MCMASTER – MOHAWK JOINT VENTURE

BACHELOR OF TECHNOLOGY PARTNERSHIP

FOUR-YEAR UNIVERSITY DEGREE PROGRAMS

Capstone Final Report: 6 Axis Robotic Arm

SUBMITTED BY:

Marcus J Cameron – 400319790

Abdullah Aboutaha – 400312855

Quinn Sheppard - 400450908

INSTRUCTOR: Kostas Apostolou

PROPOSAL DATE SUBMISSION: April 7, 2026

Authorship Statement:
This report was completed collaboratively by Marcus J. Cameron, Abdullah Aboutaha, and Quinn Sheppard. Marcus J. Cameron contributed primarily to mechanical design and fabrication, Abdullah Aboutaha contributed to software development and system integration, and Quinn Sheppard contributed to electrical design and system architecture. All members participated in report writing, review, and finalization.

CONTENTS

ABSTRACT

This project explores the design of an affordable 6-DOF robotic arm for hobby and small scale automation. Commercial robotic arms are often too expensive and rely on proprietary hardware, so this system uses accessible components such as 3D-printed parts, NEMA stepper motors, closed-loop drivers, and a custom touchscreen teach pendant in order to make our robot cost under $1000. The arm is controlled through a JSON using HTTP communication system that supports real time joint control and teach and repeat motion. Early testing confirmed reliable PC to microcontroller communication, accurate positioning, and adjustable motion timing. This report summarizes the design process, system architecture, and challenges, laying the groundwork for full mechanical assembly and multi-motor coordination in the next phase.

EXECUTIVE SUMMARY

This project focuses on building an affordable, modular, and scalable 6-axis robotic arm as an alternative to expensive commercial systems. The design uses 3D-printed parts, NEMA 17 and NEMA 23 stepper motors, closed-loop drivers, and a Wi-Fi-enabled microcontroller. A tablet-based touchscreen teach pendant sends JSON commands to the arm, allowing real-time joint control, motion sequencing, and emergency-stop functionality.

Over the term, the team completed research, mechanical prototyping, software development, and early end-to-end communication tests. The system successfully demonstrated serial and network control, accurate positioning, and adjustable motion timing. Key mechanical components including the wrist, gripper, and belt-driven joints were prototyped using 3D printing to reduce cost and speed up iteration.

The next phase will focus on full mechanical assembly, coordinated multi-motor control, safety features, and trajectory planning.

INTRODUCTION

The current 6 Degree of Freedom robotic arms are often expensive and include a wide range of advanced features. As a result, hobbyists and small businesses may find it difficult to justify the cost for personal or small-scale commercial use.

This project aims to design and develop a lower-cost and simplified 6 Degree of Freedom robotic arm tailored to this demographic. The system will include both robotic arm hardware and a custom software interface, along with a teach pendant that enables real-time control and programmed motion execution.

PROJECT STATEMENT

Design and build a 6 Degree of Freedom robotic arm using a scalable control system with a teach pendant interface, enabling real time & programable multi-joint position control through structured communication.

PROJECT OBJECTIVES

- Design and assemble a 6-DOF robotic arm structure
- Implement electrical and control systems for multi-joint actuation
- Develop a custom teach pendant interface for manual and programmed motion control
- Establish reliable communication between software and embedded hardware
- Demonstrate coordinated multi-motor motion and system integration

PROJECT REQUIREMENTS

- Independent control of 6 joints
- Absolute position control with defined range limits
- Adjustable motion speed and times movement
- Stable power distribution and communication architecture
- Safe operation under specified load condition

- Touchscreen-based teach pendant interface for intuitive control
- Wireless communication between teach pendant and microcontroller
- Ability to select and control individual joints in real time
- Teach-and-repeat functionality for saving and replaying motion sequences
- Emergency Stop button located on Teach Pendant

LITERATURE REVIEW

Modern robotic manipulators commonly use distributed motor control architecurre where each joint is actuated by a digital servo or motor controller communicating over serial protocols such as RS485, CAN, or bus systems. Serial bus servos allow multiple actuators to share a single line of communication while maintaining individual addressing, reducing wiring complexity and improving scalability.

Teach pendant systems are often used in industrial robotics to allow manual control and teach and repeat motion programming. These systems rely on structured communication protocols and real-time position control and feedback.

More recent industry trends emphasize modular software architecture, layered communication models, and network-based control systems. Separating the user interface from the embedded hardware layer enables easier testing, remote access, and future expansion to wireless control.

The design approach selected for this project aligns with these principles by implementing a structured protocol, centralized embedded control, and a scalable software architecture capable of transitioning from USB serial to Wifi based communication.

Unlike many existing robotic arm systems which rely on expensive proprietary hardware or complex industrial control systems, this project focuses on affordability, modularity, and accessibility. The system is designed using widely available components such as Arduino-based controllers and 3D printed mechanical parts.

DESIGN

INITIAL DESIGN

OBJECTIVES AND TECHNICAL REQUIREMENTS

- 6 degrees of freedom with independent joint control
- Payload capacity of approximately 1–2 kg
- Work envelope suitable for tabletop operation (~500mm reach)
- Positioning accuracy within ±2–5 mm
- Adjustable speed and motion timing for each joint
- Modular mechanical structure for easy maintenance and upgrades
- Structured communication protocol using JSON over HTTP
- Expandable software system supporting multiple actuators
- Safe operation through software limits and emergency stop system
- Modular mechanical design for 6 joints
- UI and Structured communication protocol development
- Expandable software system
- Clean wiring and power layout

PROJECT CONSTRAINTS

- Development timeline
- Budget limitations

BLOCK DIAGRAM:

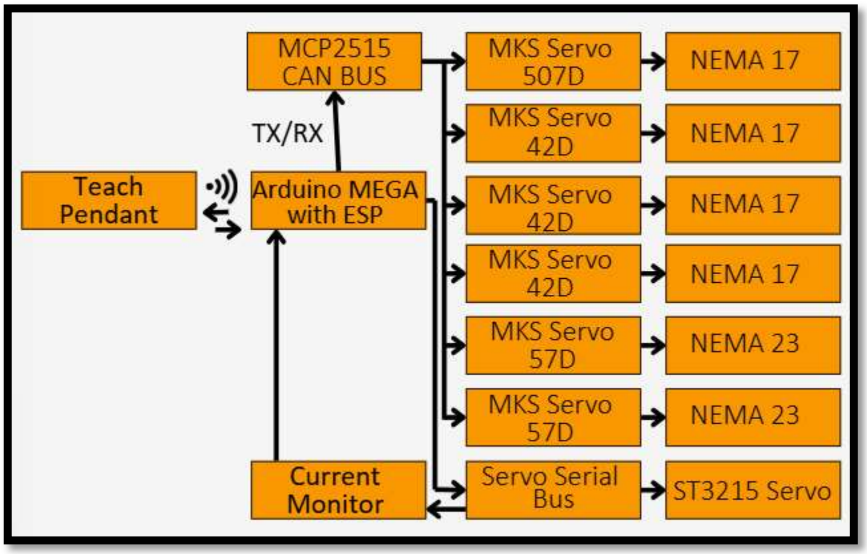

Figure 1 - Block Diagram

DESIGN ALTERNATIVES & COMPLETED WORK:

SOFTWARE

Design alternatives:

1. Direct Desktop Serial Control (PyQt + PySerial): The UI directly communicated with Arduino over USB using serial commands. This provided low latency and simple architecture but tightly coupled the Ui to the hardware and doesn't support remote based control.
2. Simple Text-Based Serial Protocol: A lightweight delimiter-based command format (ID: POS) was considered instead of structured JSON. While it was easier to parse on the microcontroller, it lacked scalability, extensibility, and clarity for adding more features such as speed, timing, and multi-servo coordination.

Chosen Implementation: We are implementing a Wi-Fi-based control architecture using a network-enabled microcontroller (arduino + wifi) where the UI communicates over HTTP without needing USB serial bridge.

A software subsystem was created to enable structured, real-time control of the robotic arm through a layered communication architecture.

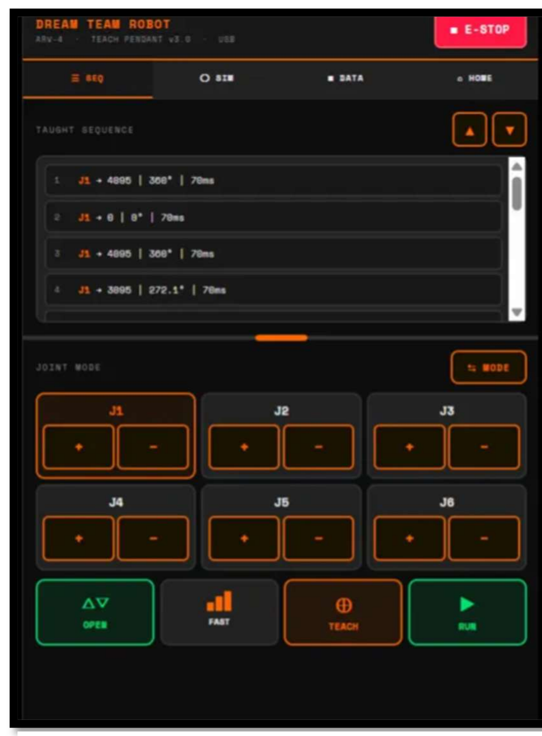

Figure 2 - Current Version of UI

A custom teach pendant interface was implemented using a web-based UI hosted through a Flask application. The interface allows users to send joint position commands through HTTP request. Motion commands are structured using a JSON-based protocol containing servo ID and position parameters.

A python-based communication bridge was developed to convert HTTP request into serial commands transmitted over USB to the microcontroller. The bridge ensures proper formatting and future multi-servo support.

On the embedded side, the Arduino firmware parses incoming JSON command strings, extracts servo ID and position values and executes motion using the ST3215 digital servo command “WritePosEx()”, which supports absolute position control and timed motion parameters.

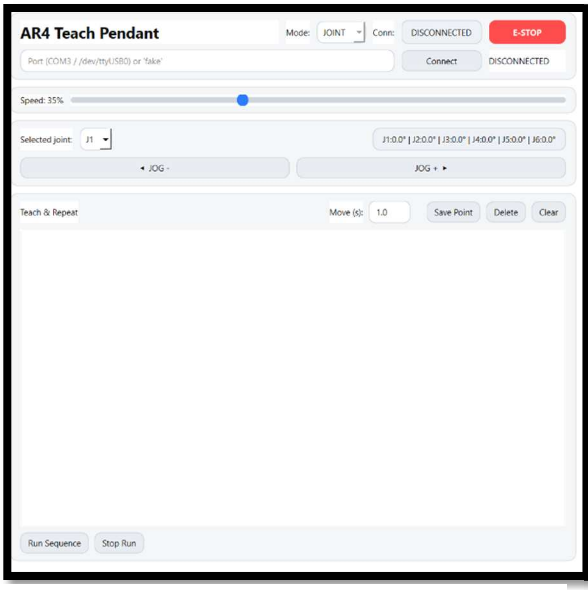

Figure 3 - First Version of UI

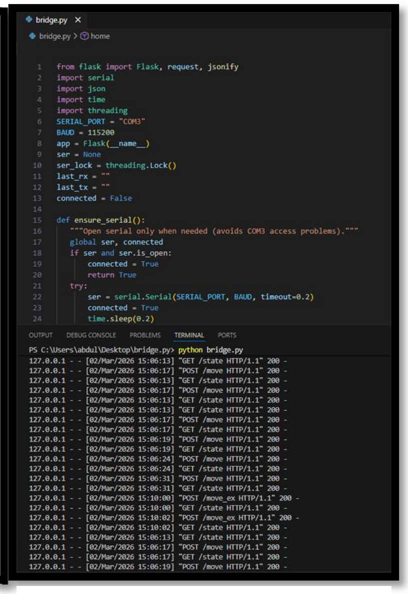

Figure 4 - Serial Code sending to Arduino

The system was validated through end-to-end testing and demonstrated:

- PC to microcontroller serial communication
- Absolute position control and movement
- Adjustable motion timing (speed)

System utilizes HTTP “POST” request to send motion commands and GET requests to retrieve system status. Attached are screen Captures of User Interface + POST & GET request working in terminal.

TEACH PENDANT & CONNECTIVITY

Design Alternatives:

Primary Device	Screen	Buttons	Connection
Raspberry Pi	Old Laptop Screen	All Touch Screen	Bluetooth
Old Tablet	Build into Tablet	All Touch Screen except emergency stop	WiFi
Raspberry Pi Remotely connected	Touch Screen	Physical Buttons with display	Wire

Chosen Implementation:

We will be using the Old Tablet which has its own built-in touch screen. This will send commands over Wi-Fi to an Arduino MEGA which will control the arm. All buttons will be built onto the touch screen, though we will have a separate system which will be able to cut the power to the arm. This will simulate an emergency stop which would be at the same location as the robot arm for people in proximity that may not have the teach pendant.

MECHANICAL & ELECTRICAL

The mechanical design of the robotic arm follows a 6-degree-of-freedom structure, allowing each joint to be independently controlled. The structure and components are primarily fabricated using a 3D printer to reduce cost and enable rapid prototyping and iteration.

To further minimize cost and weight, while maintaining functionality, a belt-driven system is being explored for some joints. A custom belt component was 3D printed and will be tested to evaluate its effectiveness in transmitting motion while maintaining sufficient torque and reliability.

Initial mechanical design work has focused on key components such as the wrist and gripper. These components are being designed to provide good range of motion and stability for basic pick-and-place tasks. The gripper design aims to handle lightweight objects while remaining easy to manufacture.

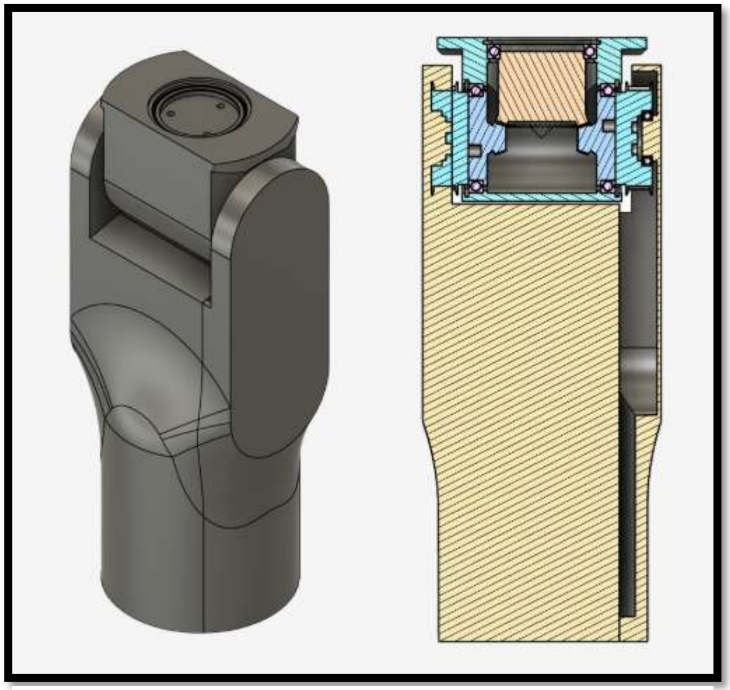

Figure 5 – 6-Axis Robot Wrist

The initial wiring design follows a layout that separates communication and power lines. CAN High and CAN Low lines are used for CAN bus communication between the controller and MKS servo motors, while dedicated servo data, power and ground connections provide stable voltage to the motors and control system.

We will be using NEMA 23 motors run by a closed loop motor controller. The gears & structure will be made from 3D printed material.

SUPPLIES

Part Name	Description	Quantity	Total Price
Servo 42D Closed Loop Stepper Motor Driver	Controls the 6 Stepper Motors on the Arm.	4	$105.53
NEMA 23 Motor	Actuator to move the Arm Axes	6	Already has 3 $150.00
NEMA 17 Motors	Actuator to move the Wrist Axes	2	$113.07
3D Printing Material	Creates the structure & gears for the 6-Axis Arm.	~	Already own Filament
Old Tablet	Used as Teach Pendant	1	Already Owned

DISCUSSION

PROJECT SCHEDULE

By the end of semester 1. We only need to have the final report complete, though it looks like we are on track to fully complete the prototype of the 6-Axis Arm. The following timeline was set at the beginning of the semester and is updated to show what has been completed so far.

TIMELINE

January 12th: Define Project Proposal & Presentation Started

January 20th: Project Proposal Presentation Complete & Report Reviewed/Submitted

January 27th: Research Alternatives

February 3rd: Final system architecture selected (M/E/S)

February 10th: Software Communication planned and Midterm Presentation and Report Complete

February 17th: Reading Week

February 24th: Midterm Presentation Practiced & Report Reviewed/Submitted

March 3rd: Create Part List, Budget, Defined microcontroller and servo communication

March 10th: Project Design (AutoCAD, Fusion 360, Inventor, etc.), initial serial communication prototype (PC to microcontroller)

March 17th: Project Design (AutoCAD, Fusion 360, Inventor, etc.), Implement JSON-based command protocol.

March 24th: Create Final Presentation & Report, put together different team member's work (Electrical, Mechanical, Software) Begin multi-servo scalability testing with UI.

March 31st: Presentation and Final Report Complete ready for review

April 7th: Final Poster Practiced & Report Reviewed/Submitted

PROJECT VIABILITY

The project is achievable because parts of the system are already at early test stages and working together. The team successfully tested communication between the software and hardware and confirmed that the servo motors respond to commands in real time. The team is also regularly using 3D printing mechanical parts and testing usability. Going from testing one motor to multiple motor control is the next logical next step and brings us closer to having a fully functioning 6-dof robotic arm.

PRACTICAL APPLICATIONS

Some practical applications of the Robotic Arm:

- Educational robotic platforms
- Automation system prototyping
- Teach-and-repeat robotic manipulators
- Embedded systems training
- Small-scale industrial automation research

CHALLENGES

CURRENT CHALLENGES

- Coordinated multi-servo synchronization
- Power distribution stability
- Mechanical alignment and structural rigifity of parts
- Communication latency during rapid command execution

POTENTIAL FUTURE CHALLENGES

- Wi-fi communication stability
- Real-time trajectory planning
- Feedback/state integration to UI Simulator
- Safety implementations (E-stop, limits)
- Load handling

CONTINGENCY PLAN

CURRENT PLAN

- Complete mechanical design
- Expand from single servo to multi servo control
- Implement coordinated testing
- Fully develop and test backend logic and multi motor control

FUTURE

We are aiming to:

- Transition to Wi-Fi enabled microcontroller
- Implement coordinated trajectory control
- Add feedback monitoring for motors (position/state)
- Integrate safety mechanisms
- Optimize motion smoothness and speed control

CONCLUSION

The first phase of the 6-axis robotic arm project successfully built the foundation for a low cost, fully functional robotic arm. The team created and validated a scalable control system, a structured communication protocol, and a touchscreen teach pendant capable of real time joint control. Mechanical prototypes made from 3D-printed parts showed that lightweight, customizable components are practical for educational and small scale automation use.

Early testing confirmed reliable communication between the software and hardware, accurate servo positioning, and adjustable motion timing. These results show that the system is ready to expand into full multi motor coordination. Challenges such as synchronized motion, power stability, and safety features have been identified and planned for in the next phase.

By the end of the term, the project delivered a validated design and integration plan. The next term will focus on full mechanical assembly, coordinated trajectory control, safety integration, and complete system testing, bringing the project closer to a fully operational 6-DOF robotic arm.

FINAL DESIGN FOR NEXT TERM

By the end of this term, the team has a validated control architecture, a finalized mechanical design, and a complete integration plan. This sets up next semester to focus fully on fabrication, assembly, and full system testing, moving the project toward a complete working prototype.

REFERENCES AND FIGURES

1. **TheInvention**. (2025). 3D PRINTED DIFFERENTIAL ROBOT ARM WRIST. YouTube. https://www.youtube.com/shorts/tJ4rwWNeLlE
2. **Yue Jiang**. (2025). SSG-48 OPEN SOURCE ADAPTIVE GRIPPERS. YouTube. https://www.youtube.com/watch?v=X9dFV6vFFMk
3. **Novaspirit Tech**. (2021). STREAMING VIA RASPBERRY PI. YouTube. https://www.youtube.com/watch?v=ZxdhG1OhVng
4. Simplify3D. (2021). 3D PRINTING G-CODE TUTORIAL. https://www.simplify3d.com/resources/articles/3d-printing-gcode-tutorial/
5. **Automation & Tech**. (2020). CLOSED-LOOP STEPPER MOTOR INSTALLATION. YouTube. https://www.youtube.com/watch?v=mQyXR3hITy0
6. **James Bruton**. (2025). 6-DOF ROBOT ARM PROJECT. YouTube. https://www.youtube.com/watch?v=vQxvbbsWGwE
7. **How To Mechatronics**. (2026). 6-AXIS ROBOTIC ARM BUILD. YouTube. https://www.youtube.com/watch?v=7z6rZdYHYfc
8. **Mert Arduino & Tech**. (2025). DIY 6-DOF ROBOTIC ARM. YouTube. https://www.youtube.com/watch?v=1GaLZmEvN2c
9. **Robotics Lab**. (2025). ROBOTIC ARM DEMONSTRATION. YouTube. https://www.youtube.com/watch?v=O0qlNowndRw
10. **Build It**. (2024). 6-AXIS ROBOT ARM MOTION TEST. YouTube. https://www.youtube.com/watch?v=I3O61P-iSCw
11. **DIY Tech Projects**. (2024). HOMEMADE 6-DOF ROBOT ARM. YouTube. https://www.youtube.com/watch?v=dy6YKtoMtWI
12. **TechBuilder**. (2023). ROBOTIC ARM MOVEMENT DEMO. YouTube. https://www.youtube.com/watch?v=e3TNaIyTAnY

Figure 6 - Gripper Design

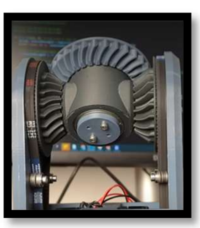

Figure 7 - Multi Directional Movement using 1 Motor

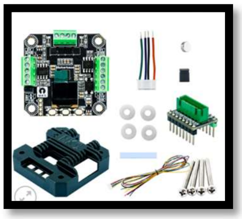

Figure 8 - Servo 42D Closed Loop Stepper Motor Driver

Figure 9 - NEMA 23 Motor

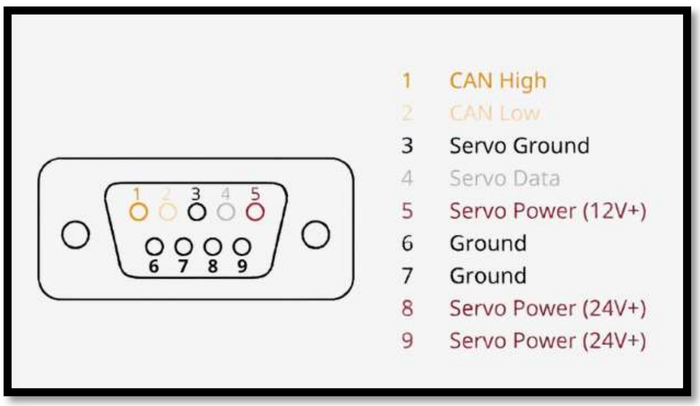

Figure 10 - Electrical Wire Mapping