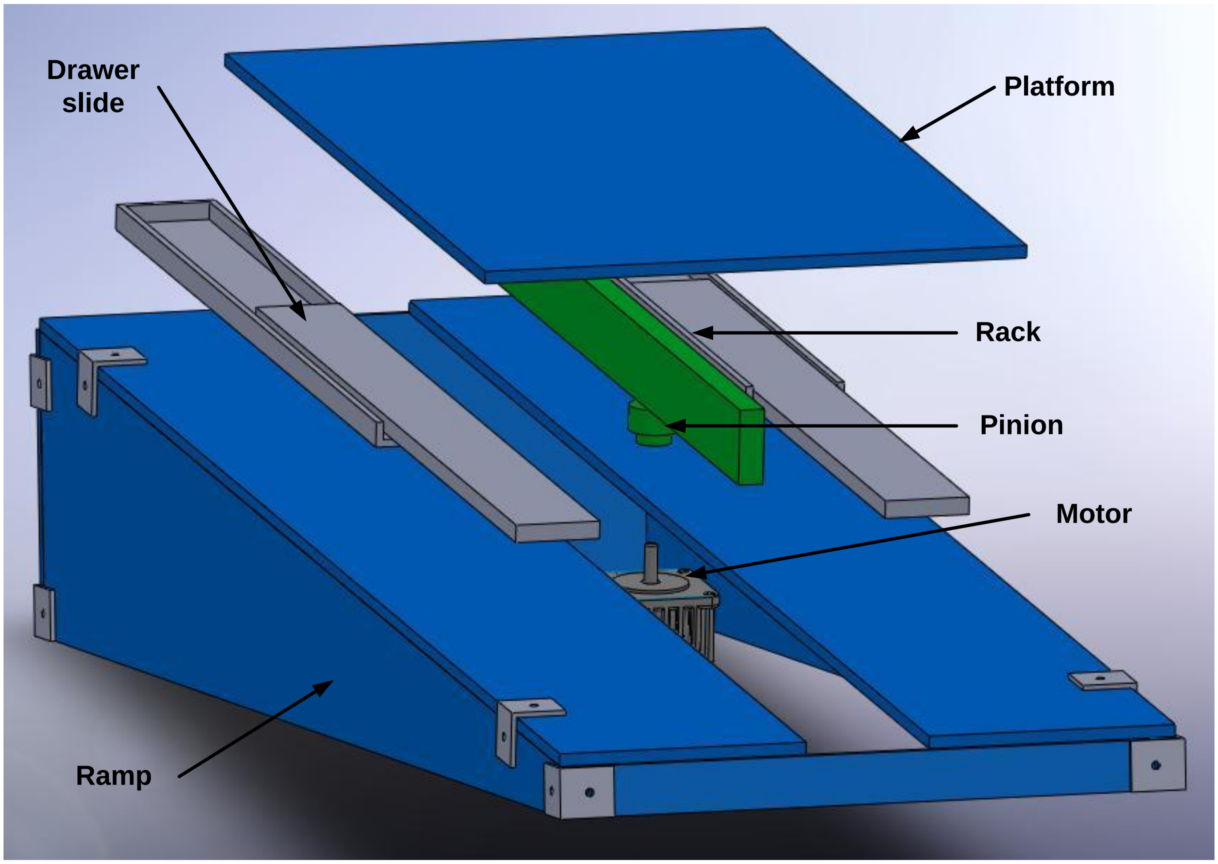
Translating Table



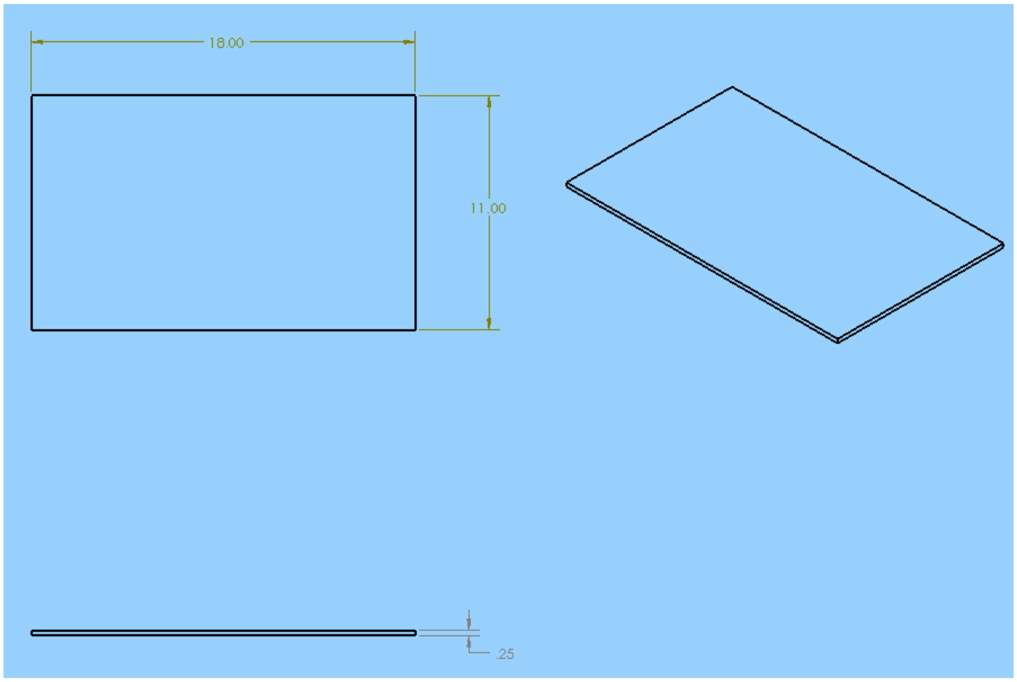
Ramp assembled with aluminum brackets



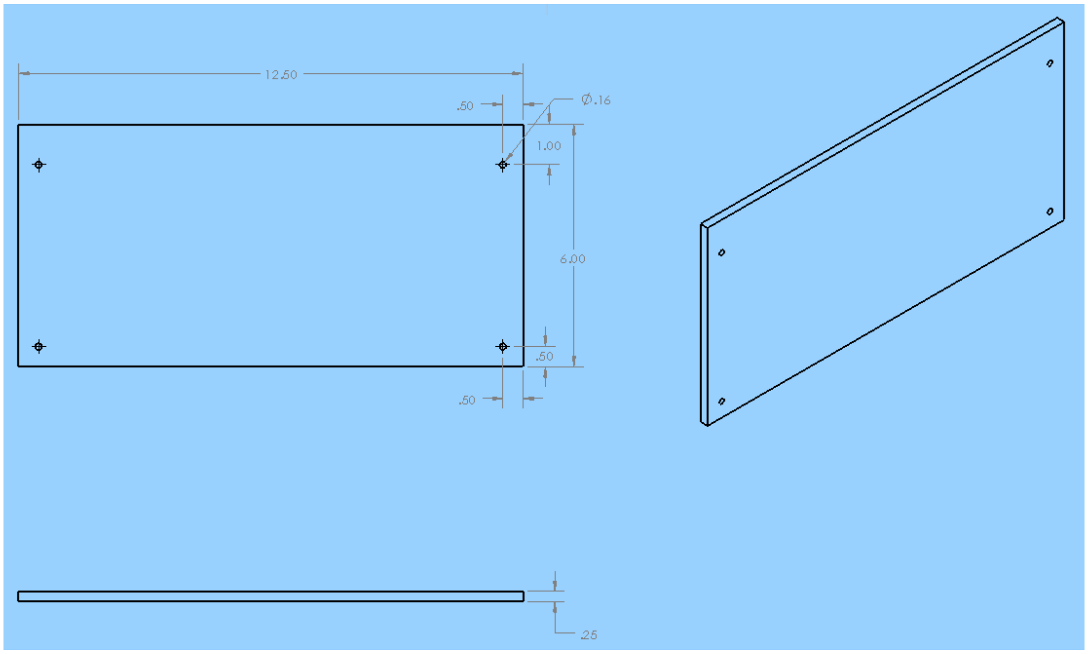
Translating table assembly



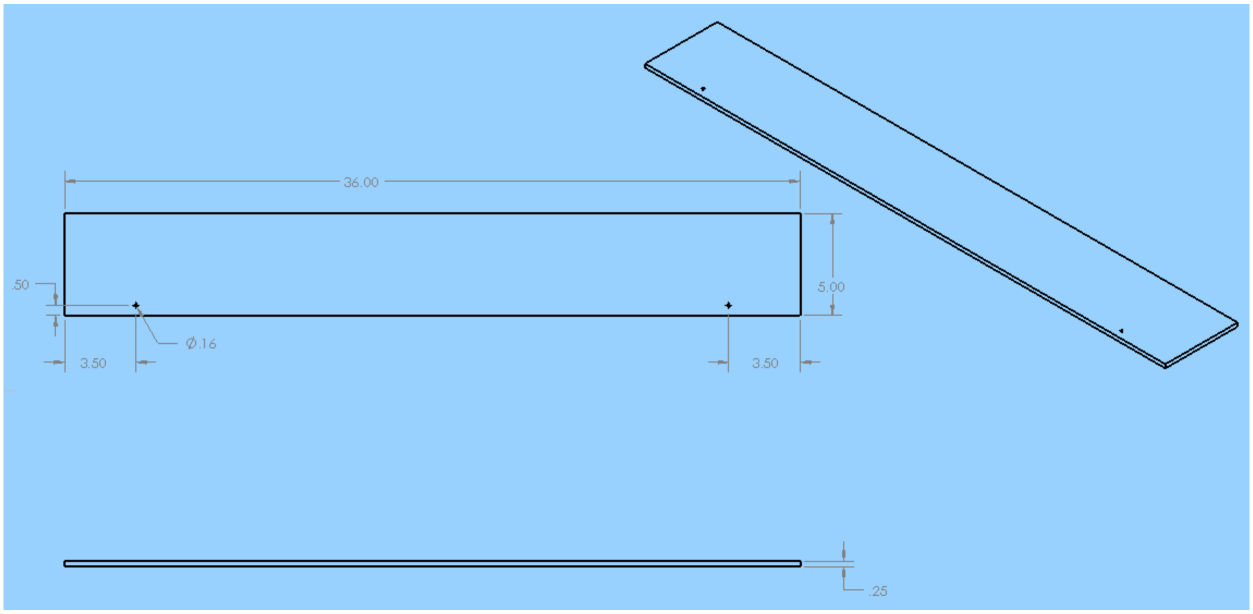
Translating table assembly exploded



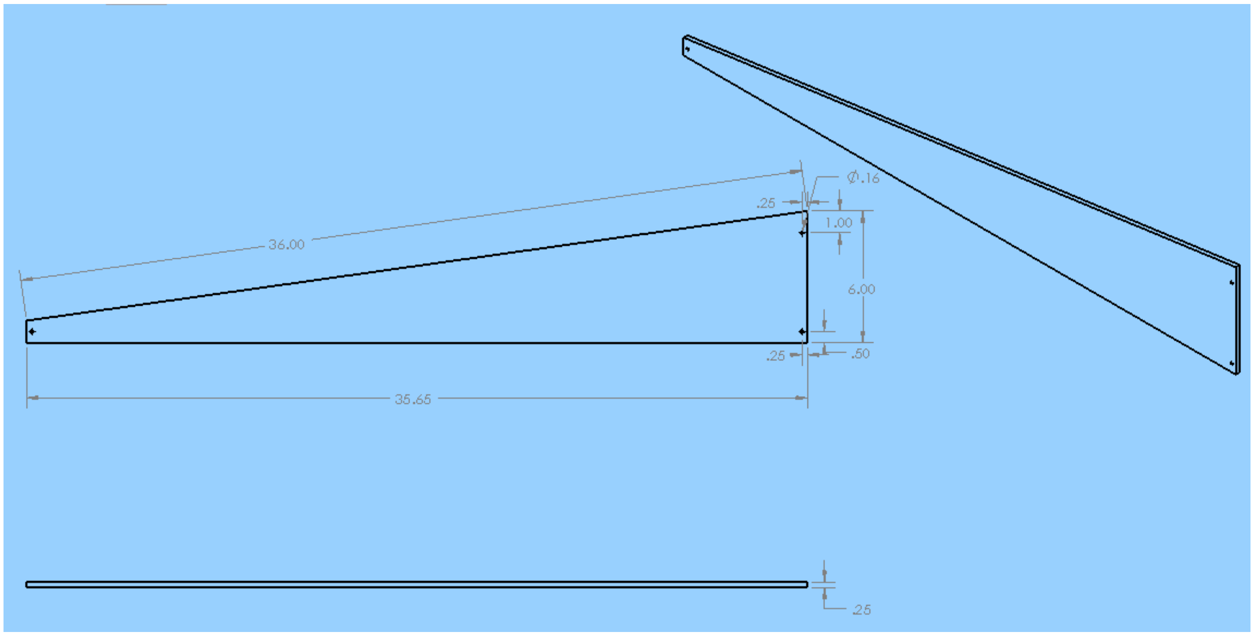
2D Dimensioned Drawing of Platform



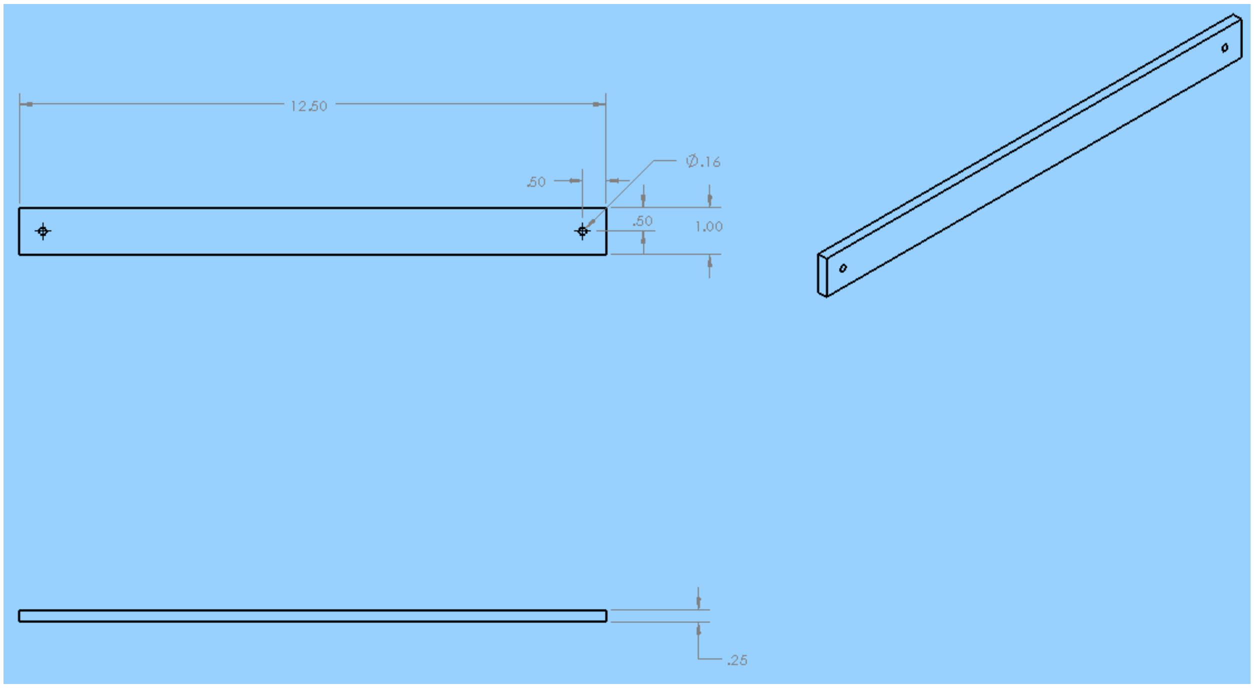
2D Dimensioned Drawing of Back of Ramp



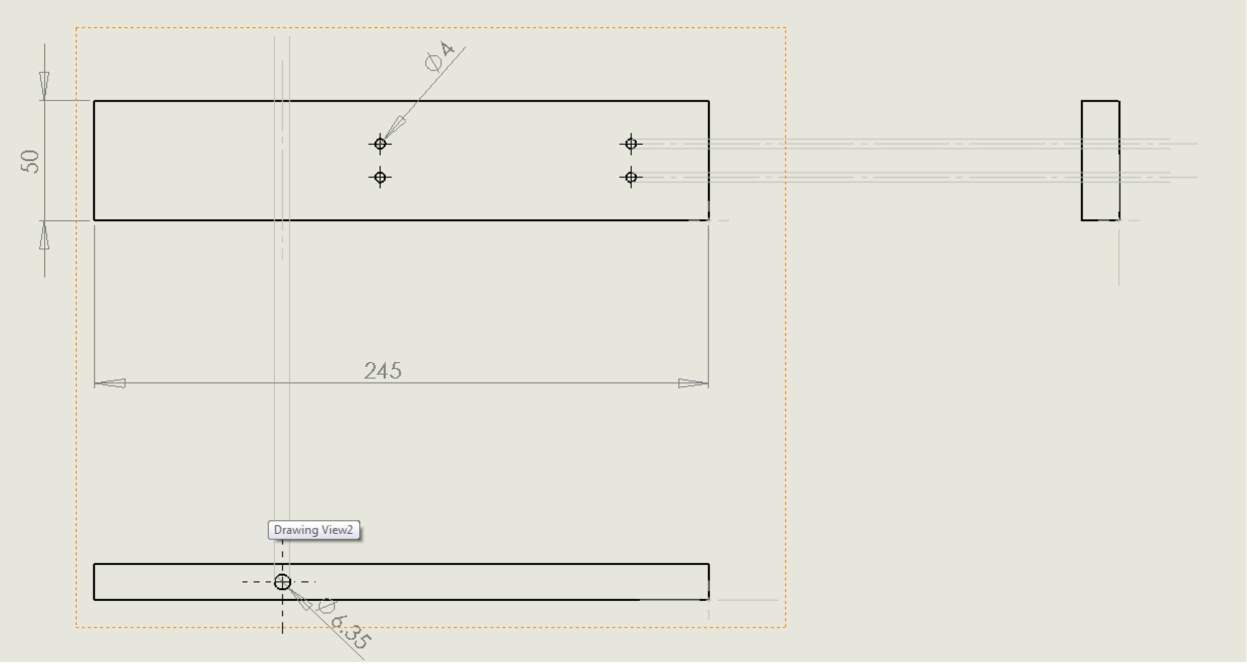
2D Dimensioned Drawing of Top of Ramp



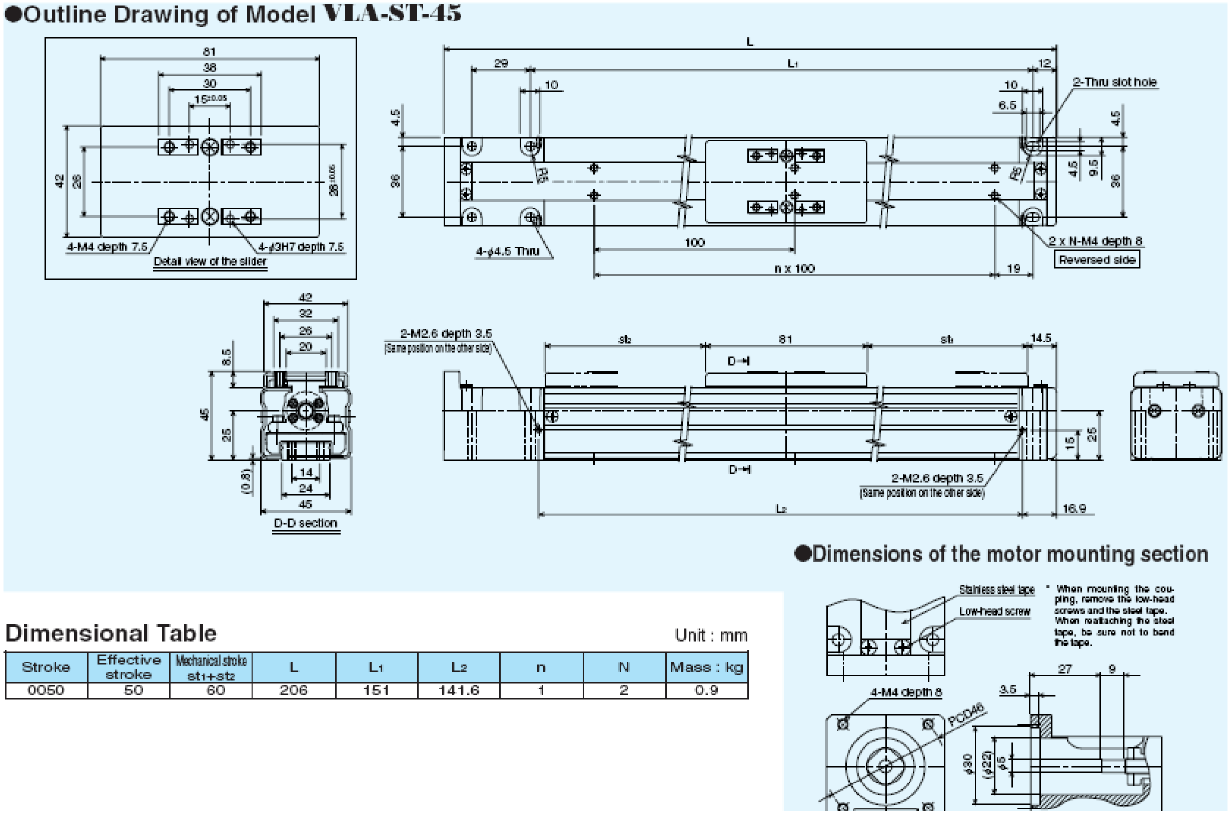
2D Dimensioned Drawing of Side of Ramp



2D Dimensioned Drawing of Front of Ramp



2D Dimensioned Drawing of Rotating Base



●Outline Drawing of Model VLA-ST-45

●Dimensions of the motor mounting section

* When mounting the coupling, remove the low-head screws and the steel tape. When reattaching the steel tape, be sure not to bend the tape.

Dimensional Table

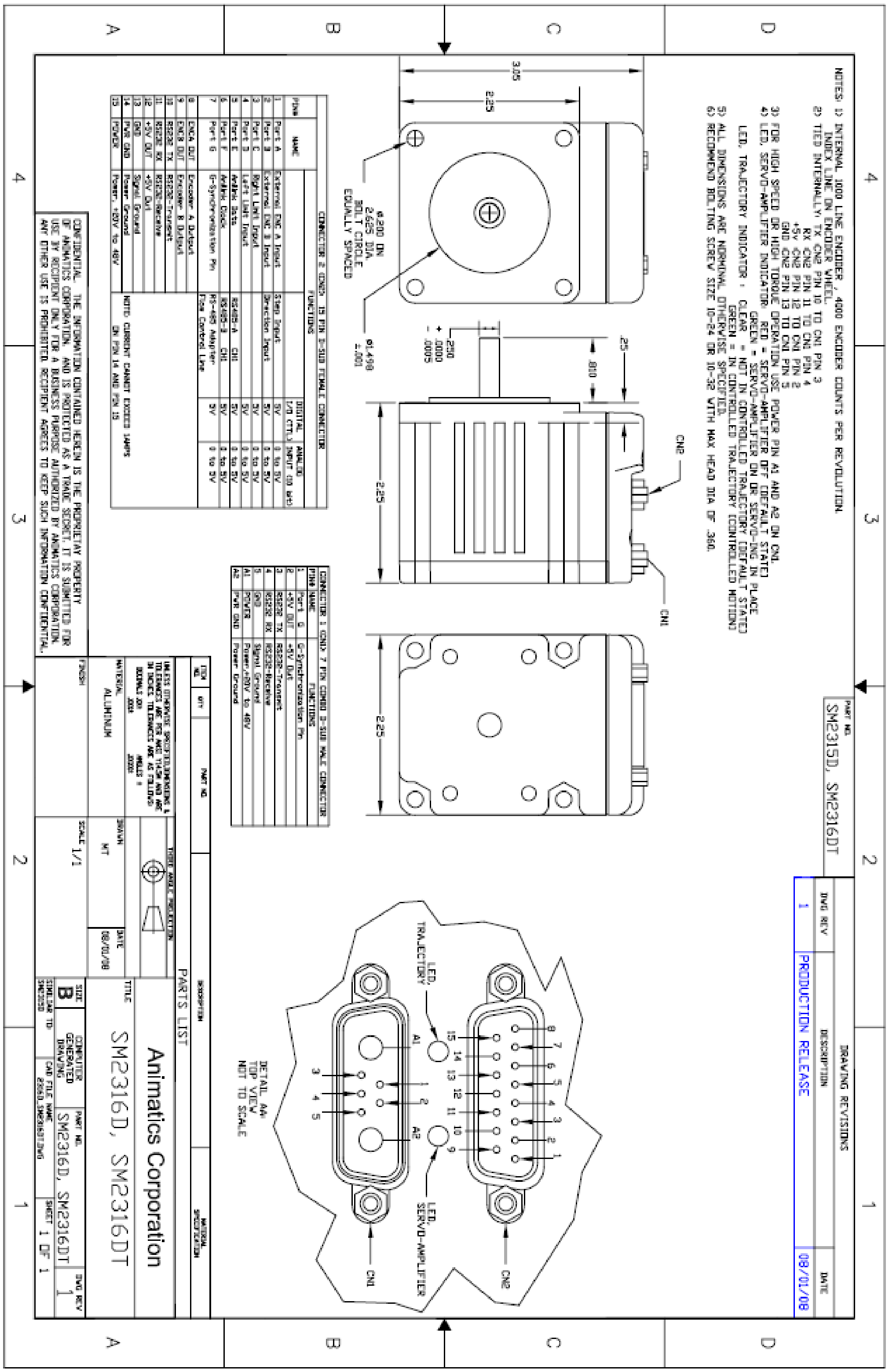
Unit : mm

Stroke	Effective stroke	Mechanical stroke st1+st2	L	L1	L2	n	N	Mass : kg
0050	50	60	206	151	141.6	1	2	0.9

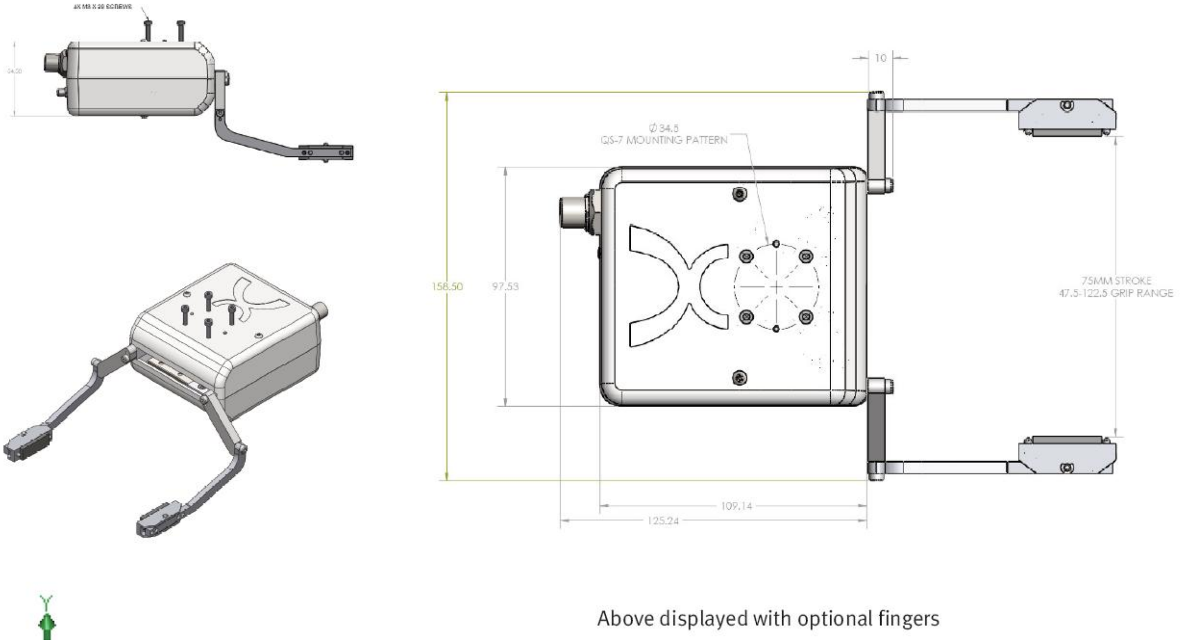
2D Dimensioned Drawing of THK VLA-STA-45 Linear Actuator

https://tech.thk.com/upload/catalog_claim/pdf/320E_VLA.pdf

Old Gripper - Drawings



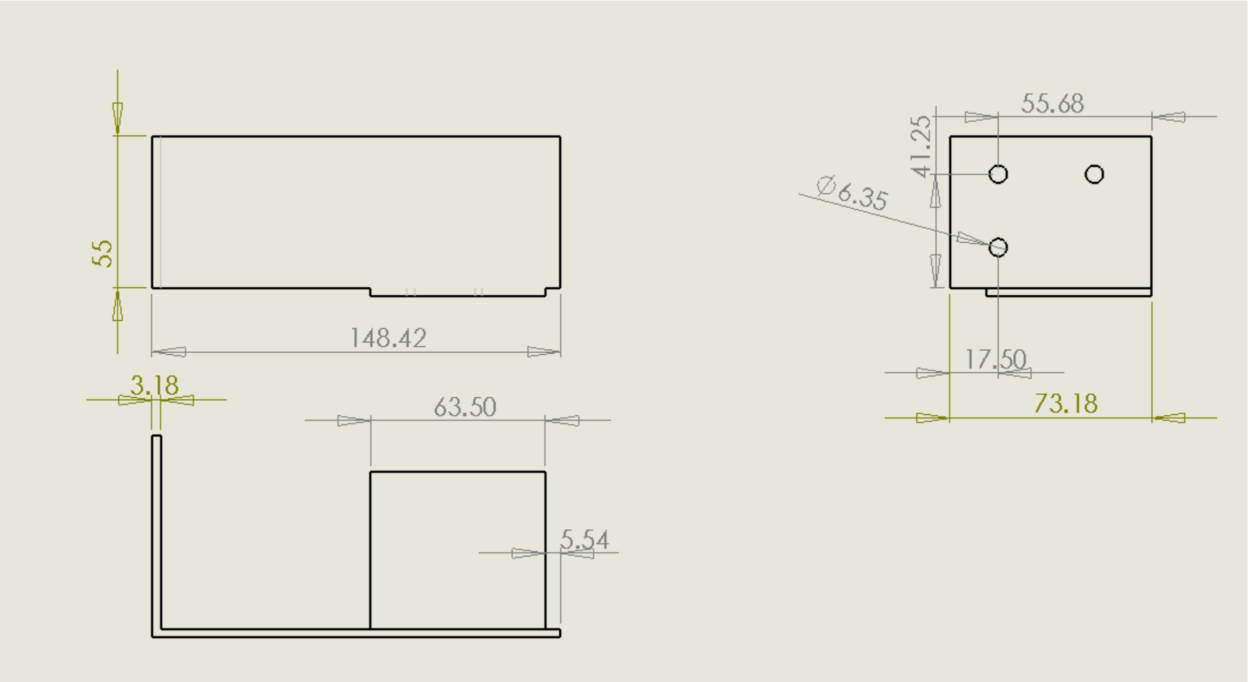
2D Dimensioned Drawing of Animatics SM2316DT http://animatics.com/download/SM2316D_SM2316DT.pdf



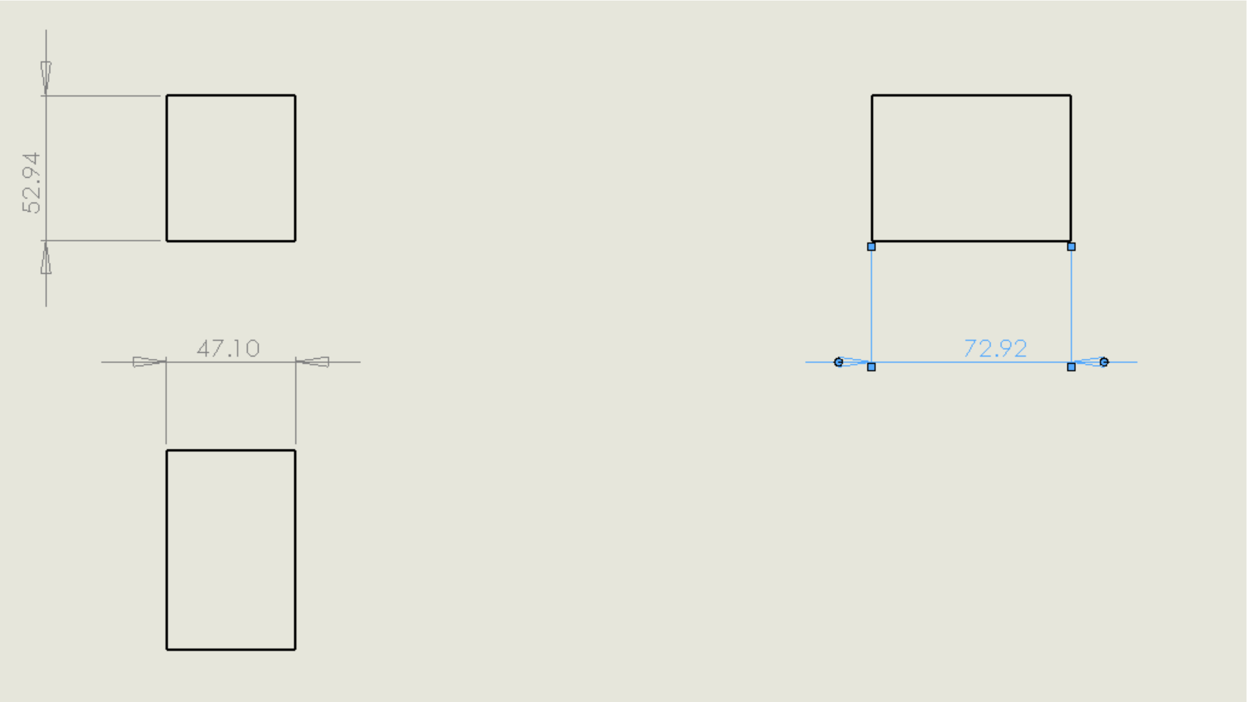
Above displayed with optional fingers

2D Dimensioned Drawing of Smart Gripper 2.0

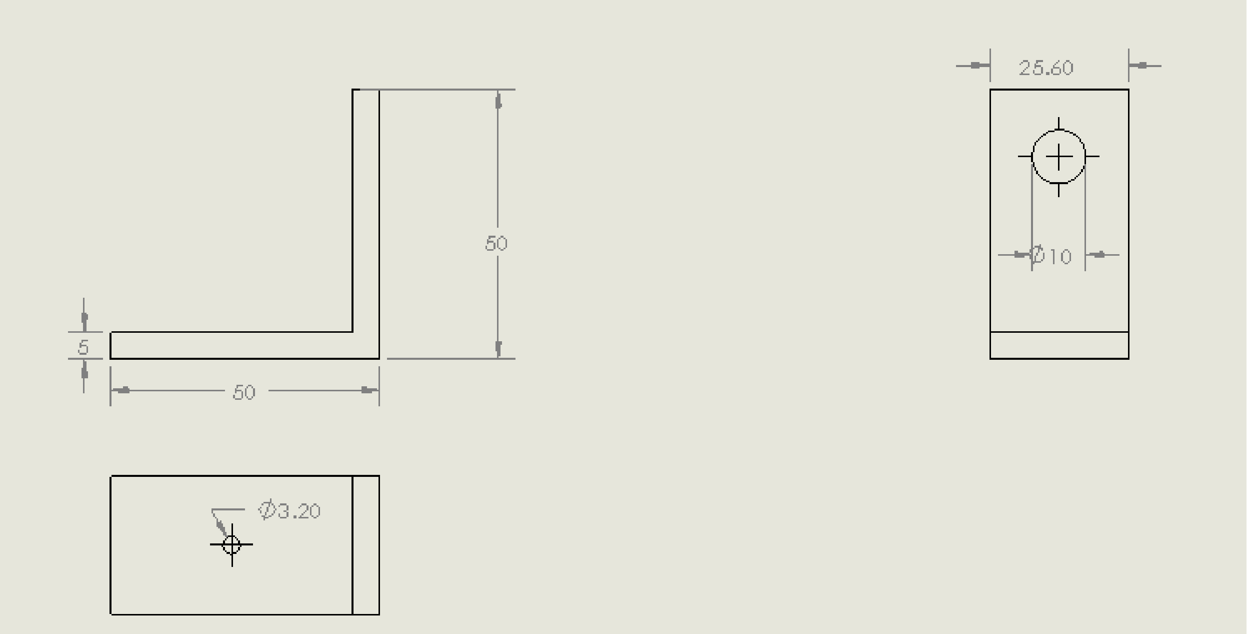
http://appliedrobotics.com/technical/drawingdocs/datasheets/Smart%20Gripper%202.1%20Data%20Sheet060308_final.pdf



2D Dimensioned Drawing of Bracket

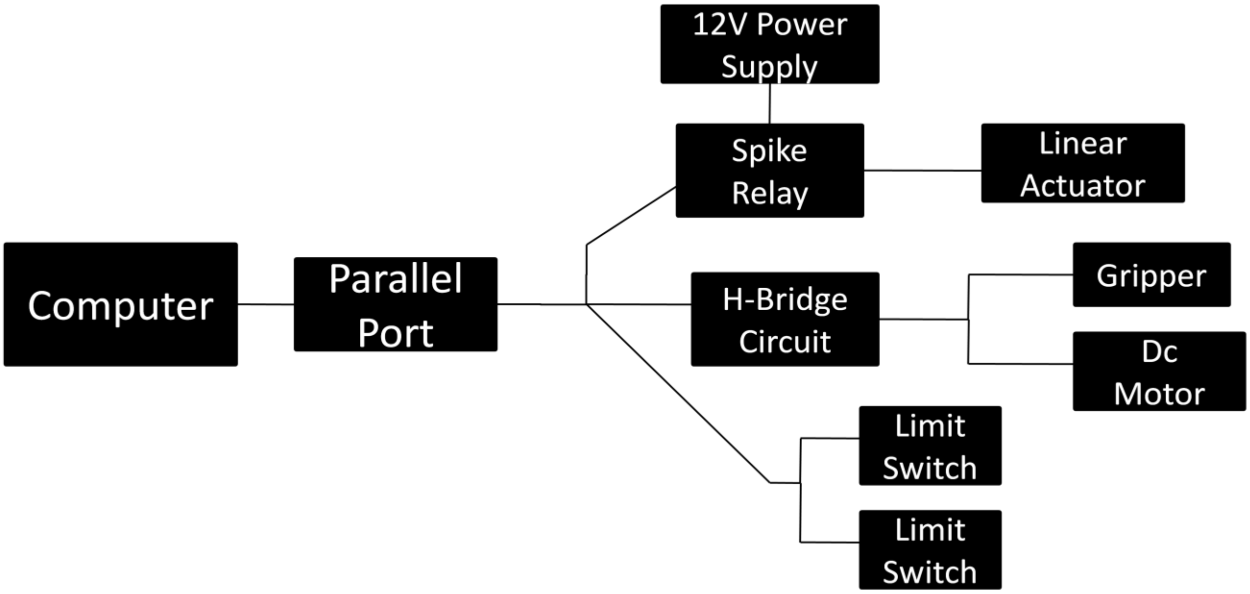


2D Dimensioned Drawing of Counter mass

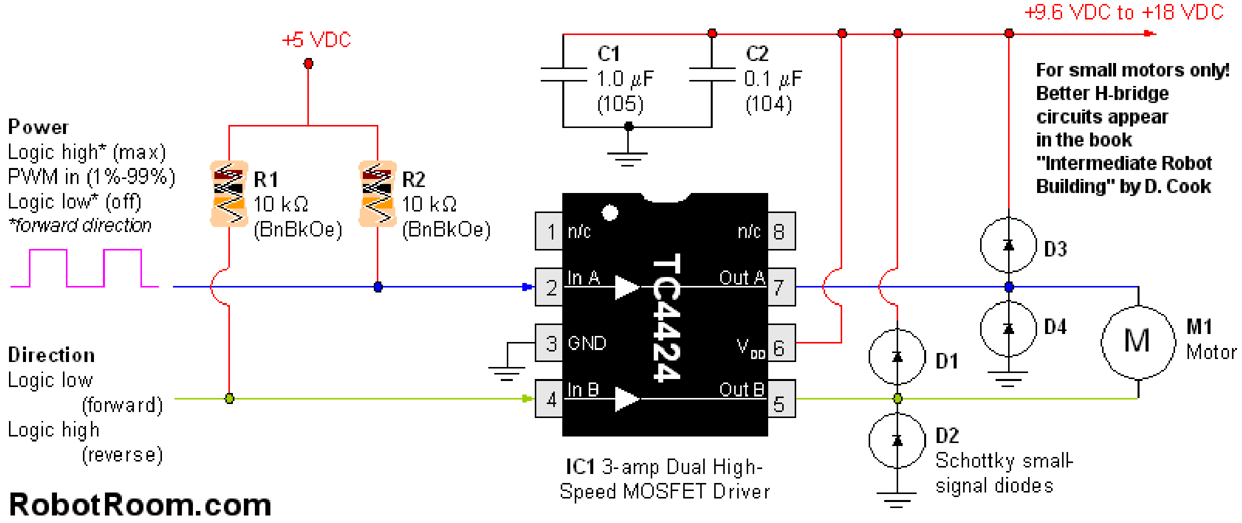


2D L-Bracket Drawing

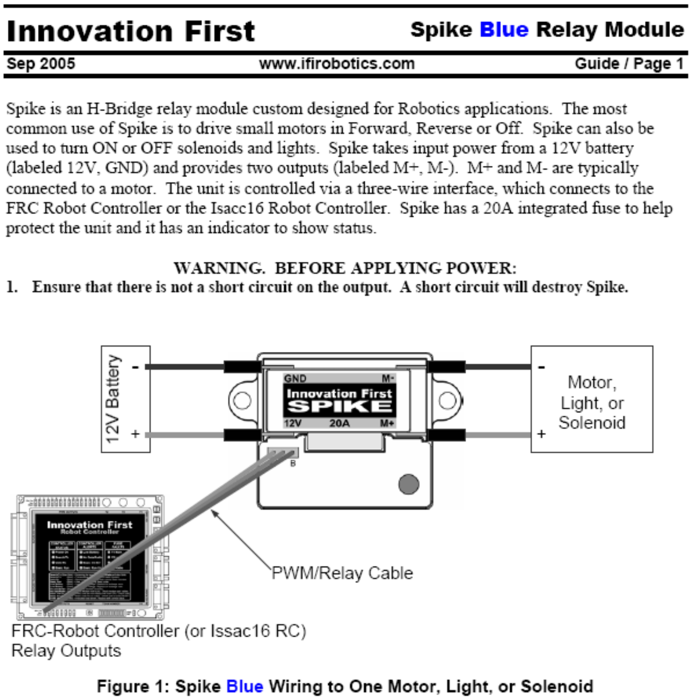
Gripper – Electrical diagrams



Wiring diagram for gripping motion



H-bridge schematic used for gripper



Innovation First **Spike Blue Relay Module**

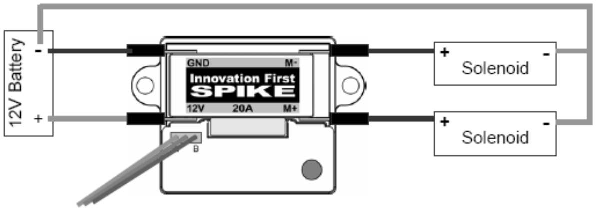
Sep 2005 **www.ifirobotics.com** **Guide / Page 1**

Spike is an H-Bridge relay module custom designed for Robotics applications. The most common use of Spike is to drive small motors in Forward, Reverse or Off. Spike can also be used to turn ON or OFF solenoids and lights. Spike takes input power from a 12V battery (labeled 12V, GND) and provides two outputs (labeled M+, M-). M+ and M- are typically connected to a motor. The unit is controlled via a three-wire interface, which connects to the FRC Robot Controller or the Isacc16 Robot Controller. Spike has a 20A integrated fuse to help protect the unit and it has an indicator to show status.

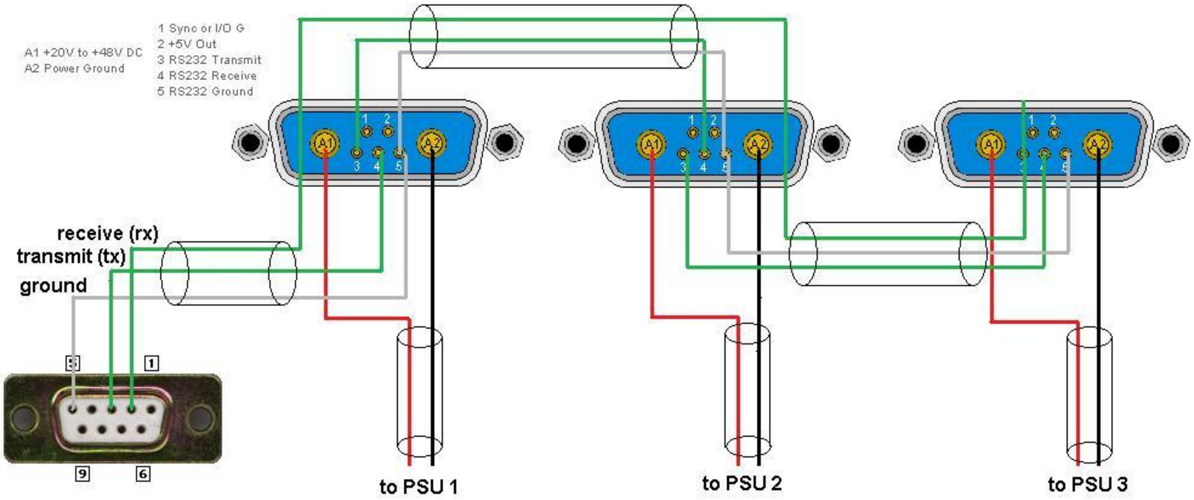
WARNING. BEFORE APPLYING POWER:

1. Ensure that there is not a short circuit on the output. A short circuit will destroy Spike.

Figure 1: Spike Blue Wiring to One Motor, Light, or Solenoid



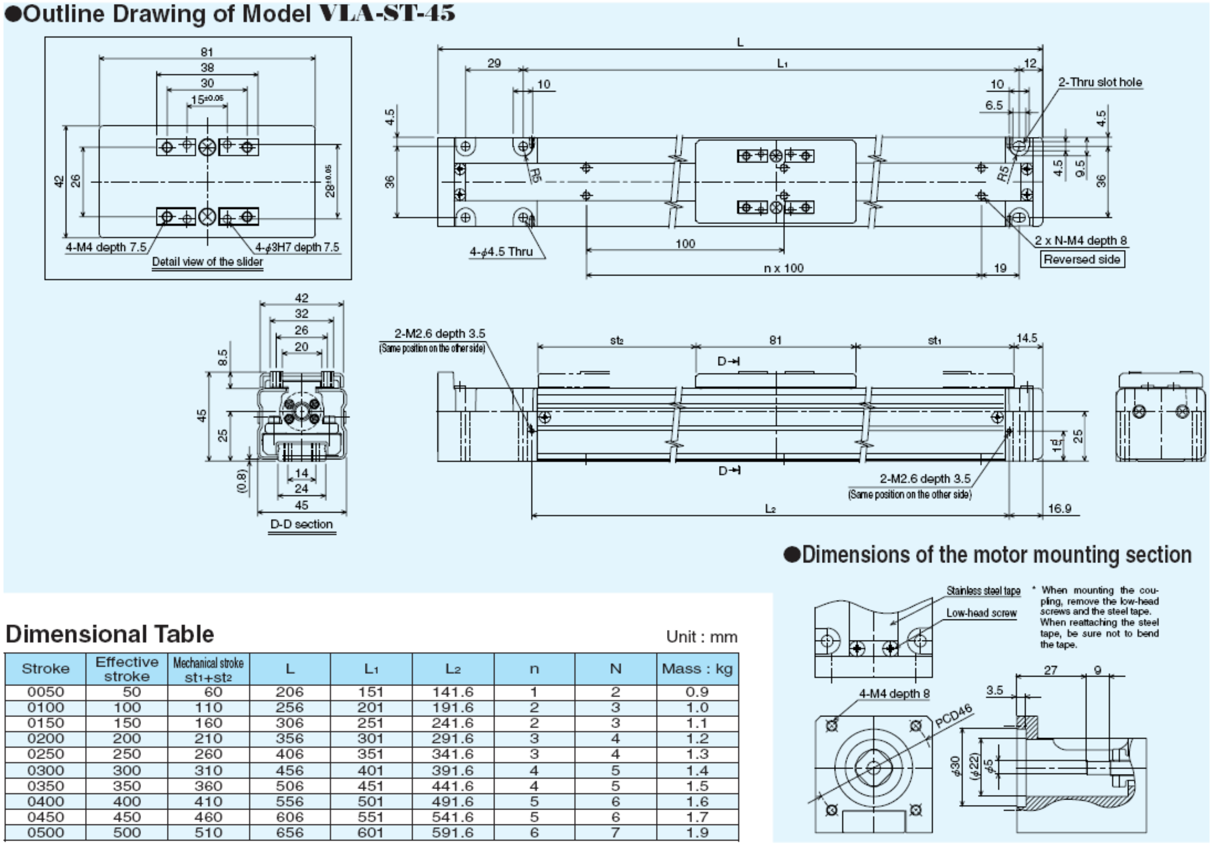
Spike relay used for gripper



Daisy chained motor cable

APPENDIX D – ECN DIAGRAMS

From:



●Outline Drawing of Model VLA-ST-45

●Dimensions of the motor mounting section

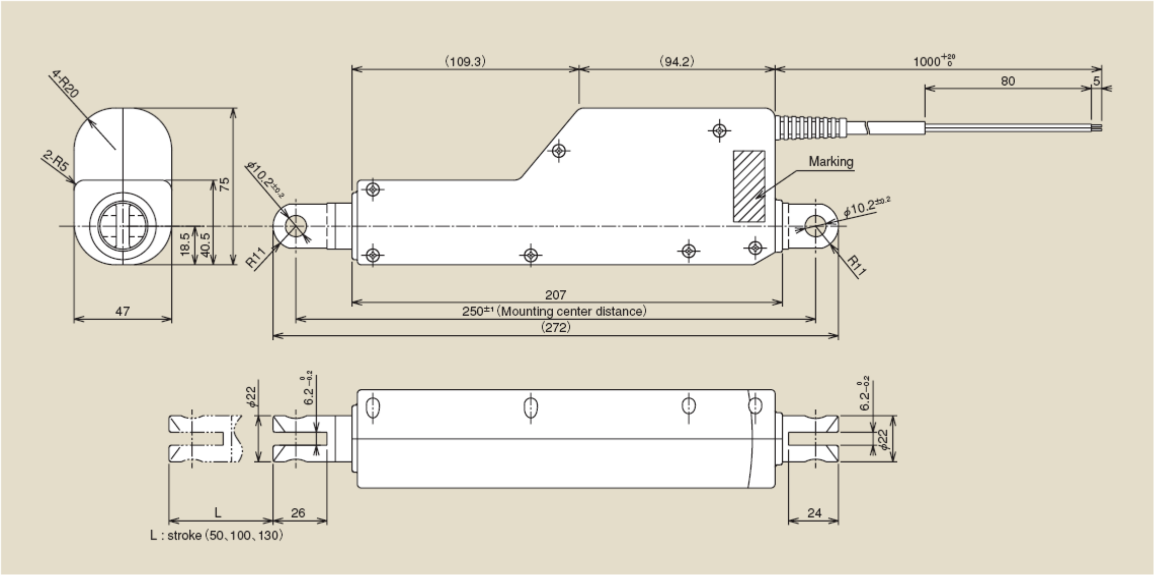
* When mounting the coupling, remove the low-head screws and the steel tape. When reattaching the steel tape, be sure not to bend the tape.

Dimensional Table

Unit : mm

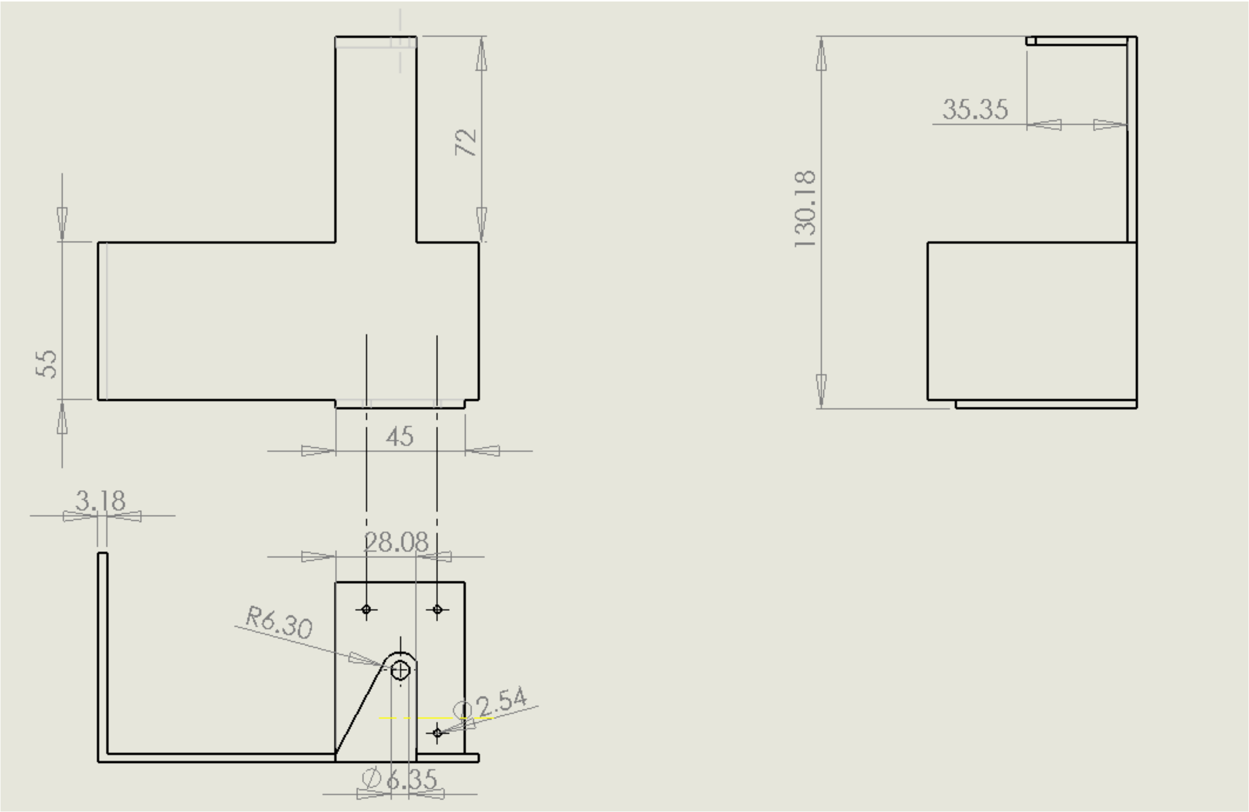
Stroke	Effective stroke	Mechanical stroke st_1+st_2	L	L_1	L_2	n	N	Mass : kg
0050	50	60	206	151	141.6	1	2	0.9
0100	100	110	256	201	191.6	2	3	1.0
0150	150	160	306	251	241.6	2	3	1.1
0200	200	210	356	301	291.6	3	4	1.2
0250	250	260	406	351	341.6	3	4	1.3
0300	300	310	456	401	391.6	4	5	1.4
0350	350	360	506	451	441.6	4	5	1.5
0400	400	410	556	501	491.6	5	6	1.6
0450	450	460	606	551	541.6	5	6	1.7
0500	500	510	656	601	591.6	6	7	1.9

To:

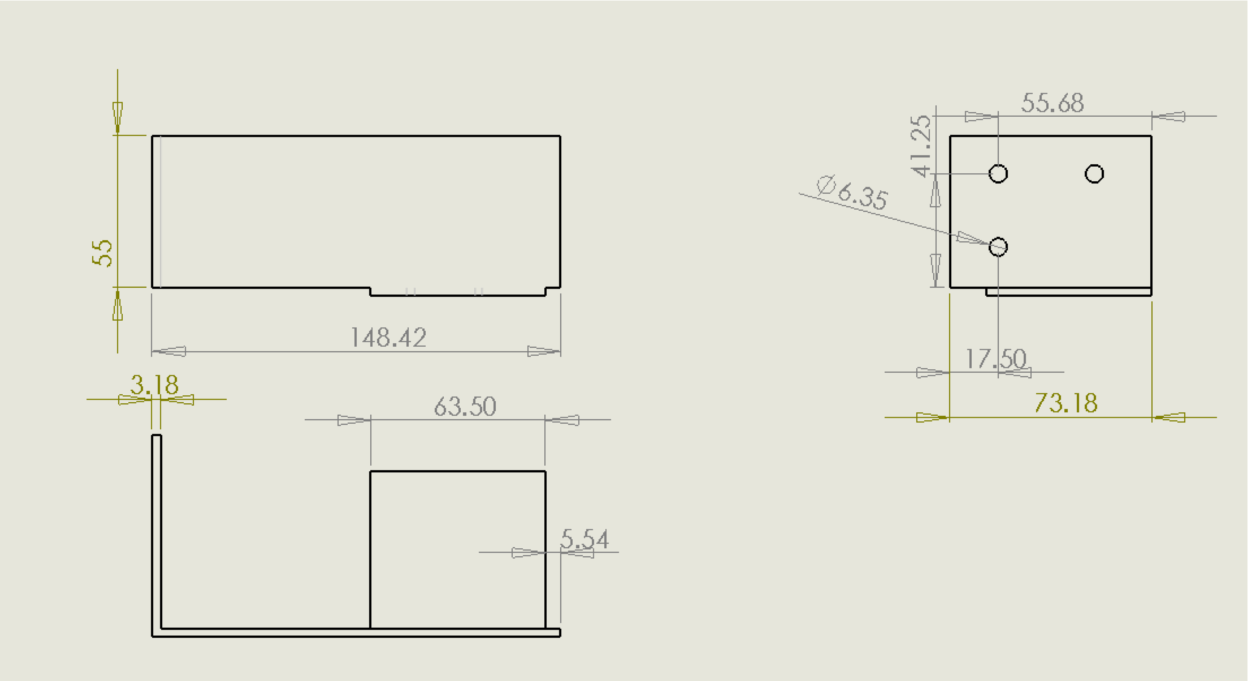


This change affects the gripper actuating function, and was made due to the long lead time of the VLA linear actuator. Justin Booms made this change 11/19/08, approved by Grant Kruger

From:

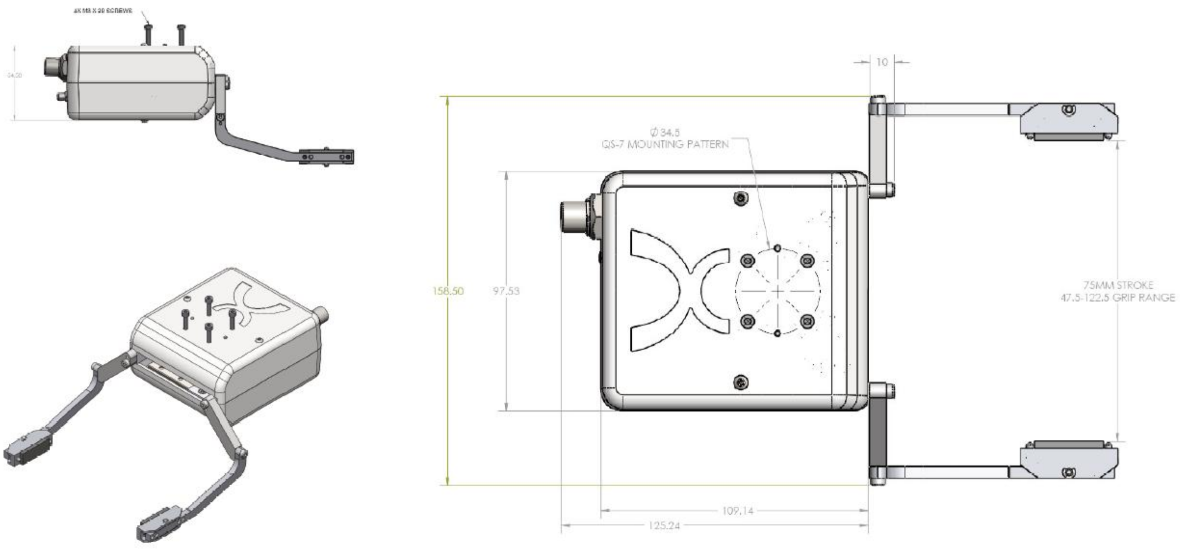


To:



This change affects the slide, linear actuator, and the way the bracket is mounted to the XZ table. This change was made due to the unnecessary features of the original bracket requiring additional machining.. Justin Booms made this change 11/19/08.

From:

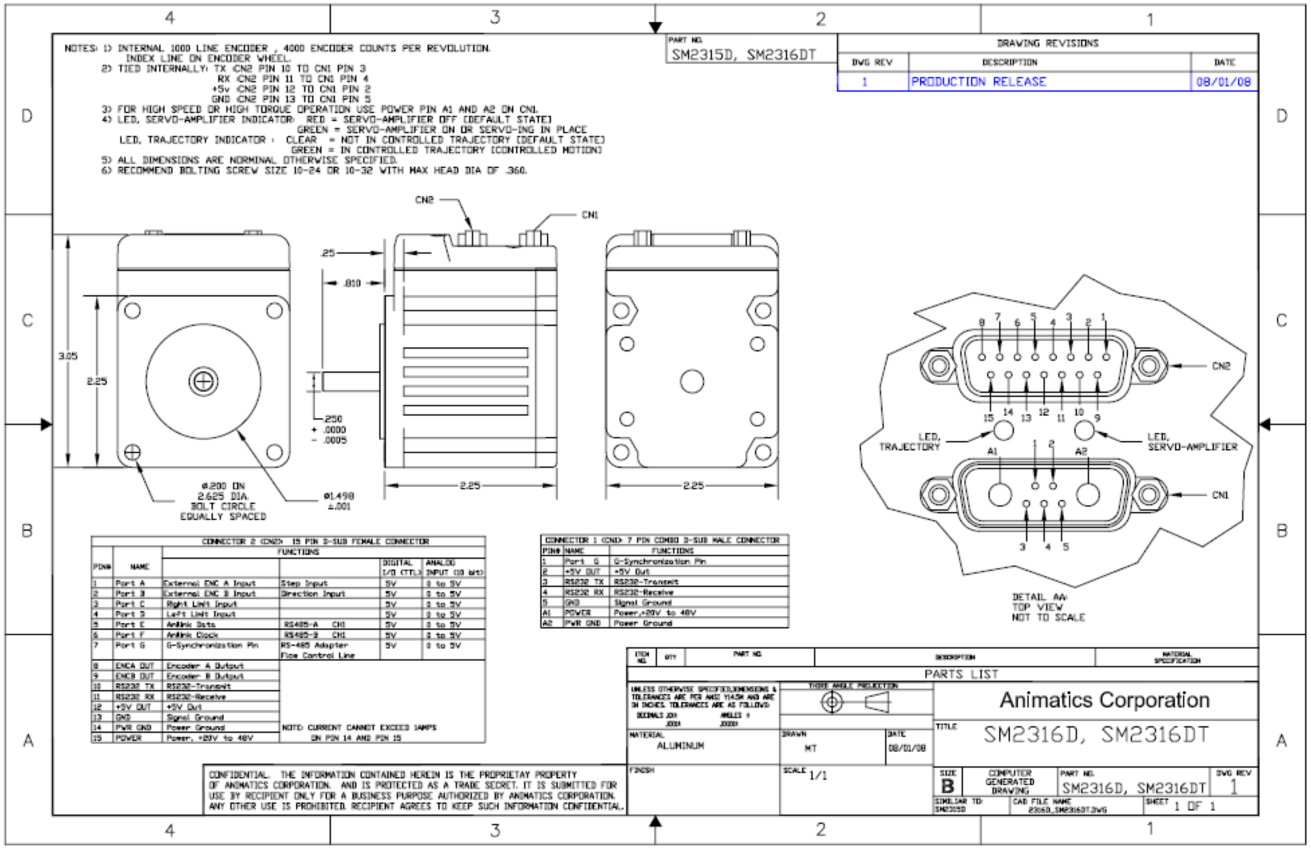


Above displayed with optional fingers

To:

This change affects the gripper. This change was made due to large size of the SmartGripper 2.0, the extensive programming required, and the TransGripper accomplishes 2 motions. Justin Booms made this change 11/30/08.

From:



NOTES: 1) INTERNAL 1000 LINE ENCODER , 4000 ENCODER COUNTS PER REVOLUTION.
INDEX LINE ON ENCODER WHEEL.
2) TIED INTERNALLY: TX (CN2 PIN 10 TO CN1 PIN 3
RX (CN2 PIN 11 TO CN1 PIN 4
+5v (CN2 PIN 12 TO CN1 PIN 2
GND (CN2 PIN 13 TO CN1 PIN 5
3) FOR HIGH SPEED OR HIGH TORQUE OPERATION USE POWER PIN A1 AND A2 ON CN1.
4) LED, SERVO-AMPLIFIER INDICATOR: RED = SERVO-AMPLIFIER OFF [DEFAULT STATE]
GREEN = SERVO-AMPLIFIER ON OR SERVO-ING IN PLACE
LED, TRAJECTORY INDICATOR : CLEAR = NOT IN CONTROLLED TRAJECTORY [DEFAULT STATE]
GREEN = IN CONTROLLED TRAJECTORY [CONTROLLED MOTION]
5) ALL DIMENSIONS ARE NORMINAL OTHERWISE SPECIFIED.
6) RECOMMEND BOLTING SCREW SIZE 10-24 OR 10-32 WITH MAX HEAD DIA OF .360.

CONNECTOR 2 (CN2) 15 PIN D-SUB FEMALE CONNECTOR

PIN#	NAME	FUNCTIONS			
				DIGITAL I/O (TTL)	ANALOG INPUT (10 bit)
1	Port A	External ENC A Input	Step Input	5V	0 to 5V
2	Port B	External ENC B Input	Direction Input	5V	0 to 5V
3	Port C	Right Limit Input		5V	0 to 5V
4	Port D	Left Limit Input		5V	0 to 5V
5	Port E	Anilink Data	RS485-A CH1	5V	0 to 5V
6	Port F	Anilink Clock	RS485-B CH1	5V	0 to 5V
7	Port G	G-Synchronization Pin	RS-485 Adapter Flow Control Line	5V	0 to 5V
8	ENCA OUT	Encoder A Output			
9	ENCB OUT	Encoder B Output			
10	RS232 TX	RS232-Transmit			
11	RS232 RX	RS232-Receive			
12	+5V OUT	+5V Out			
13	GND	Signal Ground			
14	PWR GND	Power Ground			
15	POWER	Power, +20V to 48V			

NOTE: CURRENT CANNOT EXCEED 1AMPS ON PIN 14 AND PIN 15

CONNECTOR 1 (CN1) 7 PIN COMBO D-SUB MALE CONNECTOR

PIN#	NAME	FUNCTIONS
1	Port G	G-Synchronization Pin
2	+5V OUT	+5V Out
3	RS232 TX	RS232-Transmit
4	RS232 RX	RS232-Receive
5	GND	Signal Ground
A1	POWER	Power,+20V to 48V
A2	PWR GND	Power Ground

DETAIL AA:
TOP VIEW
NOT TO SCALE

PART NO.	
SM2315D, SM2316DT	

DRAWING REVISIONS

DWG REV	DESCRIPTION	DATE
1	PRODUCTION RELEASE	08/01/08

ITEM NO.	QTY	PART NO.	DESCRIPTION	MATERIAL SPECIFICATION

PARTS LIST

UNLESS OTHERWISE SPECIFIED,DIMENSIONS & TOLERANCES ARE PER ANSI Y14.5M AND ARE IN INCHES. TOLERANCES ARE AS FOLLOWS:
DECIMALS .XX± .XXX± ANGLES ± .XXX±

THIRD ANGLE PROJECTION

Animatics Corporation

TITLE SM2316D, SM2316DT

MATERIAL ALUMINUM

DRAWN MT

DATE 08/01/08

FINISH

SCALE 1/1

SIZE B

COMPUTER GENERATED DRAWING

PART NO. SM2316D, SM2316DT

DWG REV 1

SIMILAR TO: SM2315D

CAD FILE NAME 2316D_SM2316DT.DWG

SHEET 1 OF 1

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APPENDIX E- BILL OF MATERIALS

Qty	Prt. Desc.	Purchased From	Part #	Price (ea.)	Subsystem
1	12" x 12" x 1/8" Aluminum Sheet	McMaster-Carr	1651T31	$37.16	Gripper
2	SPDT Switch Without Roller	RadioShack	275-016	$2.99	Gripper
1	Rokenbok RC TransGripper & Trailer	Ryder's Hobby Shop	#04245	$64.99	Gripper
1	Threaded Lamp Pipe	Home Depot	70603	$1.57	Gripper
1	Package of Felt Pads	Home Depot	70700	$1.98	Gripper
1	Pack of 4 1-1/2" Corner Brackets	Home Depot	339563	$2.29	Gripper
1	Pack of 8 Rounded Machine Bolt and Nuts	Home Depot	27611	$1.79	Gripper
1	U-Bolt 5/16" x 2.5" x 5.19"	Ace Hardware	51617	$2.99	Gripper
1	Sq. U-Bolt 3/8" x 3" x 6"	Ace Hardware	55407	$3.99	Gripper
1	Drawer Slides, 14" Full Extension	Home Depot	D75014-ZP-A	$12.33	Gripper
1	Symbol Mini Barcode Scanner	University of Michigan	MS4400	$0.00	Gripper
1	THK Waterproof CRES Rod Actuator	Small Parts	CRES200-100-12	$269.33	Gripper
1	H-Bridge Relay Module, 20A.	IFI Robotics	SPIKE-RELAY-H	$34.95	Gripper
1	Pinion: 16 Pitch— 1/2" Face Width; 1" OD	McMaster-Carr	6325K12	$12.68	Translating Platform
1	Rack: 16 Pitch— 1/2" Face Width; 2' length	McMaster-Carr	6295K14	$21.05	Translating Platform
2	Liberty Ball Bearing Full Extension 18 In. Model D43	Home Depot	D80618C-UC-CU	$13.48	Translating Platform
1 pack (100)	Crown Bolt LLC #8-32 x 1/2 In. Machine Screw, Round-Head	Home Depot	27622	$4.24	Translating Platform; Shelf
1 pack (100)	Crown Bolt LLC #8-32 Machine Screw Nut Coarse Thread Zinc Plated	Home Depot	18512	$2.98	Translating Platform; Shelf
1 pack (100)	Crown Bolt LLC #8 Washer Sae Zinc Plated	Home Depot	19802	$3.24	Translating Platform; Shelf
1 pack (8)	Crown Bolt LLC #8-32 x 3/4 In. Socket Cap Screw Flat Head Stainless Steel	Home Depot	69898	$0.98	Translating Platform
2 pack	#10-32 x 3 In. Bolt and Nut	Home Depot		$0.98	Translating Platform; Shelf

(3)					
1	Acrylic Sheet 1/4 thick, 3'x6'	Home Depot		$60.00	Translating Platform
2	Crown Bolt LLC 1 In. x 36 In., 1/8 In. Thick Angle Aluminum	Home Depot	41880	$9.27	Translating Platform; Shelf
1	Animatics Smart Motor SMD2315	University of Michigan		$0.00	Translating Platform
1	Threaded Rod 18" length	University of Michigan		$0.00	Translating Platform
8	5/16" bolt	University of Michigan		$0.00	Translating Platform
8	5/16" nut	University of Michigan		$0.00	Translating Platform
8	Washers	University of Michigan		$0.00	Translating Platform
1	Aluminum tubing 1" length	University of Michigan		$0.00	Translating Platform
1	Acrylic Sheet 0.118" thick, 3'X6'	Home Depot		-	Shelf
3	Aluminum sheet, .02" thick, 36"x36"	Home Depot		$19.27	Shelf
2	Steel angle bracket (dimensions)	University of Michigan		$ -	Shelf
840	Inches of t-slot extruded aluminum, 1.5 x 1.5 in	HH Barnum	650006	$408.24	System frame
36	T-slot corner bracket	HH Barnum	653136	$114.48	System frame
56	Economy t-nut	HH Barnum	651097	$15.90	System frame
56	Economy t-nut and cap screw package	HH Barnum	651129	$36.18	System frame
1	HLD60 with external single rails actuator, 784mm Stroke, 10mm/rev pitch, including a SM2316DT, Plus firmware, 4000cnt/rev encoder, Drive Enable, 12:00 orientation.	Axis Systems	H2-0784-100B-23F-P1N1N0N	$3,029.00	XZ Cartesian System
1	HLD60 with external dual rails actuator, 784mm Stroke, 10mm/rev pitch, including a SM2316DT, Plus firmware, 4000cnt/rev encoder, Drive Enable, 12:00 orientation.	Axis Systems	H2-0784-100E-23F-P1N1N0N	$3,534.00	XZ Cartesian System
2	Switching power supply, 48 V, 10 A	Axis Systems	PFC500W-48	$420.00	XZ Cartesian System
4	NPN Magnetic sensor, NC, Flying Leads	Axis Systems	SEN-NC-1M	$220.00	XZ Cartesian System
6	Toe Clamp for HLD60, 2 holes	Axis Systems	HLD60-TC2	$210.00	XZ Cartesian System
	Wire	Home Depot		$9.38	XZ Cartesian System
	Wire connectors	Home Depot		$11.96	XZ Cartesian System
	Wire + ethernet cable	Carpenter brothers		$18.02	XZ Cartesian

					System
	Solder and solder wick	RadioShack		$9.48	XZ Cartesian System
	Wire mounts	RadioShack		$6.58	XZ Cartesian System
	Dsub connectors and pins	RadioShack		$7.96	XZ Cartesian System
	Wire ties	RadioShack		$8.47	XZ Cartesian System
	USB to serial cable	RadioShack		$34.99	XZ Cartesian System
	Fasteners	Home Depot		$10.39	XZ Cartesian System
	Solder	Ace Hardware		$6.29	XZ Cartesian System
	Ethernet cable	Ace Hardware		$19.99	XZ Cartesian System
	Fasteners	Ace Hardware		$3.60	XZ Cartesian System
	Power cords	Ace Hardware		$18.98	XZ Cartesian System
	Wire	Ace Hardware		$28.98	XZ Cartesian System
			Total:	**$8,831.68**	

APPENDIX F – INFORMATION SOURCES AND BENCHMARKING

This section provides an overview of technology that relates to our project. Since no machines currently exist for pathology block sorting, the focus of this research is on automated machines used in a variety of industries for sorting, manufacturing, and product handling.

ARUP Laboratory

The ARUP laboratory at the University of Utah is a large research and testing laboratory and uses advanced technology in the sorting and storage of its clinical pathology (i.e. bodily fluid) specimens, including an automated storage and retrieval system (Figure 56). This is a fully automated system which stores over 5000 trays and can retrieve trays in less than 2.5 minutes. The storage area is a two story freezer with a one story anteroom refrigerator, which is used as the interface between the ambient air and the freezer [1]. Inbound and outbound conveyor belts are used to input specimens or retrieve them and tracking numbers allow retrieval of a specified specimen. Robotic cranes are used to shuttle specimens to and from their shelf locations.

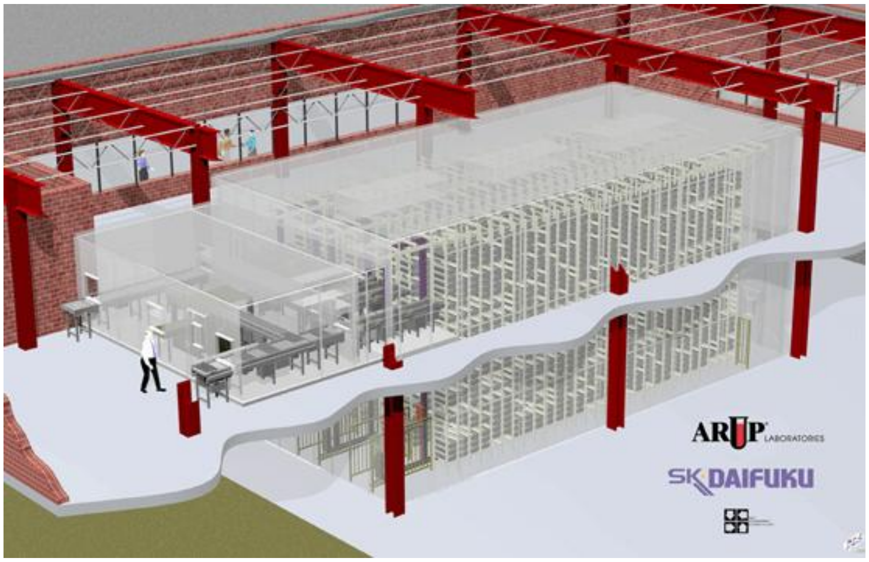


Figure 56: ARUP Laboratory's automated storage and retrieval system

ViaStore Systems

ViaStore Systems is a company that specializes in creating systems for material handling. They have three models for storage and retrieval systems. One of these models is the Viaspeed model which is used for storage of smaller parts that require faster sorting and retrieval speeds. A Cartesian robot is used to shuttle a robotic arm to the correct location to retrieve or store a container. These models use suction cups located on the robotic arm of the Cartesian robot to handle containers. Conveyor belts are used to move the containers to new locations after being taken from storage. The system can be controlled by a standard Microsoft Windows Operating system on a PC. An application of this is shown in Figure 57. In this application the robotic arm moves on the X and Z axes to store and retrieve the containers [2].

Figure 57: Viastore Systems' Viapal S/R application can retrieve and store containers

Quickplacer Robot

The Quickplacer robot, developed by Spanish company Fatronik, is a complete pick and place robotic system with four degrees of freedom. The system is intended for handling small mass objects, mainly the food, pharmaceutical, hygiene, electronics, and telecommunications industries. The company claims that the Quickplacer is the fastest robot in the world for the food processing industry, and will help food makers increase productivity by up to 20 percent. [3] The Quickplacer has a maximum acceleration of 15G, enabling it to process parts at a rate of 215-250 parts per minute. The robot is designed to be integrated with a vision system and conveyer system. This allows the machine to pick objects up while in motion and set them down on a moving conveyer belt. [4] The machine is shown in Figure 58.

Figure 58: The Quickplacer robot processes parts at a rate of 215-250 parts per minute.

The Quickplacer uses four arms each with an attached forearm, known as kinematic chains. This design helps to increase the stiffness of the system, allows for higher accelerations, evenly distributes the torque applied to the actuators, and standardizes the components since all four kinematic chains are the same. [4] The robot has four degrees of freedom: translation about three axes and rotation about the vertical axis. [3]

XZ Table

The motorized linear guide rod stage shown in Figure 59 is a linear positioner developed by Newmark Systems Incorporated. It consists of an aluminum square stage mounted on a stainless steel ACME lead screw which allows it to translate linearly driven by a stepper motor. The stage is machined from 6061 aluminum alloy and measures 3.8 inches in width and 1.784 inches in thickness. A guide with a travel length of 6 inches weighs 5 pounds, without a motor attached. The guide's maximum travel speed is 2 inches per second. The length of travel, and consequently the length of the stage, can be customized depending on the application. Two of these linear guides can be assembled in an XZ configuration as shown in Figure 59 [5].

The aluminum allows for a both lightweight and stable mechanism. The entire travel of the moving carriage is supported on the stage, allowing the guide to have a good cantilevered load capacity (15 pounds).

Figure 59: Linear guide can move at a maximum speed of 2 in/s.

Automated Storage Library with Rotatable Arm and Oblique Angle Effectors

During the 1990's some data storage was done with magnetic tape storage devices, magnetic direct access storage devises, and optical storage devices. Due to the amount of data stored by certain companies or the government, vast libraries developed making data retrieval very labor intensive. Automated storage was then developed to minimize human labor and expedite retrieval and storage of the data. This patent uses slotted storage shelves and a rotatable arm with four degrees of freedom. The arm can move both along the x and z axis, rotate about the horizontal axis, and rotate about an axis parallel to the arm itself. The robotic arm and gripper are shown in Figure 60 [6].

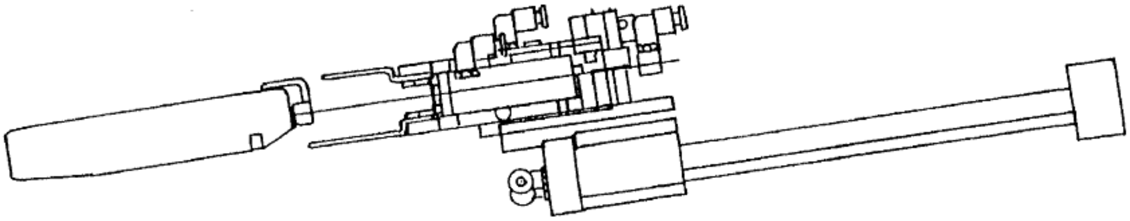


Figure 60: Robotic arm and gripper has four degrees of freedom

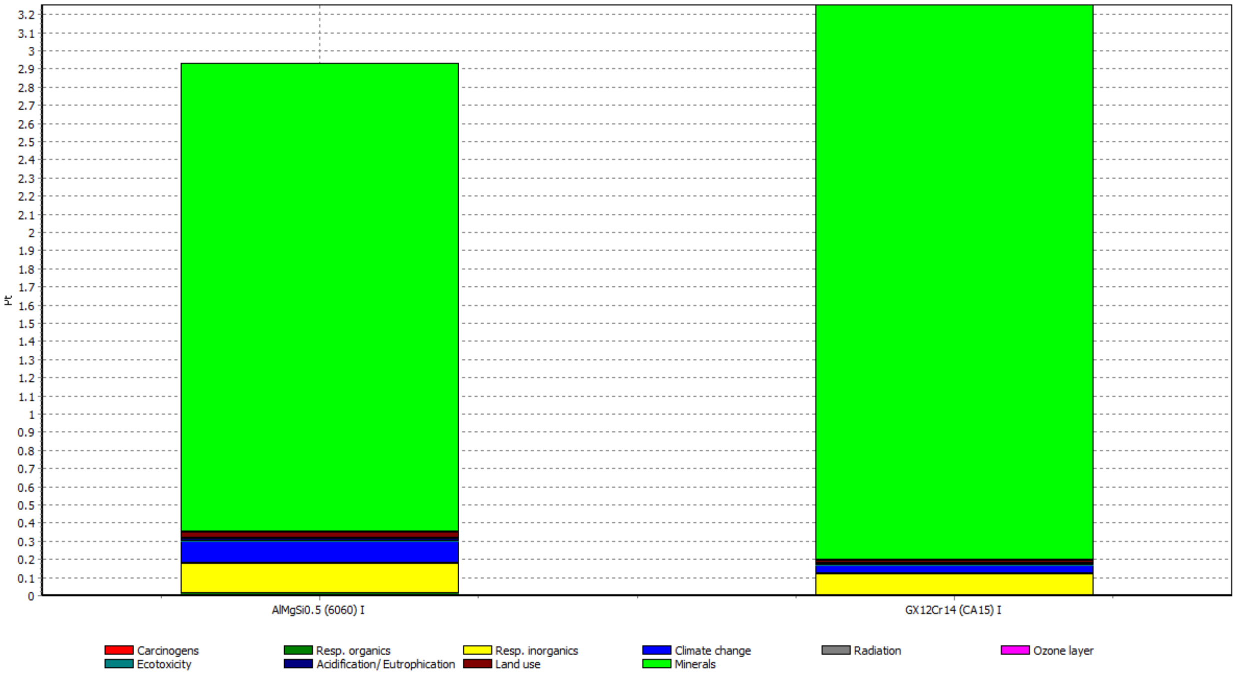
Sommer Automatic

Sommer Automatic is a German based company that specializes in various robotic parts, specifically grippers. The grippers include angular grippers, which are similar to many grippers used in our preliminary concepts and Alpha design. These grippers are both pneumatic and electrically operated. The Sommer Automatic's SGW series gripper is seen in Figure 61 [7].

Figure 61: Pneumatically operated angular gripper

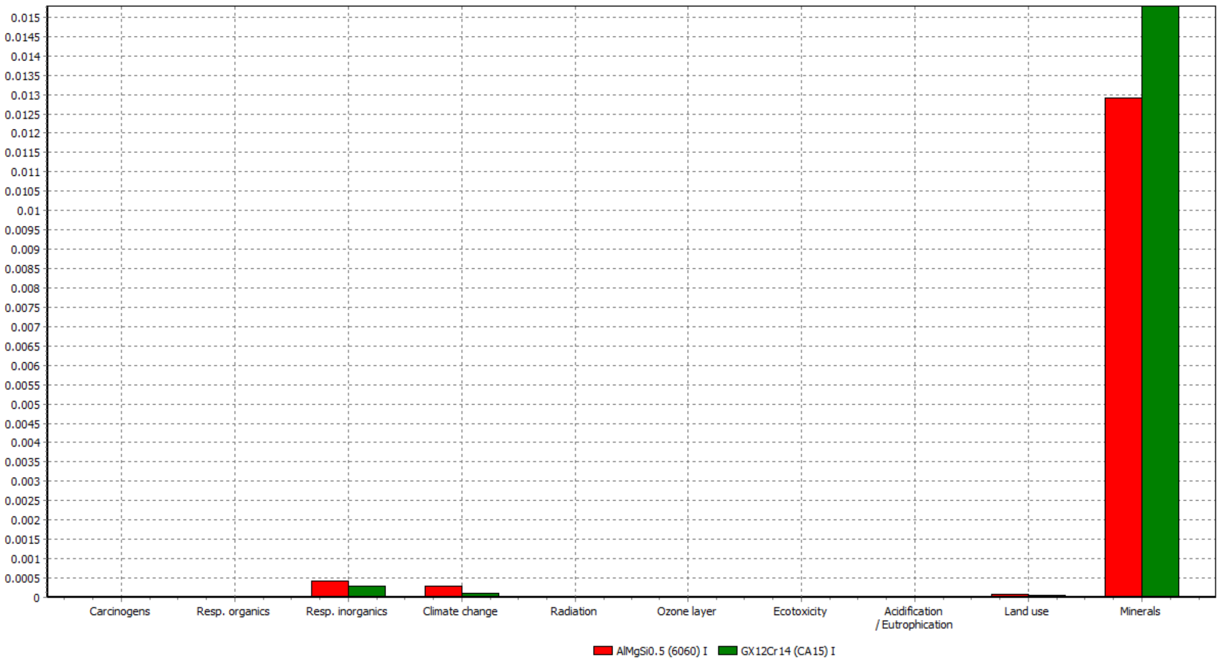
APPENDIX E – DESIGN FOR THE ENVIRONMENT

Comparison of aluminum and stainless steel



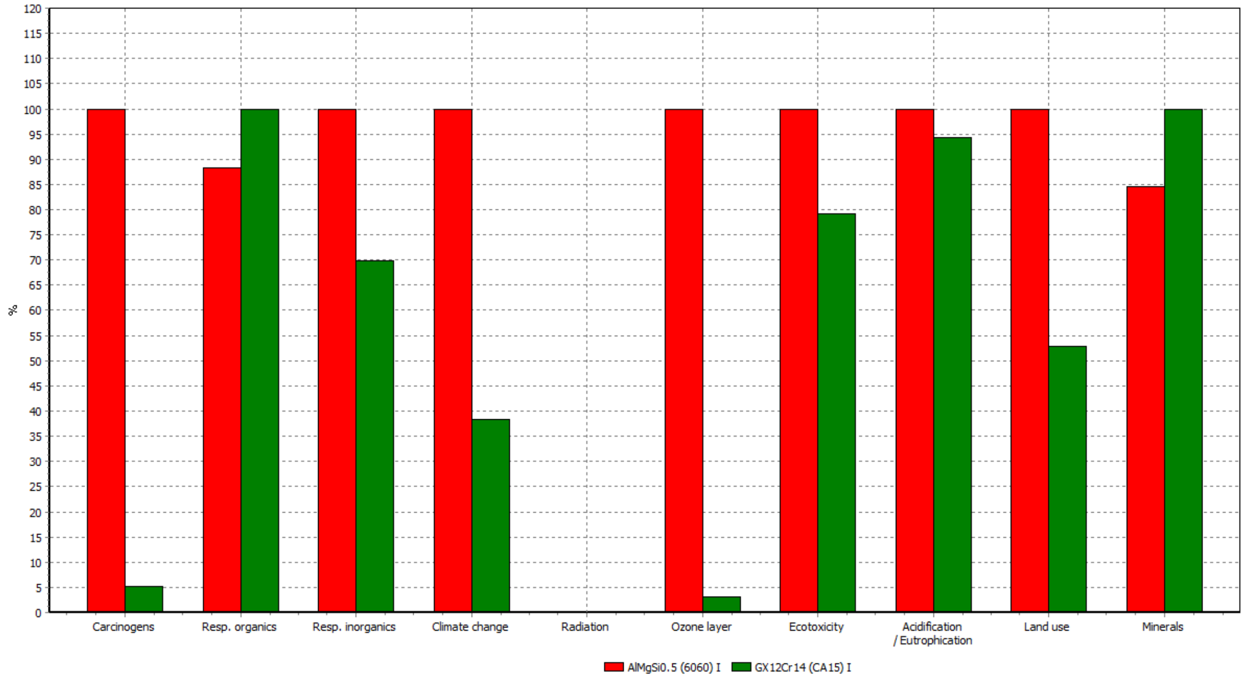
Comparing 1 kg 'AlMgSi0.5 (6060) I' with 3 kg 'GX12Cr14 (CA15) I'; Method: Eco-indicator 99 (I) V2.02 / Europe EI 99 I/A / single score

Single score assessment of eco-impact



Comparing 1 kg 'AlMgSi0.5 (6060) I' with 3 kg 'GX12Cr14 (CA15) I'; Method: Eco-indicator 99 (I) V2.02 / Europe EI 99 I/A / normalization

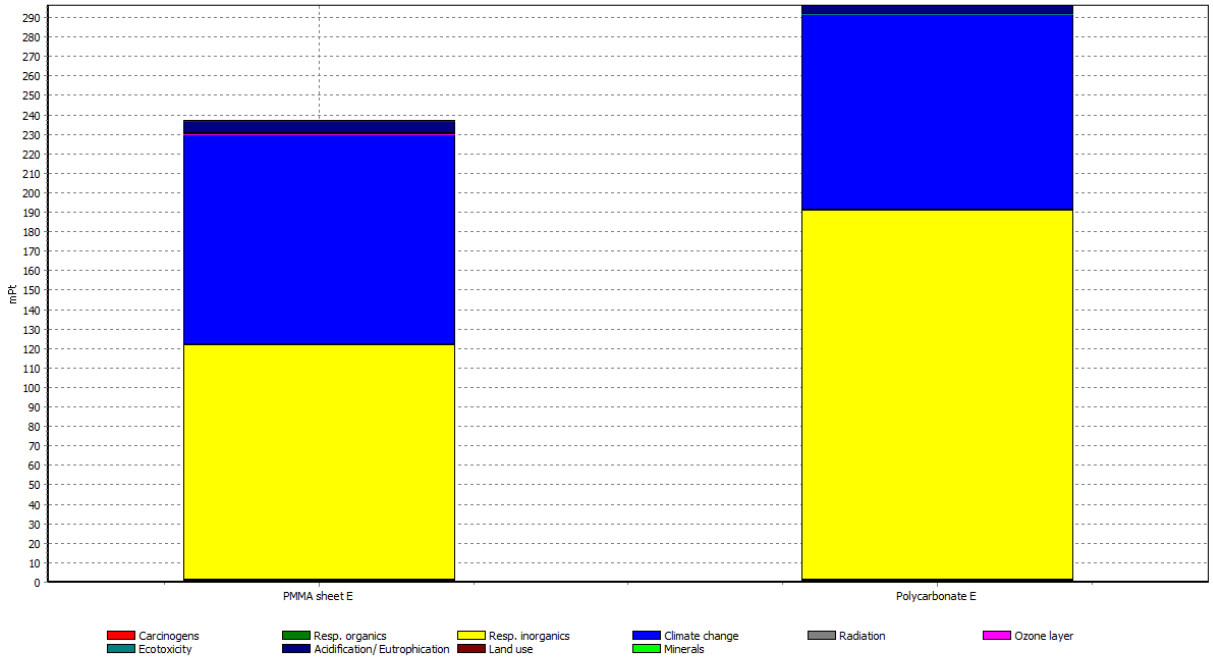
Normalized Assessment of Eco Impact



Comparing 1 kg 'AlMgSi0.5 (6060) I' with 3 kg 'GX12Cr14 (CA15) I'; Method: Eco-indicator 99 (I) V2.02 / Europe EI 99 I/A / characterization

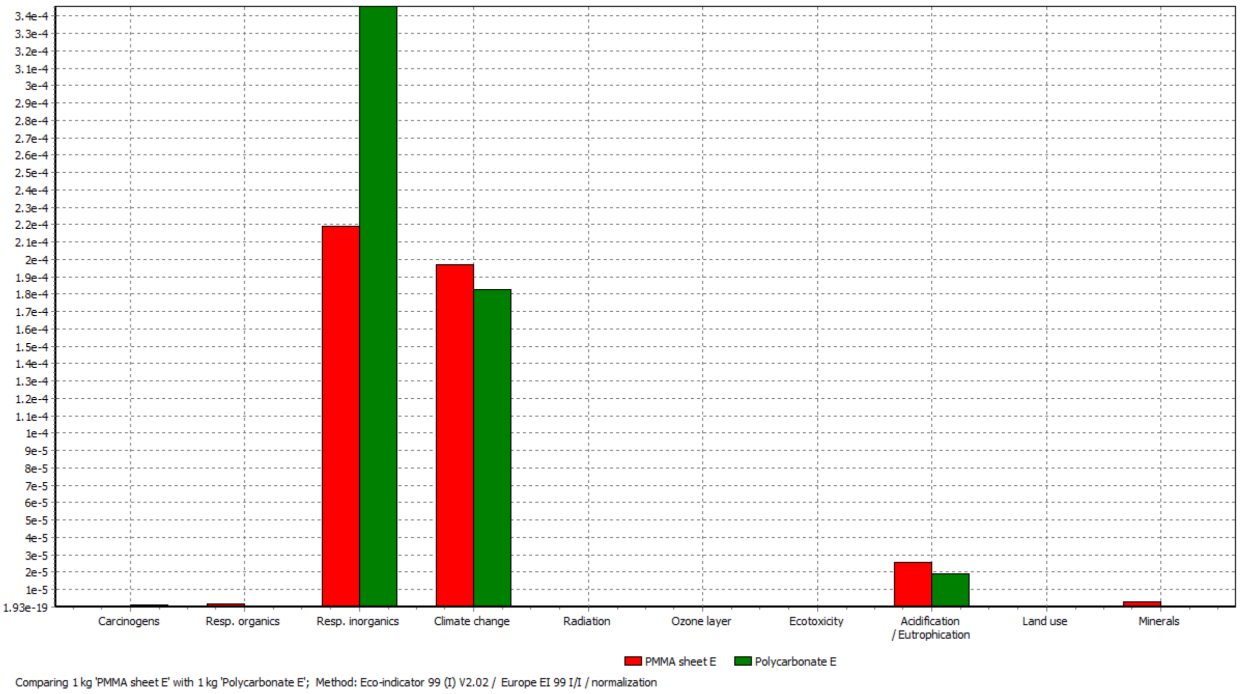
Characterization of Eco Impact

Comparison of PlexiGlass and Polycarbonate

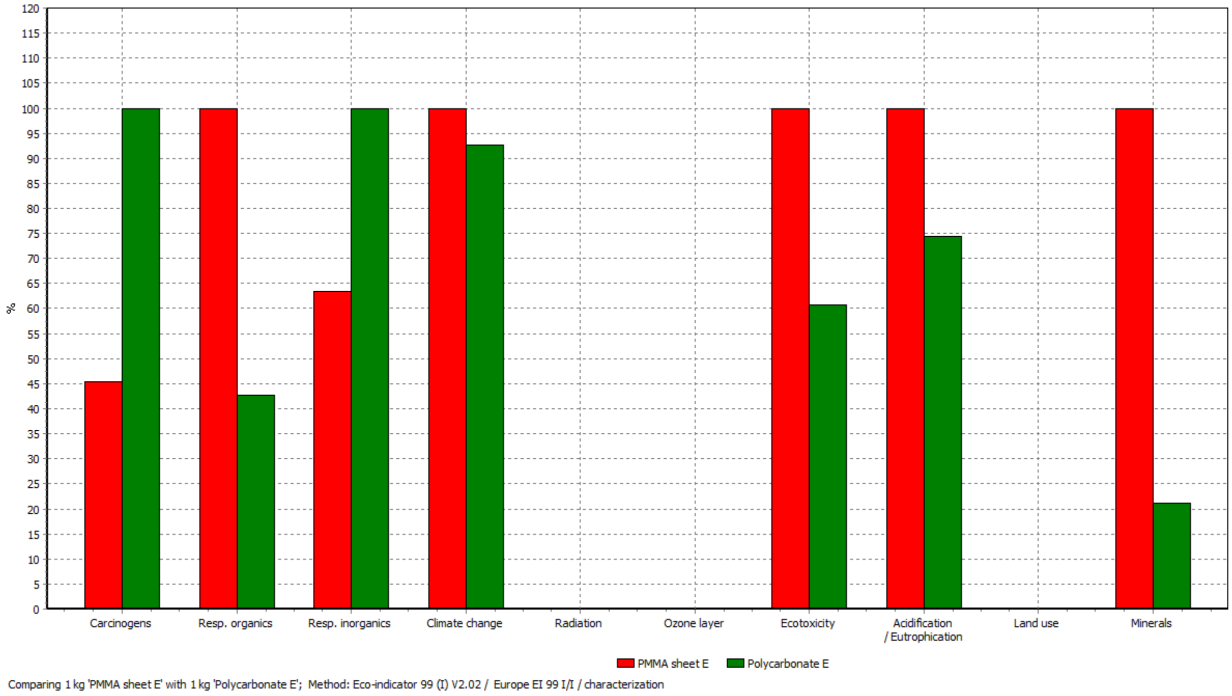


Comparing 1 kg 'PMMA sheet E' with 1 kg 'Polycarbonate E'; Method: Eco-indicator 99 (I) V2.02 / Europe EI 99 I/I / single score

Single Score Assessment of Eco Impact



Normalized Assessment of Eco Impact



Characterization of Eco Impact