Rehabilitation of an Automatic Matrix Storage Unit

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***Abstract*—The purpose of this paper is to summarize the development of the rehabilitation of an automatic PLC controlled matrix storage unit currently located inside the *LARI* (*Laboratorio de Automatización y Robótica Industrial*) in *Universidad Modelo*. The project is now in an early development stage, where it was determined the best approach to overhaul the current system, and to get quotations and initial 3D CAD designs utilizing the new actuators and structures.**

***Index Terms*—Automated Storage, Initial Designs, Robotics.**

I. Introduction

The project focuses on redesigning and automating the matrix warehouse of the Automation Laboratory at Universidad Modelo. It aims to rehabilitate the structure using new technologies alongside resources provided by the university, emphasizing material reuse from the original design. The redesign prioritizes reducing the warehouse size, improving mobility within university facilities, and integrating it with the laboratory's collaborative robotic arm. This setup allows the robot to simulate part of a production line, handling items such as goods or boxes to be stored in the warehouse.

The warehouse serves as a didactic tool for students, enabling hands-on experience with advanced automation technologies crucial for modern industrial processes. It emphasizes automation's growing importance across industries while focusing on educational value rather than direct industrial application. Students will learn to operate, optimize, and evaluate robotic systems, gaining critical skills for addressing challenges in increasingly technological workplaces.

Initial phases included defining objectives for size reduction, structural mobility, and robotic integration, along with functional and performance requirements such as automated storage and retrieval, inventory management, and an educational interface. The team developed 2D and 3D designs with technical specifications for materials, aluminum profiles, and key components like shelves, a gripper, and sensors. These efforts laid a solid foundation for assembling the structure and obtaining advanced technologies.

Design decisions were guided by criteria such as accessibility, practicality, and adaptability to the university environment. Faculty feedback during a seminar helped refine the proposals, with the second proposal—a complete redesign—selected for its comprehensive alignment with project needs.

II. System design

A. Initial Considerations

The main objective of the project is to get the didactic matrix warehouse running, by means of a rehabilitation or redesign of the didactic matrix warehouse. To achieve this, the project has been divided into 6 objectives.

1. Research the state of the art on automated warehouses in the industry.
2. Optimal redesign of the structure and organization of actuators to be used.
3. Definition, effective selection of new technologies (actuators), and their cost estimation.
4. Manufacturing of the structure.
5. Development of the electrical board.
6. System commissioning.

To achieve this, the following requirements for the system were established:

- Location Accuracy: Navigation and positioning must have a maximum error margin of 0.5–1 cm to ensure proper object handling.
- Error Rate: Maintain an error rate below 1% in object handling, with quick detection and correction of operational failures.
- Weight Capacity: The storage system must handle objects up to 1 kg, simulating a realistic warehouse environment.

Figure 1. Current storage located at the LARI

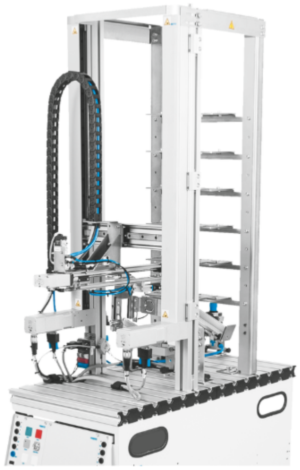


Figure 2. Reference Model - Festo Storage Station

B. Prototype Development

The structural design of the prototype was based on an existing model widely used in automation, the Festo Dynamic Storage, which is a modular system employed in both educational and industrial environments to simulate storage and inventory management operations. This system has been adapted and expanded to meet the specific automation needs of the project.

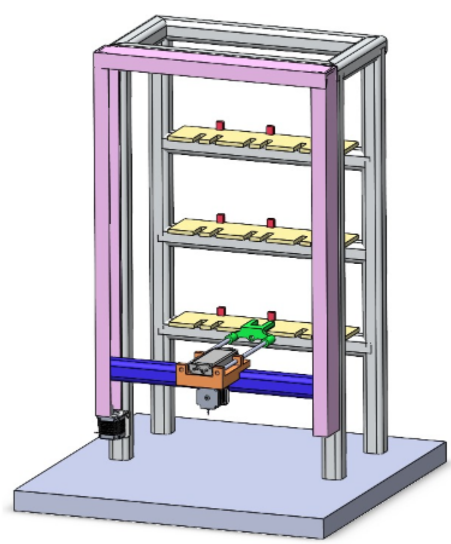
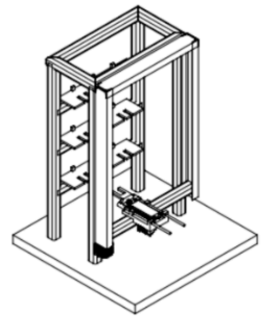


Figure 3. First prototype

Storage Structure

The storage system designed for this prototype is a modular dynamic warehouse that allows simulating the basic functions of a medium-sized warehouse. Using a modular approach, the structure enables easy reconfiguration and scalability of the system to adapt to different testing scenarios and logistics operation simulations.

1. Warehouse base structure: The base was designed to be sufficiently robust to support the movements of the actuators and the transportation of objects, ensuring stability during operation. Materials such as high-strength steel were used for the bases, and reinforced plastic for lighter components, providing durability without compromising weight.



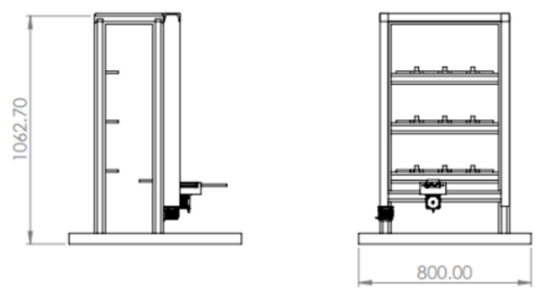


Figure 4. General dimensions (mm)

2. Rails and tracks: The structure includes rails and sliding tracks that allow the efficient and smooth movement of actuators across the surface. These components are distributed according to the specifications of the Festo dynamic warehouse, ensuring that the actuators can operate along predefined paths without interference.

3. Storage modules: The system includes storage modules that simulate shelves where products can be neatly placed. These modules are designed to house the units that will be handled by the actuators, providing enough space to simulate loading and unloading operations for products of various sizes.

Base for Actuators

The base for the actuators is a crucial component for the proper functioning of the prototype. This design has been optimized to ensure that the actuators can move freely and with high precision within the warehouse environment.

1. Structural base: A solid base was designed to support all the moving components of the system, including the actuators and sensors. The base is made of high-strength materials, such as steel and aluminum, which provide rigidity and stability to the structure,

reducing any unwanted vibrations or displacement during operation.

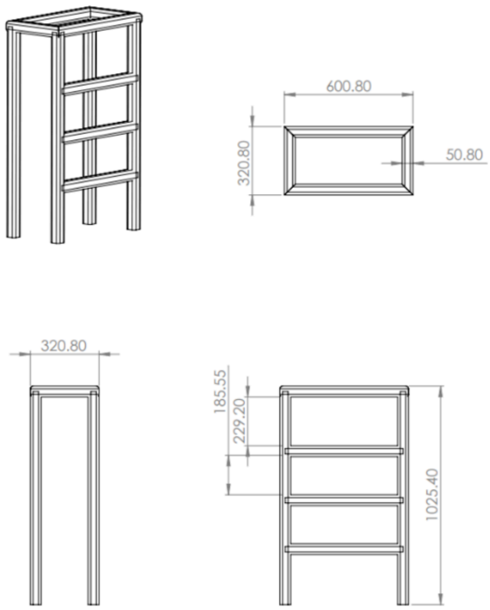


Figure 5. Aluminum structure dimensions (mm)

2. Component distribution: The base for actuators includes enough space for the integration of motors, transmissions, and additional sensors. These components are efficiently distributed to optimize workflow and prevent collisions between the actuators or with the storage modules. Regarding the sensors, a **BMS300-DDT-P photoelectric sensor** is used. Its main function will be to detect the presence of objects in the warehouse and register the positions of the X and Y axes. This, combined with encoders, will enable precise location control of the gripper at all times, ensuring that the system accurately knows the position of each component, thereby improving the accuracy in object handling.

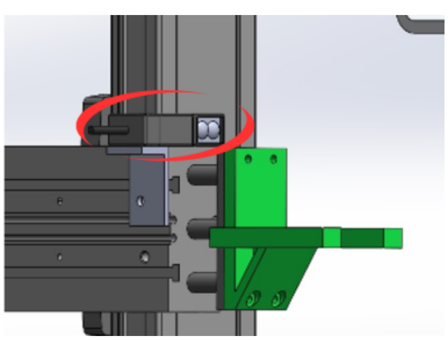


Figure 5. BMS300-DDT-P photoelectric sensor

Gripper and shelves function

The shelves were designed with the purpose of accommodating the selected storage system. For the gripper to place an object on the shelf, it must fit into the holes designed in the shelf. This feature also ensures safety during the movements made by the system.

The design of the gripper was inspired by the forks of a forklift truck, aimed at facilitating the handling of various types of objects. This includes items resting on a pallet (wooden pallet) as well as those simply placed on the shelves.

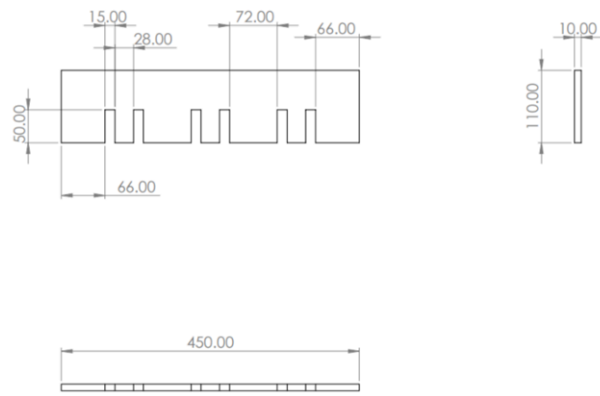


Figure 6. Shelves dimensions (mm)

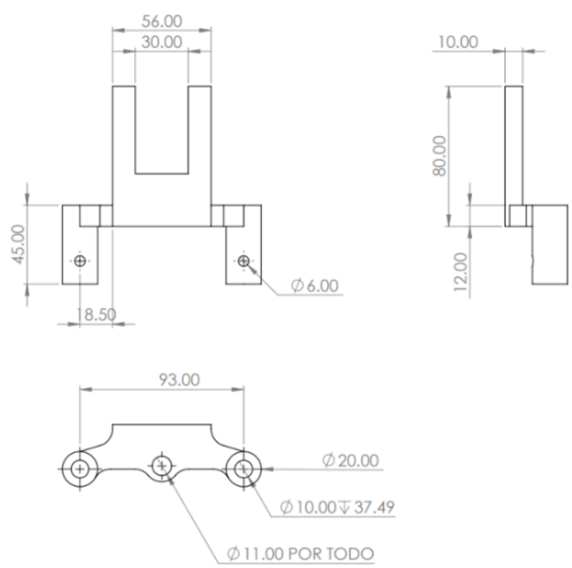


Figure 7. First design gripper

The assignment should contain technical/non-technical illustrations of important aspects of the work.

C. Logic system design

The connections necessary for the proper protection and operation of the servomotor and ServoDrive are as seen in the following figure, with a connection using a thermomagnetic switch to a 220VAC terminal, the system does not require more protection for the servomotor such as a motor protection switch, this is due to the fact that the ServoDrive itself will already protect the motor from the majority of electrical risks that are prone to happen in these types of systems.

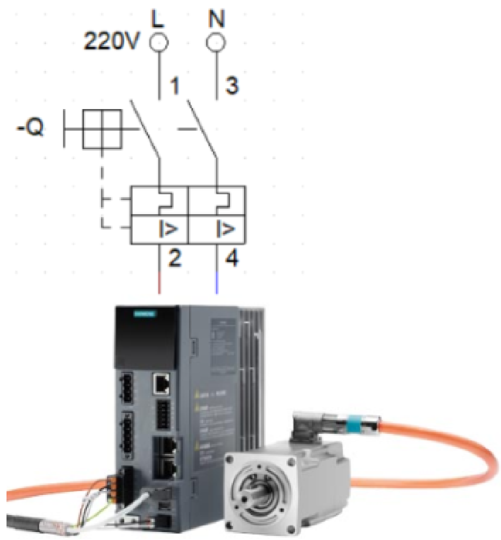


Figure 8. Electrical connection diagram for ServoDrive and Servomotor

The connection with the PLC network will look something along the lines of the following electrical diagram, with a connection to a 24VDC power supply that will supply all the energy required for every connection to the PLC itself, this being buttons to engage and stop the system, as well as select a specific routing, this assuming we do not use an HMI to communicate with the user. It will also read the signals from multiple sensors, these being the ones in the pneumatic actuator and the end of lane sensors in each of the axis, as well as depending on the technology used, 8 more inputs would be required to read the current position of the linear actuators, these would not be necessary if the *LEFS* linear actuators are not used, as the ServoDrives themselves would communicate their positions through either *RS-485* or *PROFINET* as shown in the diagram.

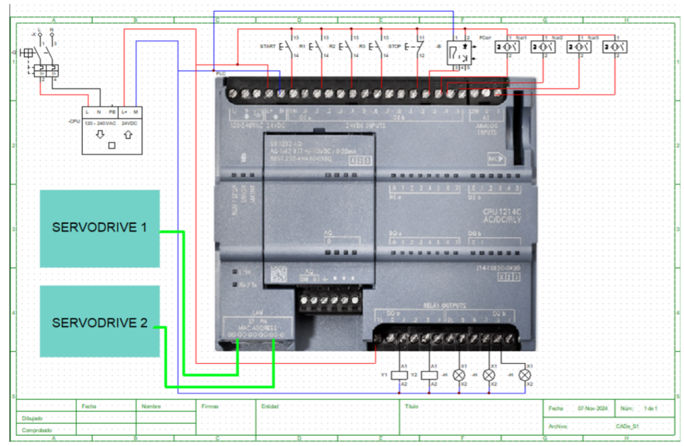
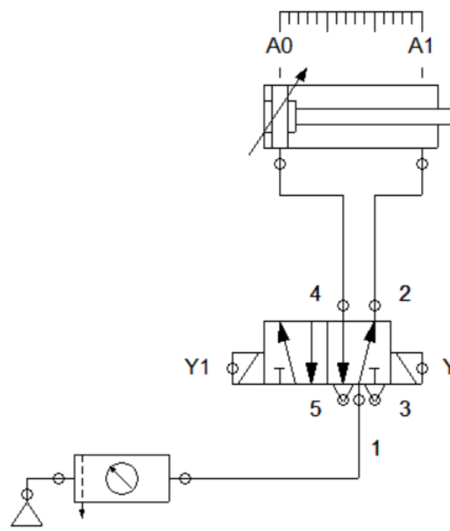


Figure 9. Electrical connection diagram for PLC-ServoDrive and PLC-Pneumatic Actuator

For the pneumatic connection diagram for the "gripper", a simple extension circuit was needed, utilizing a 5/2 bi-stable valve, controlled electronically with signals incoming from the PLC to extend or retract the cylinder.



Figue 10. Pneumatic diagram for double-acting cylinder connection

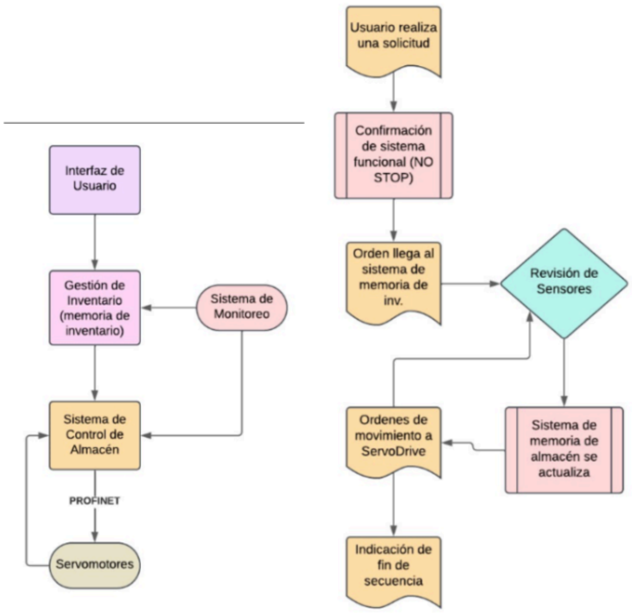


Figure 11.High-level system representation

D. Design alternatives

Torque is a fundamental variable in mechanics and the design of systems involving rotational motion. Its proper understanding and calculation are crucial to ensuring that actuators, such as servomotors, can meet the operational requirements of a given application.

The following information illustrates the steps necessary to determine the required torque and select an appropriate servomotor. This systematic approach allows for a detailed analysis of each stage, from the initial calculation to the final selection, ensuring an efficient and reliable solution [7, 16].

1. Calculate the Required Torque

The torque needed for a specific application depends on several factors related to the system's load and operational conditions. Here's a step-by-step breakdown:

- **Determine the load**:

Identify the object or mechanism the servomotor will move. This involves calculating its weight (W) or mass (mmm), and in some cases, the force (F) applied to overcome resistance.

Example: For a rotating arm, the weight of the object at the end of the arm must be considered, along with the arm's weight if applicable.

- **Consider operating conditions**:

Friction: Account for friction in the system (e.g., bearings or contact surfaces), which adds to the force required.

Acceleration: For systems requiring quick starts or stops, include the additional torque required to overcome inertia.

Gravity: For vertical or inclined systems, the gravitational force significantly impacts the required torque.

External forces: Any additional forces, such as wind resistance or tension, must be factored in.

- **Torque calculation formula**:

Use the formula:

$$T = F \cdot r$$

Where T is the torque (in N·m or oz·in), F is the applied force (in Newtons or ounces) & r is the distance from the axis of rotation to the point of force application (in meters or inches).

- Example: If a force of 50 N is applied at a distance of 0.2 m from the axis, the torque is:

$$T = 50 \cdot 0.2 = 10\ \mathrm{N} \cdot \mathrm{m}$$

2. Choose a Servomotor with the Appropriate Torque

After calculating the torque, selecting the right servomotor involves comparing its specifications to the system's requirements.

- **Check torque specifications**:

Review the servomotor's datasheet for the nominal torque (continuous operation) and peak torque (short bursts).

Ensure the nominal torque exceeds the calculated torque to provide a safety margin (commonly 20–50% higher than the required torque).

- **Verify other factors**:

Operating speed: Torque often varies with speed. Some servomotors are optimized for high torque at low speeds, which may align better with your application.

Voltage and current availability: Confirm that the power supply matches the motor's requirements. Undersized power supplies may cause the motor to underperform.

Dimensions and weight: If the application has spatial constraints, ensure the servomotor fits the available space and does not add excessive weight.

Thanks to the calculations performed, it was possible to approximate the weights required to evaluate the performance and specifications of the three alternatives presented below. These calculations provided a solid foundation for comparing the options in terms of efficiency, load capacity, and compliance with the established requirements. By having accurate estimated values, each alternative can be assessed consistently, facilitating decision-making during the selection process.

Option 1 - Linear Actuators

For option one, electric linear actuators were chosen due to their ease of use, as they eliminate any of the torque calculations and mechanical concerns in their majority, this is due to the fact that great majority of it has already been calculated and established in their datasheets by the manufacturers.

Two linear actuators of SMC's LEFS line were chosen for this design:

- ➔ For the Y axis LEFS 32 S7 A - 750 - S 2 B1, with a total length of ~800mm a stroke of 750mm.
- ➔ For the X axis LEFS 25 S6 B - 450 - S 2 B1, with a total length of ~500mm and a stroke of 450mm.

These actuators were chosen mostly based on their stroke length, this due to the fact that the family in general already satisfies the minimum torque requirements for this system. For them to work, ServoDrives are necessary to control them, SMC recommends the following ServoDrives:

- ➔ SMC LECSB1-S7
- ➔ SMC LECSB1-S5

However, this would bring the total price of the system (without including the pneumatic actuator for the "gripper") to the following:

LEFS 32 S7 A - 750 - S 2 B1	$1,980.00 USD* ($40,285.95 MXN)	SMC[24]
SMC LECSB1-S7	$24,989.88 MXN	SMC [Directly with a provider]
LEFS 25 S6 B - 450 - S 2 B1	$1,955.00 USD ($39,776.58 MXN)	SMC[23]
SMC LECSB1-S5	$22,891.44 MXN	SMC [Directly with a provider]
MGPL20TN-150 AZ-A90VS	$342.25 USD ($6,963.02 MXN)	SMC[26]
TOTAL PRICE	$134,906.87 MXN	

Table 1. Initial quotations for Option 1

*The closest component, with a stroke of 700mm, was selected due to the inability to find the real one.

This is too expensive for the budget a project of this scale, so a new quotation with different ServoDrives than the ones recommended by SMC for use was drafted:

LEFS 32 S7 A - 750 - S 2 B1	$1,980.00 USD* ($40,285.95 MXN)	SMC[24]
LECP1P1-LEFS32A-800	4,176.98 MXN	SMC[20]
LEFS 25 S6 B - 450 - S 2 B1	$1,955.00 USD ($39,776.58 MXN)	SMC[23]
LECP1P1-LEFS25B-400	4,176.98 MXN	SMC[21]
MGPL20TN-150 AZ-A90VS	$342.25 USD ($6,963.02 MXN)	SMC[24]
TOTAL PRICE	$95,379.51 MXN	

Table 2. Final quotations for Option 1

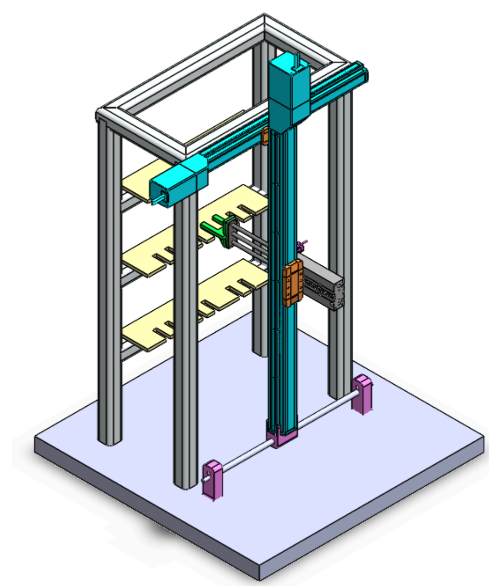


Figure 12. Prototype corrections (Option 1)

Option 2 - Zero Gravity System

In accordance with feedback obtained from the professor in charge of the project, two other alternatives were designed for the project. Option 1 being the "ideal" system, option 2 being the "sufficiently functional prototype" and option 3 being the "absolute minimum required for function", in this case, both option 2 and 3 utilize ballscrews and ballscrew kits with servomotors and ServoDrives themselves instead of linear actuators, this would a parallel X axis located at the bottom which would also be a ballscrew, these would be joined together by a synchronous pulley system.

In specific, this design incorporates a “Zero gravity” concept, which by pneumatic means, will offset and decrease the weight of the “gripper”, to do this, a pneumatic linear rodless actuator will be used, this is the same concept as the previous electronic linear actuators, the difference is that this version works pneumatically, it would be parallel to the Y axis and work to offset its load.

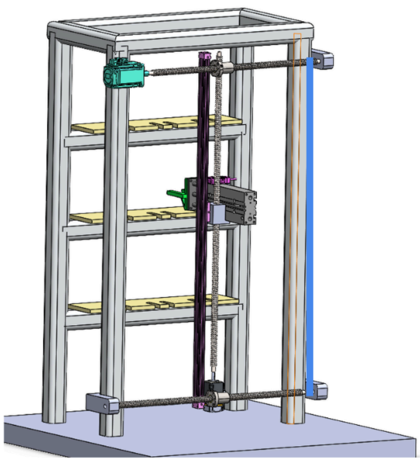


Figure 13. Prototype corrections (Option 2)

SFU 1204 (Y axis)	$2,437.13 MXN	LiMo [8]
SFU 2505 (X axis) (2 of them)	$3,861.78 MXN	LiMo [8]
Kit de servomotor Delta E3, ASD-B2-0421-B + ECMA-C20604RS + ASD-B2-0721-B 100W (Y axis)	$5,789.69 MXN	Aliexpress [15]
Kit de servomotor Delta E3, ASD-B2-0421-B + ECMA-C20604RS + ASD-B2-0721-B 400W (X axis)	$5,883.77 MXN	Aliexpress [15]
SMC MY1B10G-800	$4,501.79 MXN	SMC [17]
MGPL20TN-150AZ-A90VS	$342.25 USD ($6,963.02 MXN)	SMC[26]
TOTAL PRICE	$29,437.18 MXN	

Table 3. Final quotations for Option 2

Option 3 - Basic CNC System

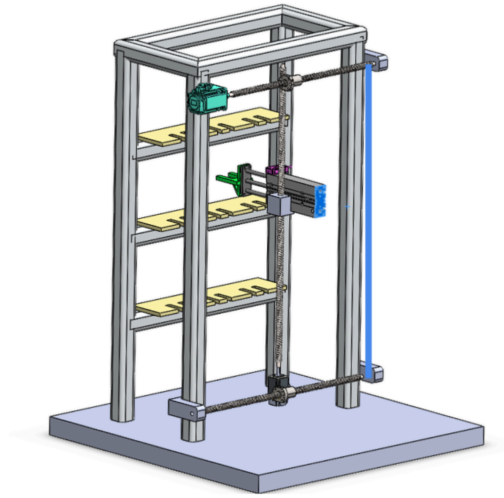


Figure 14. Prototype corrections (Option 3)

For option 3, as mentioned, is the “absolute minimum” required for function of the system, this means that the zero gravity system is no longer included in it, changing the model necessary for the Y axis to perform up to standard, as well as changing the ballscrew needed for it.

SFU 1610 (Y axis)	$3,310.38 MXN	LiMo [8]
SFU 2505 (X axis) (2 of them)	$3,861.781 MXN	LiMo [8]
Kit de servomotor Delta E3, ASD-B2-0421-B + ECMA-C20604RS + ASD-B2-0721-B 200W (Y axis)	$6,070.79 MXN	Aliexpress [15]
Kit de servomotor Delta E3, ASD-B2-0421-B + ECMA-C20604RS + ASD-B2-0721-B 400W (X axis)	$5,883.77 MXN	Aliexpress [15]
MGPL20TN-150AZ-A90VS	$342.25 USD ($6,963.02 MXN)	SMC[26]
TOTAL PRICE	$26,089.741 MXN	

Table 4. Final quotations for Option 3

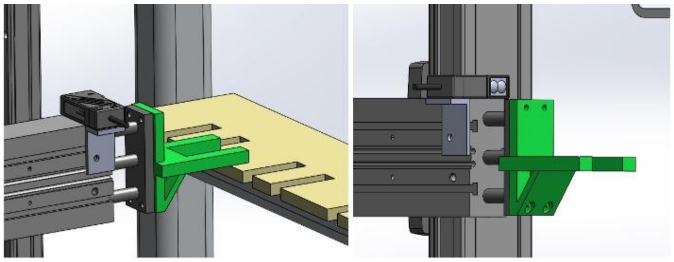


Figure 15. Gripper final design (works on every option) (1)

III. Conclusion

The rehabilitation of the automatic matrix storage unit represents a well-rounded effort to integrate automation technologies within an academic context, combining practical functionality with educational value. A notable aspect of the project was the comprehensive evaluation of various design options and their respective quotations, ensuring the feasibility of the system within budgetary constraints. Three alternatives were analyzed: a high-performance option featuring advanced linear actuators, a mid-tier option with a pneumatic zero-gravity system, and a cost-effective prototype relying on basic mechanical components.

The first option prioritized precision and reliability, employing high-end linear actuators and ServoDrives, but its cost exceeded the budget, leading to the exploration of more economical configurations. The second option balanced functionality and affordability by integrating pneumatic components to offset mechanical loads, demonstrating an innovative approach to cost optimization without compromising operational efficiency. The third option offered the minimum viable system to ensure functionality, focusing on essential components for object handling and storage.

This iterative process of design and cost analysis not only ensured financial feasibility but also fostered the identification of scalable solutions adaptable to educational and practical requirements. By aligning technical performance with budgetary considerations, the project exemplifies the importance of economic engineering in developing automated systems. This approach provides a solid foundation for further advancements in automation, enabling the design of flexible, efficient, and sustainable solutions tailored to diverse needs.

IV. References

[1] 1FK2102-0AG10-1SA0 Siemens. (n.d.). Automation-Warehouse.com. https://automation-warehouse.com/products/1fk2102-0ag10-1sa0?currency=USD&utm_source=google&utm_medium=cpc&utm_campaign=Google%20Shopping&stkn=97f825ced3d0

[2] 6SL3210-5HB10-1UF0 Siemens. (n.d.). PLC Direct. https://plc-direct.com/products/6sl3210-5hb10-1uf0

[3] Ackerman, E. (2022, August 18). IAM Robotics takes on automated warehouse picking. IEEE Spectrum. https://spectrum.ieee.org/iam-robotics-takes-on-automated-warehouse-picking

[4] Ackerman, E. (2022a, August 18). Fetch Robotics introduces fetch and freight: Your warehouse is now automated. IEEE Spectrum. https://spectrum.ieee.org/fetch-robotics-introduces-fetch-and-freight-your-warehouse-is-now-automated

[5] BMS300-DDT-P Side Sensing. Autonics.com https://www.autonics.com/glb/model/BMS300-DDT-P

[6] BMS300-DDT-P Side Sensing. Autonics.com https://www.autonics.com/glb/model/BMS300-DDT-P

[7] Budynas, R. G., & Nisbett, J. K. (2020). Shigley's mechanical engineering design (11th ed.). McGraw-Hill Education.

[8] CNC Ball Screw Assembly parts | Ball screw CNC Router | 12mm Ball Screw | LIMO. (n.d.). LiMo. https://limobearing.com/ball-screw-assembly-parts

[9] Deng, M., Mao, J., & Gan, X. (2018). Development of automated warehouse management system. MATEC Web of Conferences, 232, 03051. https://doi.org/10.1051/matecconf/201823203051

[10] Ferrari, A., Zenezini, G., Rafele, C., & Carlin, A. (2022). A Roadmap towards an Automated Warehouse Digital Twin: current implementations and future developments. IFAC-PapersOnLine, 55(10), 1899–1905. https://doi.org/10.1016/j.ifacol.2022.09.676

[11] FESTO DGC-K-25-1000-PPV-A-GK 1312501 Unidad lineal : Amazon.com.mx: Industria, Empresas y Ciencia. (n.d.). https://www.amazon.com.mx/FESTO-DGC-K-25-1000-PPV-A-GK-1312501-Unidad-lineal/dp/B0DDT1TKQC?__mk_es_MX=%C3%85M%C3%85%C5%BD%C3%95%C3%91&crid=FJ5PNMJVIEWI&dib=eyJ2IjoiMSJ9.ZlanVYBwzf3NimFuz92rqGj9Hr4UodgSK8z7blS0LaZ6e4MrDhycw9rch9JkdIYITlUp6l5CKMKiqQ6vYoO2zA.NGSYf56Yy27dvt-sZ2V8RqB5CBX3GkjwL-ow6isFTEQ&dib_tag=se&keywords=DGC-K-25-1000-PPV-A-GK&qid=1731044079&sprefix=dgc-k-25-1000-ppv-a-gk%2Caps%2C153&sr=8-1&ufe=app_do%3Aamzn1.fos.de93fa6a-174c-4df7-be7c-5bc8e9c5a71b

[12] FESTO DGC-K-25-1000-PPV-A-GK 1312501 Unidad lineal : Amazon.com.mx: Industria, Empresas y Ciencia. (n.d.). https://www.amazon.com.mx/FESTO-DGC-K-25-1000-PPV-A-GK-1312501-Unidad-lineal/dp/B0DDT1TKQC?__mk_es_MX=%C3%85M%C3%85%C5%BD%C3%95%C3%91&crid=FJ5PNMJVIEWI&dib=eyJ2IjoiMSJ9.ZlanVYBwzf3NimFuz92rqGj9Hr4UodgSK8z7blS0LaZ6e4MrDhycw9rch9JkdIYITlUp6l5CKMKiqQ6vYoO2zA.NGSYf56Yy27dvt-sZ2V8RqB5CBX3GkjwL-ow6isFTEQ&dib_tag=se&keywords=DGC-K-25-1000-PPV-A-GK&qid=1731044079&sprefix=dgc-k-25-1000-ppv-a-gk%2Caps%2C153&sr=8-1&ufe=app_do%3Aamzn1.fos.de93fa6a-174c-4df7-be7c-5bc8e9c5a71b-

[13] Finco, S., Ashta, G., Persona, A., & Zennaro, I. (2023). Investigating different manual picking workstations for robotized and automated warehouse systems: Trade-offs between ergonomics and productivity aspects. Computers & Industrial Engineering, 185, 109668. https://doi.org/10.1016/j.cie.2023.109668

[14] Guizzo, E. (2022, September 1). Kiva Systems: three engineers, hundreds of robots, one warehouse. IEEE Spectrum.

[15] Kit de servomotor Delta B2/E3 AC, 100/200/400W/750W/1KW/1.5kw/2KW/3KW ASD-B2-0421-B + ECMA-C20604RS + ASD-B2-0721-B - AliExpress 13. (n.d.). [Video]. Aliexpress. https://es.aliexpress.com/item/1005006141454061.html?spm=a2g0n.productlist.0.0.3cbd3acewCxSrD&browser_id=9314e51e887645be85f2d3a9a96afd91&aff_trace_key=f519c075d3474f73bfe173fc52f35ed6-1732910618145-09880-UneMJZVf&aff_platform=msite&m_page_id=gqzrhwusuiscabck193798615941fb3e51f9176376&pdp_npi=4%40dis%21MXN%2111061.73%216084.03%21%21%21530.03%21291.52%21%402103244617329106507473320ef6bd%2112000035945348368%21sea%21MX%210%21ABX&algo_pvid=478a8166-01fc-4f8c-bb2d-fe2c14974b3f&_universallink=1

[16] Meriam, J. L., & Kraige, L. G. (2020). Engineering mechanics: Dynamics (9th ed.). Wiley.

[17] SMC MY1B10G-800 cyl, rodless, mech joint, MY1B GUIDED CYLIND. (n.d.). SMCpneumatics.com. https://www.smcpneumatics.com/MY1B10G-800.html

[18] Sensor magnético Reed Switch para Cilindro CS1-U Cilindro neumático de aire magnético Interruptor magnético Reed Sensor DC AC 5V- 240V: Amazon.com.mx: Industria, Empresas y Ciencia. (n.d.). https://www.amazon.com.mx/Sensor-magn%C3%A9tico-Cilindro-neum%C3%A1tico-Interruptor/dp/B07Q74XRVZ?__mk_es_MX=%C3%85M%C3%85%C5%BD%C3%95%C3%91&crid=2UV45ZEOFFCC0&dib=eyJ2IjoiMSJ9.f1iTWi7MY7pSgfJHu7aJhmVQlel7zZYaBoO6Hfyb2VTheEDEVho3VNhS6LkzVYZKBCotv19ob6ltppgboaGuSUggUPwoLnwL3otrealE0pymzwslzWxWudmPyFuRaPbAmVe7lgBbjh50mcrcmjuv2Za

DFHXKlVU1NWO2pC4jXfA0xZFT32mc42MSBye83vyLu9mFLB0SJHygH0qcZIuPd-5NpL2dVny18gsYFgPsYdnfz47aOrXZZUcBpO9p9IHtd5unBPry_2IABS35Z4QmPXzMqptLu3N8gfHSlemeQ1s.zyfLWaJkjOzegGIM0CutisXCZ7iBD0DKfYQfsqT-DwI&dib_tag=se&keywords=24V+reed+switch&qid=1731043985&sprefix=24v+reed+switc%2Caps%2C182&sr=8-8&ufe=app_do%3Aamzn1.fos.de93fa6a-174c-4df7-be7c-5bc8e9c5a71b

[19] Sensor magnético Reed Switch para Cilindro CS1-U Cilindro neumático de aire magnético Interruptor magnético Reed Sensor DC AC 5V- 240V: Amazon.com.mx: Industria, Empresas y Ciencia. (n.d.). https://www.amazon.com.mx/Sensor-magn%C3%A9tico-Cilindro-neum%C3%A1tico-Interruptor/dp/B07Q74XRVZ?__mk_es_MX=%C3%85M%C3%85%C5%BD%C3%95%C3%91&crid=2UV45ZEOFFCC0&dib=eyJ2IjoiMSJ9.f1iTWi7MY7pSgfJHu7aJhmVQlel7zZYaBoO6Hfyb2VTheEDEVho3VNhS6LkzVYZKBCotv19ob6ltppgboaGuSUggUPwoLnwL3otrealE0pymzwslzWxWudmPyFuRaPbAmVe7lgBbjh50mcrcmjuv2ZaDFHXKlVU1NWO2pC4jXfA0xZFT32mc42MSBye83vyLu9mFLB0SJHygH0qcZIuPd-5NpL2dVny18gsYFgPsYdnfz47aOrXZZUcBpO9p9IHtd5unBPry_2IABS35Z4QmPXzMqptLu3N8gfHSlemeQ1s.zyfLWaJkjOzegGIM0CutisXCZ7iBD0DKfYQfsqT-DwI&dib_tag=se&keywords=24V+reed+switch&qid=1731043985&sprefix=24v+reed+switc%2Caps%2C182&sr=8-8&ufe=app_do%3Aamzn1.fos.de93fa6a-174c-4df7-be7c-5bc8e9c5a71b

[20] SMC LECP1P1-LEFS25B-400 controller, pnp, ELECTRIC ACTUATOR-L. (n.d.). SMCpneumatics.com. https://www.smcpneumatics.com/LECP1P1-LEFS25B-400.html

[21] SMC LECP1P1-LEFS32A-800 programless controller, ELECTRIC ACT. (n.d.). SMCpneumatics.com. https://www.smcpneumatics.com/LECP1P1-LEFS32A-800.html

[22] SMC LEFS25S6A-400-S2 ball screw drive actuator, ELECTRIC ACT. (n.d.). SMCpneumatics.com. https://www.smcpneumatics.com/LEFS25S6A-400-S2.html

[23] SMC LEFS25S6A-450B-S2 ball screw drive slider actuator, ELEC. (n.d.). SMCpneumatics.com. https://www.smcpneumatics.com/LEFS25S6A-450B-S2.html

[24] SMC LEFS32S7A-700 25mm le electric actuator, ELECTRIC ACTUATOR. (n.d.). SMCpneumatics.com. https://www.smcpneumatics.com/LEFS32S7A-700.html

[25] SMC LEFS32S7A-800 electric actuator, ELECTRIC ACTUATOR-LEFS3. (n.d.). SMCpneumatics.com. https://www.smcpneumatics.com/LEFS32S7A-800.html

[26] SMC MGPL20TN-150Z 20mm mgp ball bearing, MGP COMPACT GUIDE C. (n.d.). SMCpneumatics.com. https://www.smcpneumatics.com/MGPL20TN-150Z.html