University of Central Florida

Department of Electrical &
Computer Engineering

EEL 4914
Senior Design

Industrial Robotic Animatronic

Divide and Conquer Document, Group 21

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Chapter 2: Project Scope

2.1 Background & Motivation:

In the world of modern engineering and entertainment, animatronics stand at the intersection of creativity, technology, and innovation, captivating audiences and pushing the boundaries of what machines can achieve. From their origins in theme parks to their growing presence in museums, theatrical productions, and public displays, animatronics have become a symbol of storytelling brought to life through precision and artistry. These robotic creations, controlled by advanced systems, seamlessly blend lifelike movements with interactivity, creating immersive experiences that inspire wonder and curiosity.

The evolution of animatronics and robotics is rooted in decades of innovation within mechanical and electrical engineering. Early examples of mechanical automation date back to simple automata powered by springs and gears running on pneumatic or hydraulic power, which laid the groundwork for modern robotics. Over time, advancements in control systems, actuators, and sensors enabled the creation of more complex and realistic machines capable of replicating human and animal movements. The integration of microprocessors, digital control systems, and real-time programming revolutionized the field, allowing engineers to precisely choreograph intricate movements and responses. This progress highlights how animatronics has evolved as an engineering discipline, driven by the pursuit of greater precision, efficiency, and adaptability in both hardware and software design.

Our project aims to explore and contribute to this fascinating field by designing and developing an animatronic robot that integrates industry-standard technologies such as Programmable Logic Controllers (PLC) systems and Human-Machine Interfaces (HMI). These tools, widely utilized in industrial automation, offer robust control, precise motion coordination, and highly redundant safety and protection, making them ideal for robotic technology. By leveraging these systems, we can ensure high reliability, efficiency, and safety while enabling complex, synchronized movements and interactive capabilities. We aspire to push the boundaries of animatronic design by utilizing industry-grade tools and methods to create a system that is adaptable, cost-effective, and efficient.

The motivation behind this project stems from the desire to combine engineering expertise with creative expression to build a platform that not only entertains but also educates and inspires. Animatronics provide a unique opportunity to merge all types of engineering into a cohesive system, allowing for both technical and artistic growth. Moreover, as these systems continue to evolve, they could offer new applications in education or healthcare; beyond traditional entertainment.

2.2 Existing Products & Current Markets:

The field of animatronics has long been dominated by large-scale productions developed by industry leaders such as Disney and Universal. These companies have pioneered the use of animatronics to create immersive experiences in theme parks, with highly detailed and lifelike robots that captivate audiences worldwide. The animatronics used in their attractions are known for their sophisticated movements, extensive lifespans, and high reliability. However, these systems come with substantial costs due to proprietary designs, custom-built components, and advanced software tailored exclusively for their specific applications. While these animatronics set the gold standard for performance and realism, their high expense makes them largely inaccessible for smaller-scale productions, independent creators, or educational institutions.

The core of these systems often relies on proprietary or highly customized control systems that are designed in-house or through exclusive partnerships with major industrial automation companies. Brands like Allen-Bradley (Rockwell Automation) and Siemens are frequently involved in providing the Programmable Logic Controllers (PLCs) and related components that power the precise movements and control logic of these animatronics. These PLCs, while renowned for their reliability and advanced capabilities, come at a premium cost due to their robust design, high-performance features, and brand reputation. In addition, the proprietary nature of the control software and hardware integration used in these animatronics often locks buyers into a closed ecosystem, driving up costs further and limiting opportunities for cost-effective customization or expansion.

The current market for animatronics also includes a small number of companies that develop simpler, lower-cost systems intended for smaller venues, educational use, or hobbyists. However, these systems often lack the precision, reliability, and safety redundancies found in high-end systems, making them unsuitable for professional or demanding applications. This gap in the market leaves many potential users with limited options: either invest heavily in proprietary high-end systems or compromise on quality and reliability with more affordable but less capable alternatives.

Our project seeks to address this issue by designing an animatronic system that utilizes widely available, industry-standard PLCs and Human-Machine Interfaces (HMIs) while prioritizing cost-effectiveness and reliability. By focusing on open integration and avoiding proprietary constraints, we aim to demonstrate that advanced animatronic capabilities can be achieved without the excessive costs typically associated with current market offerings. This approach could make professional-grade animatronics more accessible to a broader range of applications, from education and research to smaller-scale commercial use.

2.3 Engineering Design Requirements, Goals & Objectives:

The primary focus of this project is to design and build a reliable, cost-effective animatronic system capable of delivering precise, synchronized movements while maintaining safety and efficiency. By leveraging industry-standard technologies such as PLCs and HMIs, the system will integrate mechanical, electrical, and software components into a cohesive unit. Below, the overall goals and objectives of the project are outlined, along with potential stretch goals for further enhancements.

Overall Goals:

- *Develop a Reliable and Cost-Effective Animatronic System:*
    - Design an animatronic system that prioritizes reliability, safety, and efficiency while minimizing production and operational costs.
- *Integrate Industry-Standard Technologies:*
    - Utilize PLCs, HMIs, and other automation technologies to ensure precise, synchronized control of the animatronic system's movements and interactivity.
- *Ensure Scalability and Modular Design:*
    - Create a system architecture that allows for easy customization, expansion, and adaptability to various applications and use cases.

Basic Goals:

- Execute a pre-determined control profile onto animation axes on demand.
- HMI can interface and display the status of the control system.
- At least 3 functioning axes of movement.

Advanced Goals:

- HMI can both display and write status to the control system.
- Control integration with fault protection for diagnosis and reset capabilities.
- All planned axes of movement function consistently with >80% up-time.

Stretch Goals:

- Implement Audio / Visual effects like sound and lighting.
- Ability to record and store new show profiles on demand.
- Control system has idle animation effects to run continuously.

Basic Goals:

To achieve the basic goals, the engineering design requirements must focus on establishing a reliable foundation for the animatronic system. Executing a pre-determined control profile onto animation axes requires integrating a Programmable Logic Controller (PLC) to handle precise movements. Industry-standard software, such as Siemens TIA Portal or Allen-Bradley Studio 5000, can be used for programming and optimizing control logic. Additionally, implementing an HMI (Human-Machine Interface) capable of interfacing with the control system and displaying its status will require a user-friendly graphical interface, such as a Siemens Comfort Panel or Rockwell Automation PanelView. Ensuring at least three fully functional axes of movement will involve robust servo motors and drives, such as those from ABB or Schneider Electric, calibrated for smooth and precise operations.

Advanced Goals:

Meeting the advanced goals will require a more sophisticated integration of the control and interface systems. Enhancing the HMI to allow both status display and write capabilities will necessitate bidirectional communication protocols, such as Modbus TCP/IP or Ethernet/IP. This will enable operators to modify system parameters or commands directly from the HMI. Fault protection systems must be integrated to detect, diagnose, and resolve errors efficiently, which can be achieved through advanced diagnostic modules and PLC programming with structured exception handling. To ensure consistent functionality with greater than 80% uptime, the design will include redundant components, such as dual power supplies, and regular system health monitoring using predictive maintenance software like Rockwell Automation's FactoryTalk Analytics.

Stretch Goals:

To address the stretch goals, the system must incorporate additional hardware and software features. Implementing audio/visual effects, such as synchronized lighting and sound, will require integration with audio processors and DMX lighting controllers. Software like QLC+ or Light-O-Rama can be utilized for creating dynamic lighting sequences. The ability to record and store new show profiles on demand will involve incorporating onboard memory or external storage solutions, such as SD cards or USB drives, and updating the PLC logic to handle these custom profiles. Finally, implementing idle animation effects will require continuous motion algorithms programmed into the PLC, enabling smooth transitions and lifelike movements during downtime. This will enhance the system's realism and keep it engaging when not actively performing a pre-determined sequence.

2.4 Features and Functionality:

Review of similar animatronic systems, such as those found in theme parks or entertainment venues, indicate that intuitive user interfaces, precise control, and safety are paramount. Additionally, customers expressed a desire for robust fault-handling capabilities and the ability to expand functionality without incurring prohibitive costs. Comparisons with existing industry solutions revealed that proprietary designs, while powerful, often lock users into high-cost ecosystems. By addressing these pain points, this project aims to provide a versatile and accessible alternative.

Key Prototype Features:

- Human-Machine Interface (HMI):
    - The system includes a simplified yet powerful HMI panel that allows operators to monitor system status, execute control profiles, and manage animations. The HMI integrates an indicator LED for power/status, a selector switch for mode selection, and an emergency stop button for safety, ensuring ease of use even for non-expert operators.
- Integrated Motor Control:
    - The embedded electric motors, as depicted in the prototype, provide precise control over individual axes of movement. Feedback loops through the breakout board ensure accurate position tracking and smooth operation of each motor.
- Fault Protection and Diagnostics:
    - The control panel includes advanced fault logic for diagnosing and resetting system errors, a critical feature identified as a gap in comparable, low-cost systems. This ensures that the animatronic system operates reliably, even under demanding conditions.
- Expandability:
    - With separate protection and control circuits for motor feedback, the system is designed to accommodate additional axes or functionalities as needed. This modular approach aligns with customer needs for scalability without locking them into proprietary ecosystems.
- Safety Features:
    - The inclusion of an emergency stop button (E-stop) and robust circuit protection ensures operator and equipment safety at all times. This can also allow for features such as Lock-Out Tag-Out (LOTO) capabilities, allowing for safe maintenance in a de-energized state. These features are standard in industrial applications and align with industry regulations.

2.5 Engineering Specifications:

Protection and Controls System	
Maximum Operating Voltage	24V DC
Maximum Operating Current	5A
Fault Response Time	<1 second
Continuous Fault Handling	256 (maximum)
Lock-out Tag-out capabilities	Via E-stop
Human-Machine Interface (HMI)	
Maximum Operating Voltage	12V DC
Maximum Operating Current	1A
Display Type	LCD or OLED
Communication Protocol	Ethernet, Modbus TCP, CAN
Interface Buttons	Selector Switch, Push Button, E-stop
Animatronic	
Maximum Operating Voltage	12V DC
Maximum Operating Current per Axis	2A
Number of Axes	3 (minimum)
Operational Uptime	>80%
Idle Power Consumption	<1W per Axis

The engineering specifications define critical parameters across the Protection and Control System, Human-Machine Interface (HMI), and Animatronic systems. Among these, three key specifications will be demonstrated: fault response time, operational uptime, and axes functionality.

The fault response time of less than 1 second is vital for ensuring system safety and reliability, as it showcases the ability of the Protection and Control System to quickly detect and address faults, minimizing damage and downtime. The operational uptime, exceeding 80%, highlights the Animatronic system's capability to maintain consistent functionality, demonstrating its robustness and reliability under normal operating conditions. Lastly, the functionality of multiple axes of either rotation or actuation will effectively demonstrate the capability of the system to function reliably and safely. It can also showcase its vast expandability to accommodate many different robotic features simultaneously while maintaining its overall high operational uptime and fast fault response time.

2.6 Prototype Illustration:

For a wide scope project such as this, it is important to have a general prototype illustration to allow for a clear understanding of exactly what the project scope contains. This can be used for both internal discussion of design and for use in client communications.

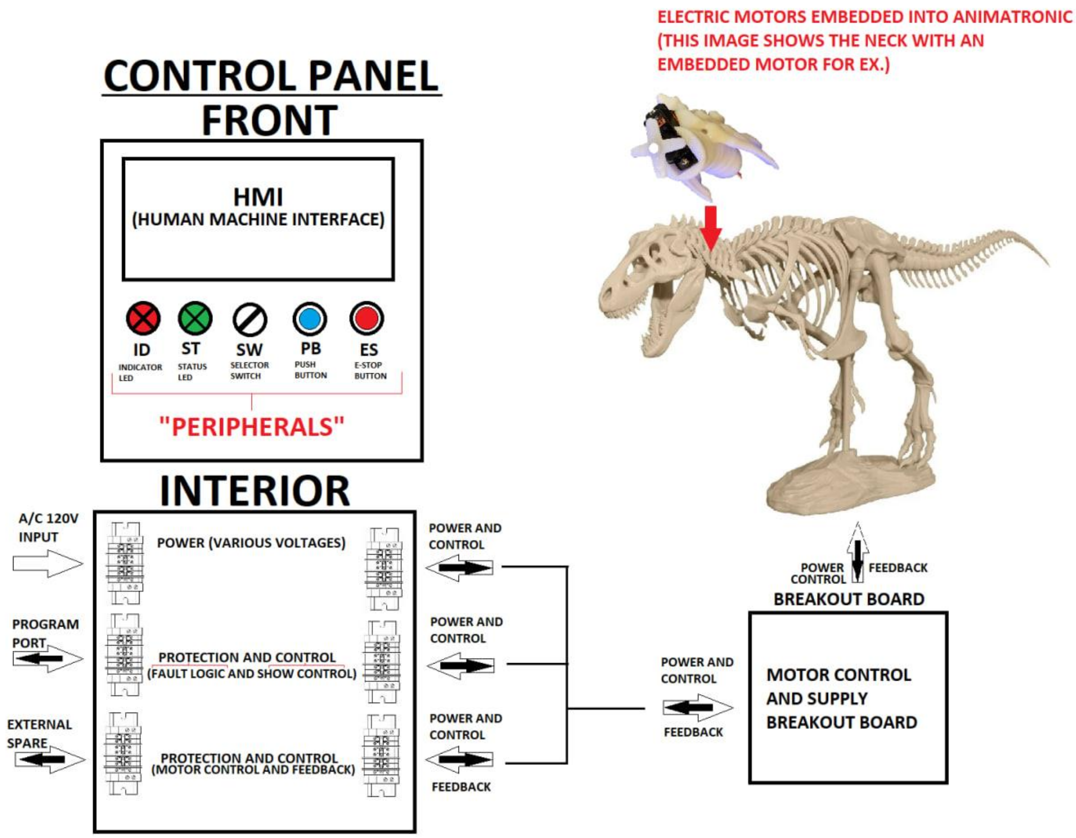


Figure 2.1: Prototype Illustration by Authors

2.7 Distribution of Work:

Austin Berg EE	Melvin Guzman EE	Tony Torres EE	Armando Diaz CpE
Protection Animatronic Team Lead	Controls Animatronic Motors / Sensors	PCB Design Power Flow Documentation	HMI Networking Peripherals

2.8 Hardware Diagram:

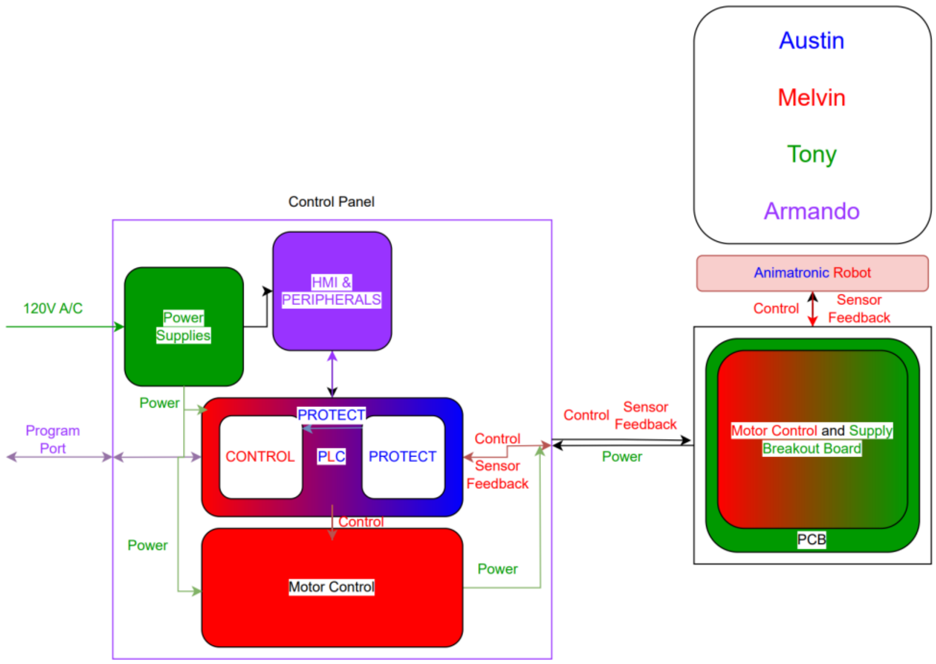


Figure 2.2: Hardware Diagram by Authors

2.9 Software Diagram:

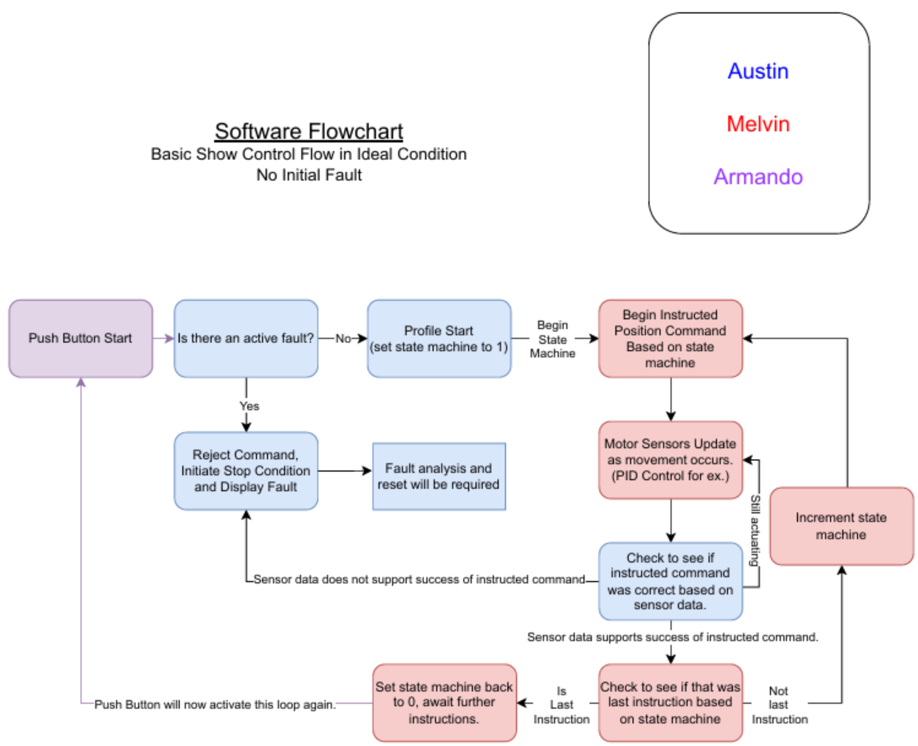
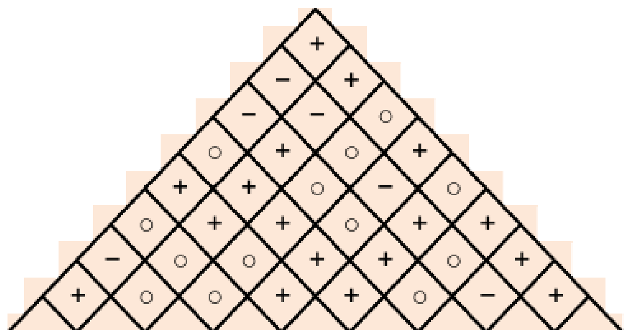


Figure 2.3: Software Diagram by Authors

2.10 House of Quality:

The House of Quality is as it connects customer needs with technical requirements, ensuring products are designed to meet expectations effectively.



Column #	1	2	3	4	5	6	7	8	9
Direction of Improvement	▲	○	▲	▽	▲	○	▽	▲	▽
Engineering Requirements / Customer Requirements (Explicit and Implicit)	Fault Response Time	Continous Fault Handling	LOTO Capabilities	Display Type	Communication Protocol	Interface Buttons	Number of Axes	Operational Uptime	Idle Power Consumption
Affordability	▽	▽	▽	▽	▽	▽	▽	▽	▽
Reliability	▲	○	○	▲	▲	▽	▽	▽	○
Safety	▲	▲	○	▲	▲	▲	▽	▽	○
Ease of Use	▽	▽	▲	▲	▲	▲	▽	○	○
Connectivity	○	○	○	▲	▲	▲	○	○	○
Expandability	○	○	○	▲	▲	▲	▽	○	○
Energy Efficiency	○	○	○	▽	▽	▽	▽	▽	▽
Ease of Maintenance	▽	▽	▲	▲	▲	○	▽	○	○
Quickly Installable	○	○	○	▲	▲	▲	▽	○	○
Industry Standardization	▲	▲	▲	▲	▲	▲	○	○	○
High Utilization	○	○	○	▲	○	○	▲	▲	▲
Scalability of Features	○	▲	○	▲	▲	▲	▲	○	○

Figure 2.4: House of Quality by Authors

Chapter 3: Research and Investigation

2.1 Technology Comparison and Selection:

This section presents a comparison of various technologies that could be utilized for the project's key components. It explores potential solutions from both hardware and software perspectives, evaluating their advantages and limitations. After determining the most suitable approach, specific technologies are selected to be implemented.

2.1.1 Electrical Enclosures

This section looks closer into various electrical enclosures we could potentially utilize for this project, aiming to maximize size while staying within a budget of approximately $100. The enclosure must accommodate essential electrical components, including a PLC, inverters, breakers, relays, and more. To ensure proper installation and sufficient space for these components, an ideal enclosure size would be 18”x18”x6”.

2.1.2 Human-Machine Interfaces (HMIs)

Our intention with the control panel is to be in-line with common industry practices and have a design in which that is intuitive to use. So, for the control panel of our project, one of our requirements was to implement an interface that would allow a user to manage and operate the animatronic. For this interface, our options were abstract in the sense of implementation. These included remote devices, web-based interfaces, and HMIs.

Consideration of HMIs and other interface technologies

- Remote Devices
    - Access from a distance
- Web Browser
    - Accessibility for different devices
    - Scalability for lower cost
- HMIs
    - Industry Standard
    - Direct Control
    - Response Time
    - Easier Programming

Defining different implementations within HMIs

- Push-Button Replacer
    -
- Data Handler
    -
- Overseer
    -
- General Characteristic for all HMIs
    -

Main three choices for our HMI

- Chipsee PPC-CM5-070 or PPC-CM4-101

2.1.3 Programmable Logic Controller

Allen Bradley, Siemens, ABB,

2.1.4 Motors & Motor Controller

Weigl show control, Dynamixel motors and motor controllers, servos generic, stepper motors, actuators, Arduino / esp32 PWM style.

2.1.5 Animatronic

3d Printed, different materials, weight, angle of momentum, design constraints and software for 3d file editing.

2.1.5 Sensors

Limit switches, potentiometers, hall-effect sensors, amperage sensors, encoders

2.2 Part Comparison and Selection:

This section presents a comparison of various parts and components that could be utilized for the project's needs. The knowledge and research gained in the previous section leads the way to deciding on the best parts to use, deliberating on their advantages and limitations. After determining the most suitable approach, specific components are selected to implement each chosen technology.

2.1.1 Electrical Enclosures

When selecting an electrical enclosure, several key factors must be considered, including dimensions, price, durability, and ease of component installation. The first two options are from McMaster-Carr, a reputable supplier known for high-quality industrial components. The 18"x12"x4" enclosure is priced at $105.84, making it the most expensive option, and having a compact depth that may limit space for wiring and larger components such as inverters and relays. The second McMaster-Carr option, measuring 18"x18"x6", is larger and more spacious, while also being more cost-effective at $80.05. Its additional depth provides greater flexibility in mounting electrical components and ensuring proper airflow within the enclosure, reducing potential heat buildup, though not a main factor in our purchase decision. Both McMaster-Carr enclosures are expected to be well-constructed and suitable for industrial applications, ensuring a reliable and robust housing for the animatronics' electrical system.

The other two enclosures are generic brands and offer significantly larger internal volumes at competitive prices. The 20"x16"x8" enclosure, priced at $89.99, provides ample room for mounting the PLC, relays, and power distribution components, making it an attractive option in terms of the amount of room we have to work with. However, its increased size may present challenges in integration within the animatronic structure, requiring careful mounting considerations. The 16"x16"x8" option, costing $98.98, offers slightly less internal volume but maintains a deeper 8" depth, which can be beneficial for cable management and component accessibility. For each enclosure, factors such as heat dissipation and weather resistance are not primary concerns, as the electrical components will remain in a controlled indoor environment. Overall, the 18"x18"x6" McMaster-Carr enclosure appears to offer the best balance of cost, space, and reliability for housing the animatronics' control electronics.

Electrical Enclosures				
Option No.	Ht,Wd, Dp.	Brand	Price	Link
1	18x12x 4”	McMaster-Carr	$105.84	https://www.mcmaster.com/products/electrical-enclosures/electrical-enclosures-2~/indoor-enclosures-7/
2	18x18x 6”	McMaster-Carr	$80.05	https://www.mcmaster.com/products/electrical-enclosures/electrical-enclosures-2~/indoor-enclosures-7/
3	20x16x 8”	Generic	$89.99	https://shorturl.at/NtEwZ
4	16x16x 8”	Generic	$98.98	https://shorturl.at/latvF

Option 1:

With Lift-Off Cover and Knockouts

Option 2:

With Hinged Cover and Knockouts

Option 3:

Option 4:

Chapter 10: Research and Investigation

10.1 Budget & BOM:

One of the major goals of this project is to minimize costs while still providing industrial level quality by using industry-standard control systems. To do this, we have budgeted a total of $1000 dollars across all members. This project does not have direct sponsorship currently, although efforts are continuing to be made to try to alleviate costs among team members.

System	Budget
HMI	250
Protection and Controls	600
Animatronic	150
Total	1000

Table 10.1: Preliminary Budget by Authors

In preparation to hit this budget goal, some preliminary research must be conducted to assess the current market prices and create a bill of materials (BOM). The prices used in this BOM are based off real products, however they are kept generalized and prices are rounded to accommodate for changes in final product or a future sponsorship.

Component		Price	Quantity		Total
PLC	$	250	1	$	250
Electrical Cabinet	$	100	1	$	100
LED	$	10	2	$	20
Selector Switch	$	7	1	$	7
Push Button	$	20	1	$	20
E-stop	$	15	1	$	15
Terminal Blocks	$	2	20	$	40
HMI (all inclusive)	$	200	1	$	200
Ethernet Cable	$	10	1	$	10
PCB (all inclusive)	$	100	1	$	100
Wires (all inclusive)	$	50	1	$	50
Cable Connectors	$	2	4	$	8
Servo Motors	$	20	5	$	100
3D printed animatronic	$	50	1	$	50
Misc.	$	30	1	$	30
			TOTAL:	**$**	**1000**

Table 10.2: Preliminary BOM by Authors

Table 10.3: Final BOM by Authors

10.2 Milestones:

Keeping track of milestones is a key tool for success when completing long-term projects. Itemizing project documentation, design and implementation tasks into clear lists with set dates make the goal posts clear and organize workload for team cohesion.

Documentation			
Start Date	End Date	Task	Description
1/6/25	1/14/25	Recruitment	Austin Berg, Melvin Guzman, Tony Torres and Armando Diaz were recruited.
1/15/25	1/24/25	D&C / Review Committee	Complete Divide and Conquer (D&C) and finalize review committee for project.
1/27/25	2/7/25	D&C Revision	After project approval, revise and submit final D&C document.
2/8/25	3/24/25	Midterm Milestone Report	Complete 60-page mid-project report.
3/25/25	4/4/25	Midterm Milestone Report Revision	Revise and submit final 60-page mid-project report.
4/5/25	4/22/25	Final Report	Complete and submit final 120-page report.

Design and Implementation			
Start Date	End Date	Task	Description
2/7/25	3/24/25	Final Component Selection	All team members should have all components selected for use.
2/7/25	4/22/25	Protection and Controls System Design	Main design should be completed.
2/7/25	4/22/25	HMI Design	Main design should be completed.
2/7/25	4/22/25	Power Flow and PCB Design	Main design should be completed.
TBD	TBD	Testing and adjusting	Testing and adjusting of implemented designs to ensure working product.
TBD	TBD	Prototype Completion	Completed prototype with working systems and functions as specified.