Robot Arm Teleoperation: Controlling 4 Joint System Through Human Manipulated Exoskeleton

MIE #37

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The integration of human-like mobility and dexterity into bipedal humanoid robots remains a challenging task in robotics. This research paper presents a novel approach to address this challenge through the teleoperation of human joint movements into a bipedal humanoid robot. By leveraging the innate capabilities of human operators, this study aims to enhance the mobility, adaptability, and overall functionality of humanoid robots, enabling them to perform a wider range of tasks in diverse environments. This research project involves the development of a teleoperation system that enables human operators to control the joint movements of a humanoid robot in real-time. The system utilizes a simple configuration of potentiometers to map the operator's movements to the corresponding robot joint angles. The paper delves into the technical details of the teleoperation system, including the hardware and software components used for a seamless human-robot interaction. Furthermore, the potential applications of this technology are explored, such as search and rescue missions, hazardous environment exploration, and precise medical procedures. Experimental results and case studies are presented to demonstrate the feasibility and effectiveness of the teleoperation system. These results display the ability of the humanoid robot to mimic human joint movements accurately and execute tasks with a higher level of precision and adaptability. Overall, this research contributes to the ongoing efforts to bridge the gap between human and robotic capabilities, thereby expanding the potential of bipedal humanoid robots in many applications. This approach could pave the way for enhanced human-robot collaboration and the development of robots capable of performing tasks that were previously deemed too complex or dangerous for autonomous operation.

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Introduction

Problem Statement

The UIC Robotics and Motion Laboratory has developed a bipedal humanoid robot used for locomotion. The laboratory has plans to extend the capabilities of the robot so that it can manipulate objects through teleoperation of the upper body. The primary objective for this team is to develop a mobile upper body arm exoskeleton that can house potentiometers at each joint to wirelessly teleoperate joint movement of the user to the arm joints of the robot. While the design will be made for the robot in the UIC Robotics and Motion Laboratory, the project has the potential to be applied in a wide variety of tasks within industry, such as reducing injury in workplace operations, reducing tolerancing of medical procedures, and aiding in search and rescue operations across the world.

Sponsor Background

Dr. Pranav Bhounsule is a professor and an accomplished researcher operating out of his own Robotics and Motion Laboratory at the University of Illinois at Chicago. One of his undergraduate student researchers approached him looking to investigate the general topic of teleoperation. Dr. Bhounsule supported this idea and extended the original pitch from simply investigating the topic of teleoperation to an end goal deliverable of teleoperating human arm joint movement into the upper body of his very own bipedal humanoid robot. Due to the range of motion of the robot's arms, a handheld controller would not be able to precisely articulate the joints. However, if a human could manually articulate each joint of an exoskeleton arm, then the controlling of the robot's upper body would become intuitive to the user.

Literature Survey

Previous endeavors in teleoperated mechanical arms and robotics machines have been explored, researched, and documented. Through analysis of past designs and specifications of models of robotic teleoperating rms, different criteria and priority of needs were generated for our design. A variety of specific developments and previous endeavors in teleoperated mechanical arms have been analyzed and brought up in discussion with our advisor, made accessible in advisor meeting slides and meeting minutes.

Design Criteria

The design of the exoskeletal arm prioritizes ease of use for educational purposes and regardless of the user's familiarity with its components. It's adjustable for various body sizes, ensuring functionality for both adults and children while emphasizing user comfort. The materials used adhere to budget constraints, focusing on functionality over aesthetics and enabling cost-effective replication. Considering time and budget constraints, the project serves as a foundational platform for potential future expansions. It emphasizes wireless communication with the robot arm, allowing user movement without compromising device-arm connectivity. It's tailored for educational settings, not intended for hazardous or intricate tasks, yet open to future enhancements for specific functions.

I.Technical Content

Assumptions

The project focuses on showing its educational utility, aligning with the existing robot provided by the UIC Robotics and Motion Laboratory. The design ensures compatibility and integration with the robot's programming and signal transference, featuring wireless teleoperation through potentiometers at each joint. Designed for educational purposes, the device aims to highlight the capabilities of robotics engineering to attract interest from visitors and students for the UIC engineering department. The presentation assumes use for individuals of varying shapes and sizes, with an age restriction of at least 10 years for safe usage. Restrictions include abstaining from operation during pregnancy, incapacitating health conditions, or neurological/physical issues hindering effective device operation. The effectiveness of the device is also contingent with its careful use, as any motion going against the device's range of motion or intended purpose could end up breaking it. These limitations prioritize user safety and align with the design's intended audience.

Metrics

Table 1.1: Metric Table

Objective	Metric	Unit
Tele-operational	Ability for exoskeleton arm to manipulate robot arm without being connected via wires	Index
Educational	Ability to be recreated in a classroom setting	Index
Lightweight	Ability for person of any age to manipulate exoskeleton arm	Index
Multiple Uses	Ability to maintain structural integrity after uses	Index
Handled Roughly	Ability for joints to remain intact with as user manipulates arm	Index
Accessible	Cost efficient	Dollars
Adjustable	People of various size and ages should be able to put on the exoskeleton arm	Index
Visually Pleasing	Appear pleasing to the customer's preference	Index

Proposed Solutions

During the design phase, the team collectively agreed upon the configuration of the human interfacing component within the project. A backpack-style harness, illustrated in Figures 1 and 2, emerged as the chosen solution for ensuring stability and comfortable attachment of the arm to the user. The team opted for a harness design resembling that depicted in Figure 2, wherein the arm will be affixed to a wooden board positioned on the user's back, as illustrated in Figure 6. Leveraging cardboard from mailing tubes for the arm model permits internal wiring placement, thus mitigating potential damage and lending a streamlined appearance by concealing the wires within the tubing.

Table 2.1

Morphological Chart

Function 1	*Teleoperates movement*	Electrical Devices						1
Function 2	*Senses Input*	Potentiometer	Motion sensor					2
Function 3	*Sends Signal*	Bluetooth	Wires	antenna	Radio Transceiver			4
Function 4	*Communicates*	Software/Code						1
Function 5	*Connect parts*	duct tape	3D Printed PLA	Hinges	Hot Glue	Super Glue	painters' tape	6
Function 6	*Exoskeleton is secured to arm*	Backpack	Velcro	Buckle				3
Function 7	*Translates Signal*	Arduino Hardware						1
Function 8	*Motor rotates*	Servo motor						1
Function 9	*Power Input*	Battery	Power bank	USB				3
Function 10	*Forms Exoskeleton Shape*	3D Printed PLA	PVC Pipe	Stainless Steel	Plywood	Cardboard	Plastic	6
Function 11	*Adjustable*	Telescopic	Adjustable Strapping	Replaceable Parts				3

Table 2.2
Top Five Concepts

Concept 1	*Potentiometer*	*Arduino*	*Cardboard*	*Bluetooth*	*Backpack Strapping*	*Duct tape*
Concept 2	*Potentiometer*	*Arduino*	*Cardboard*	*Radio Transceiver*	*Backpack Strapping*	*Duct tape*
Concept 3	*Potentiometer*	*Arduino*	*Cardboard*	*Radio Transceiver*	*Backpack Strapping*	*Rubber Sealant*
Concept 4	*Potentiometer*	*Arduino*	*Cardboard*	*Radio Transceiver*	*Backpack Strapping*	*Commercial Waterproofing Spray*
Concept 5	*Potentiometer*	*Arduino*	*PVC pipe*	*Bluetooth*	*Backpack Strapping*	*Duct tape*

After identifying the top five concepts, the team utilized Table 2.3(as seen below), a selection table, to evaluate and select the optimal design for the Tele-Operational Exoskeleton Arm. Employing the “Best of Class" method, a ranking system was used to compare the designs against their objectives and constraints. Three constraints and two objectives were considered in this evaluation to determine which design best meets the project requirements, ensuring a balance between goals and limitations. The table utilizes a rating scale from 1 to 5, with 5 being the best and 1 being the worst. Additionally, a binary “Yes and No” system was implemented for easy evaluation, where “y=Yes” and “n=No”. Each “Yes” is desirable, while each “No” yields no points. The objective of each design is to attain the highest possible score, indicating the most suitable concept for the team’s design.

Table 2.3
Concept Selection Table

Best of Class:	Design Constraint (C) and Objectives (O)	C1	C2	C3	C4	C5
	(C) Teleoperates with insignificant amount of lag	n	y	y	y	n
	(C) Accessible	4	5	3	3.5	2.5
	(C) Durable	4	4	3.5	3.5	5
	(O) Can be made Adjustable	y	y	y	y	y
	(O) Lightweight and made of fewer parts	5	5	5	5	3
Total Score		**13**	**14**	**11.5**	**12**	**10.5**

After a thorough evaluation using the concept selection table, Concept 2 emerged as the most promising design for the Tele-Operational Exoskeleton Arm project. Concept 2 incorporates potentiometers, an Arduino microcontroller, cardboard tubing, a radio transceiver, backpack-strapping, and duct-tape covering for the cardboard tubing. The decision to use a radio transceiver over Bluetooth was made because it proved to be easier to implement and demonstrated less lag in testing. Similarly, duct tape was chosen as the covering for the cardboard tubing instead of waterproofing spray or rubber sealant. This decision was based on the fact that duct tape performed similarly in testing (Figure 5), and it is much more accessible, making it easier to maintain and repair the exoskeleton arm in the long run.

Finalized Design Choice

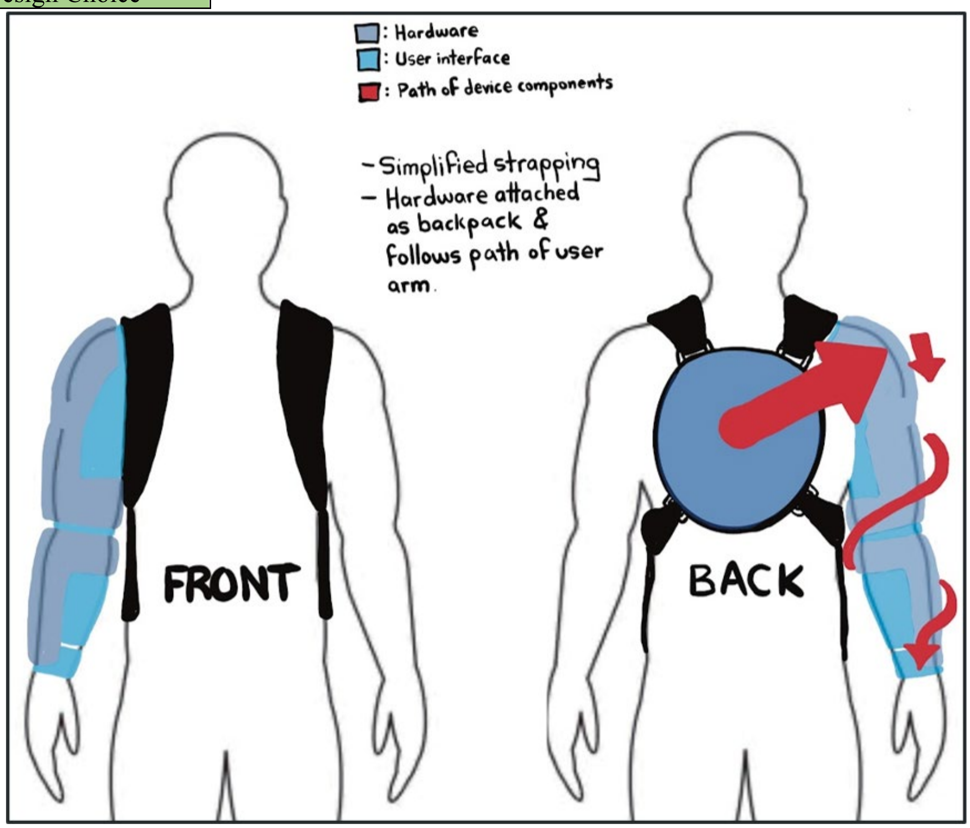


Figure 1: Graphic representation of body attachment

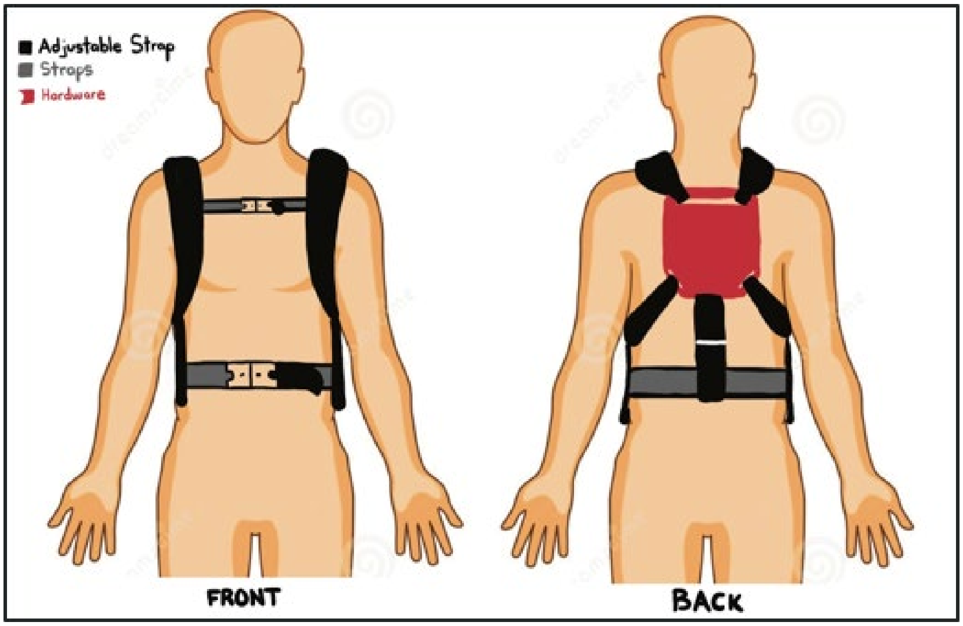


Figure 2: Graphic representation of central support

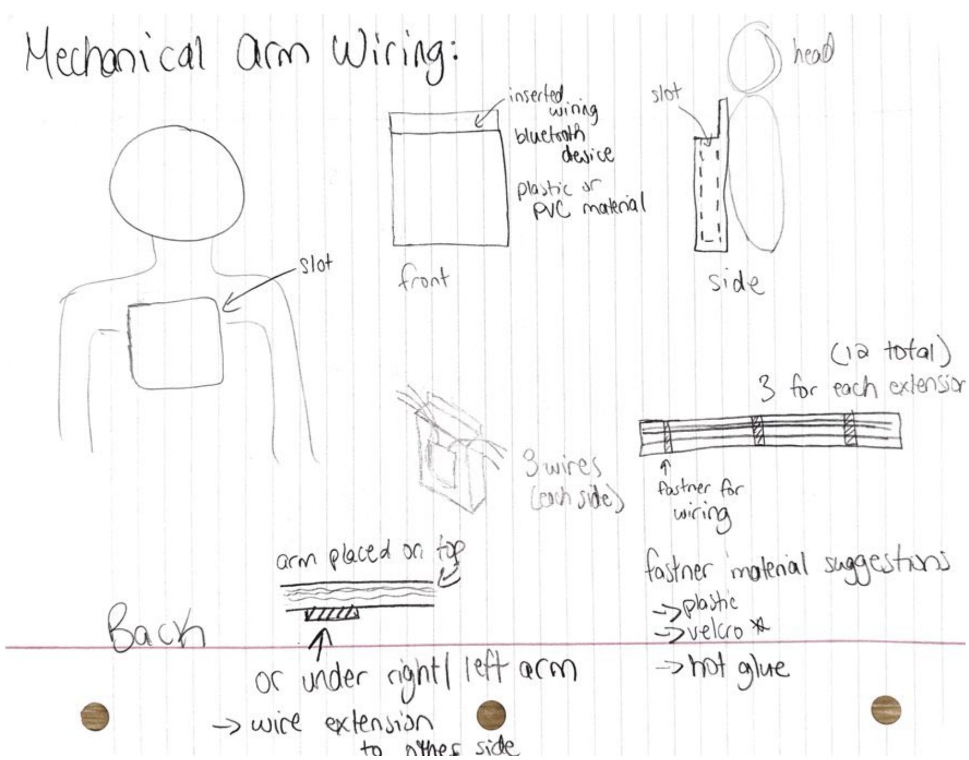


Figure 3: Initial sketches for arm attachment during preliminary prototyping stage.

Figure 4: First prototype full scale arm model.

Figure 5: Testing waterproofing solutions to improve durability.

Selected Design

In designing the teleoperating arm, our team prioritized user comfort and adaptability by incorporating adjustable features such as a utility backpack attachment and telescopic handle. These elements allow for macro adjustments to fit various body sizes and customize arm length, position, and rotation, catering to different user preferences. To address structural integrity challenges with 3D printed PLA points, we reinforced them with a surface finish of superglue. Additionally, recognizing cardboard's vulnerability to moisture, we tested various coatings and found duct tape to be the most effective in enhancing durability. The choice for cardboard as the main component for the arm was driven by its low cost and lightweight properties, maintaining affordability without sacrificing performance. We also opted for a wireless radio transceiver over Bluetooth for connectivity, prioritizing intuitive setup and reliable communication, thus optimizing user experience and operational efficiency. Though testing and exploration of alternatives, the final design of the teleoperating exoskeleton arm achieves our objectives with low manufacturing cost. Careful consideration of materials and component design ensures affordability and accessibility without compromising on performance.

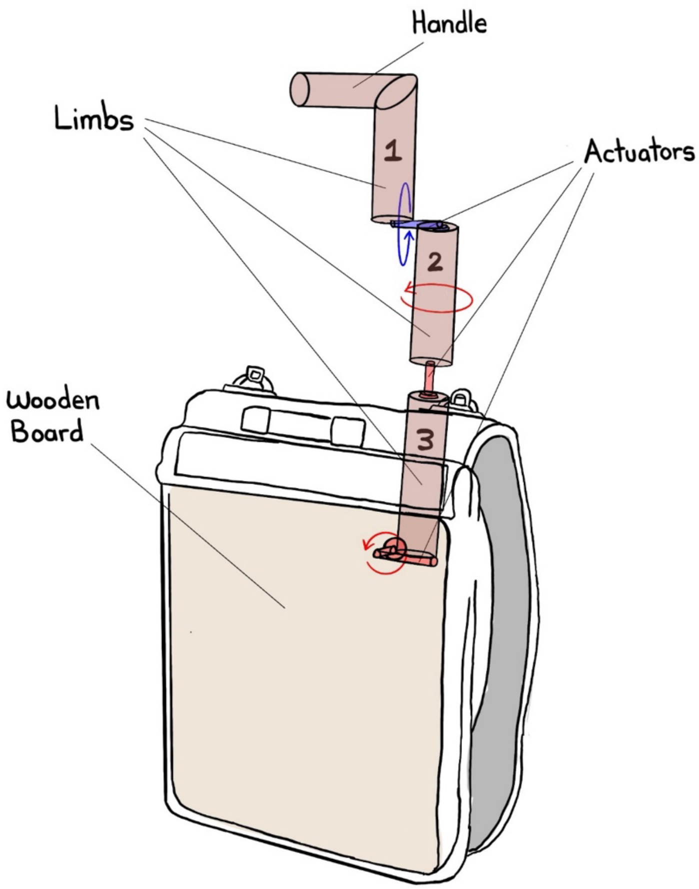


Figure 6: Finalized protype design depicting back of the harness where the protype arm will be attached.

Figure 7: Finalized design of tele-operated mechanical arm control modeled next to UIC Robotics and Motion Laboratory bi-pedal robot.

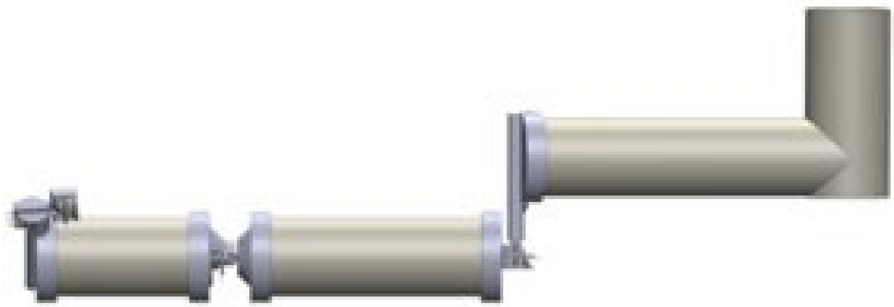


Figure 8: Finalized CAD model of final design of tele-operated mechanical arm control device.

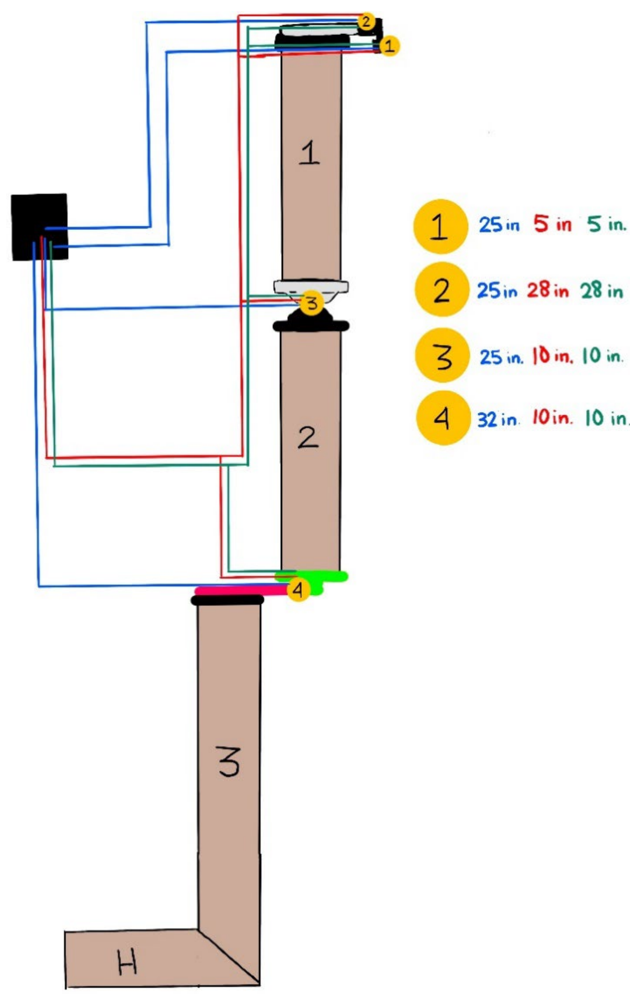


Figure 9: Finalized design including tube measurements of tele-operated mechanical arm control device.

II. Preliminary Results

Failure Mode and Effects Analysis

Device Design – Adjustability

One of the primary considerations in the design process was ensuring that the exoskeleton arm could comfortably support users of different sizes. To achieve this, the team focused on creating a design that was adjustable and customizable: The device needed to securely attach to the user's upper body while maintaining comfort. To address this, the team employed a utility backpack. The backpack provided a familiar and comfortable method of attachment for users.
This approach also allows for macro upper body size adjustments to fit different users. The device also has an integrated telescoping length handle. This feature allowed users to customize the length, positioning and rotation of the handle according to their comfort and reach. This allows portion of the device held by the user to extend or retract as needed. This telescoping feature caters to users with varying arm lengths or preferences for operating distances.

Device Design - Durability

In early stage prototypes the 3D printed PLA joints were experiencing critical failure due to the stresses applied to each joint. The team redesigned several variations of joints 1, 5, and 8, but the distribution of stresses were too great. To assist in solving this problem, a surface finish of superglue was applied to each joint. Superglue can penetrate the microscopic gaps and imperfections on the surface of 3D printed parts, reinforcing their structural integrity and making them more resilient to the stress and strains encountered during operation.
Given that cardboard has a significant loss of strength upon exposure to water and sweat, three coatings were evaluated to enhance the durability of cardboard and bolster its resistance to moisture. The coatings were a commercial waterproofing fabric spray, a painted rubber sealant, and a wrap of duct tape. First, 2.5in samples of tubing were wrapped with a moistened paper towel, then their structural integrity was assessed either through a compression test—where increasing weights were applied until noticeable deformation occurred—or by monitoring moisture penetration using dry potting soil and a sensor to detect water seepage through the coating. Among the various coatings examined, duct tape significantly outperformed others in enhancing the cardboard's crush resistance. Meanwhile, in the moisture permeability assessment, the three innovative coatings demonstrated similar levels of effectiveness.

III. Preliminary Conclusions / Future Work

As the project reaches its conclusion, considerable headway has been achieved in refining the arm design. An initial prototype crafted from cardboard has been successfully developed to enable teleoperation of the humanoid robot arm. Nonetheless, the current iteration of the prototype exhibits fragility at certain connecting parts, rendering it susceptible to breakage after constant use. Addressing this fragility stands as a critical focal point necessitating improvement as we transition into the final half of the semester. The team is also retaining the cardboard material for cost-effectiveness and ease of replication for educational purposes. The creation of the full physical prototype marks a pivotal milestone, enabling the team to pivot towards advancements in its functionality and overarching enhancements. As we approach the second half of the semester, each team member has been allocated specific tasks pivotal to our progress. These tasks encompass testing material coatings to impart waterproofing to the cardboard to increase durability, finalizing CAD drawings, conducting material assessments pertinent to human interface, delving into Bluetooth interface research, and exploring the potential for telescopic arm adjustability.

This innovative approach marks a significant leap forward in the field of robotic control, particularly for multi-joint systems. By leveraging the natural movements of the human body and translating them into precise control for robotic arms, this technology effectively bridges the gap between human intention and robotic action. This not only enhances the precision and maneuverability of these systems but also transforms the user experience, making the operation of complex robotic systems more intuitive and significantly less burdensome for the operator.

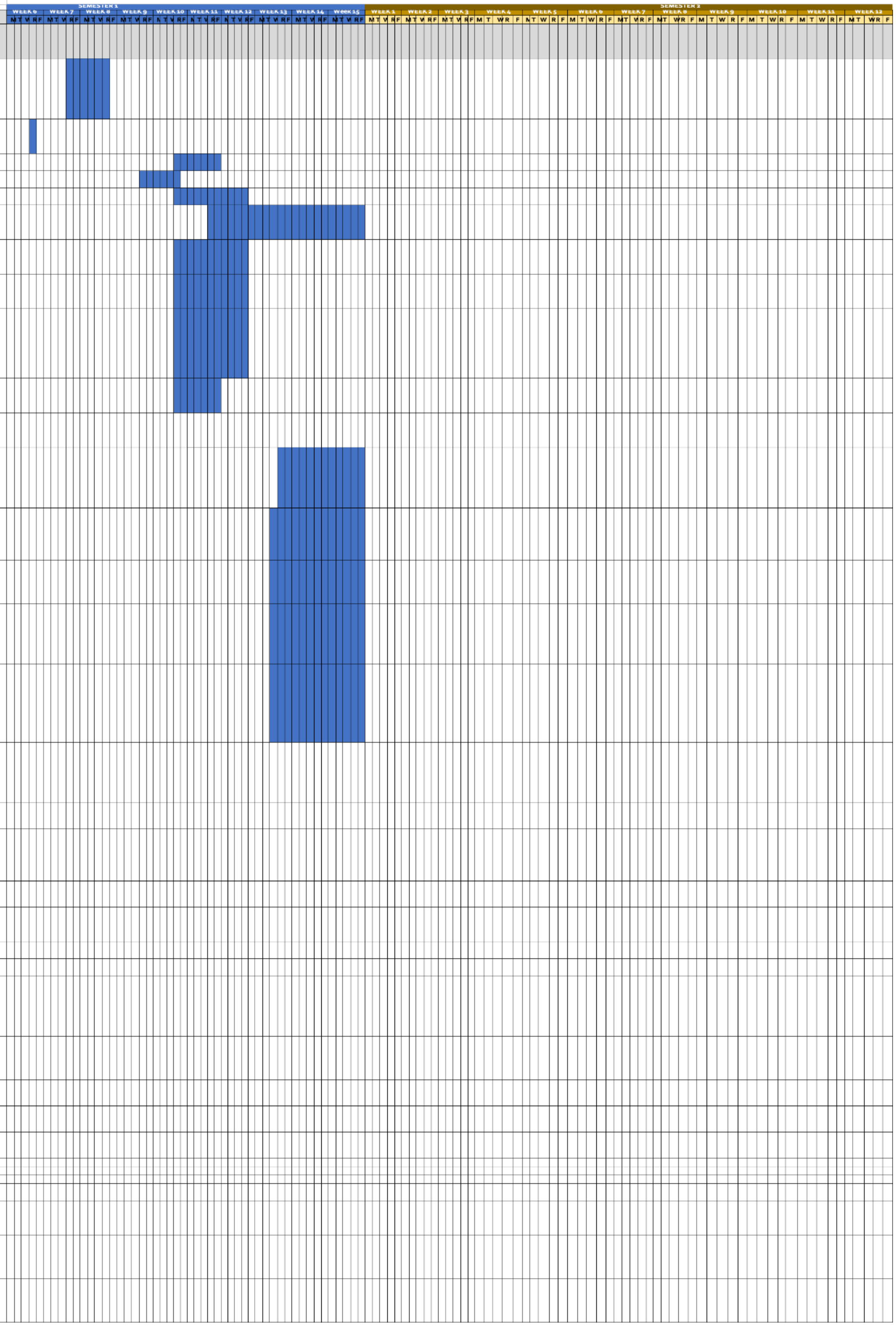
The implications of such a technological advancement are profound. In environments where the risk to human operators is too great, such as inside nuclear reactors, amid search-and-rescue operations, or within the harsh confines of space, the ability to deploy robotic systems that can be controlled with such precision and intuitiveness can significantly enhance operational effectiveness. These robots can undertake tasks that require a high degree of dexterity and adaptability, tasks that traditional remote-controlled or autonomous robots may struggle to perform efficiently.

Appendix: Gantt Chart

PROJECT TITLE Robot Arm Joint Teleoperation

PROJECT MANAGER Pranav Bhounsule

WBS NUMBER	TASK TITLE	TASK OWNER	START DATE	DUE DATE	DURATION	PCT OF TASK COMPLETE
1	Project Conception and Initiation	PP	10/3/23			
1.1	Communication and Meeting Plan for Rest of Semester	Everyone	10/5/23	10/12/23		
1.12	Meet With Project Manager	Everyone	9/28/23			
1.2	Project Charter	EE	10/26/23	11/3/23		
1.3	Design Research	Everyone	10/19/23	10/26/23		
1.4	Materials research	TL	10/26/23	11/9/23		
1.5	Begin concept design sketches	Everyone	10/26/23	12/1/23		
1.6	Prototype arm movement in CAD	PP	10/26/23	11/9/23		
1.7	Research secure strapping method	EG	10/26/23	11/9/23		
1.8.1	Research how to integrate wiring into design for comfort	SM	10/26/23	11/9/23		
1.9	Write Project midterm report	Everyone	10/26/23	11/3/23		
2	Project Launch & Execution					
2.1	Write Project Final Report for Semester 1	Everyone	11/16/23	12/1/23		
2.2	Look at potential use of telescoping in design	EE	11/23/23	Begining of Semester 2		
3.2.1	Combine and finalize CAD parts	SM	11/23/23	Begining of Semester 2		
3.2.2	Finalize material selection and begin moisture testing	TL	11/23/23	Begining of Semester 2		
3.3	Finalize strapping method and begin ordering materials for testing	EG	11/23/23	Begining of Semester 2		
3.3.1	Finalize cardboard model w/ potentiometer housing	PP	11/23/23	Begining of Semester 2		
4	Semester 2 Project launch		1/8/24			
	Meet with Project Sponsor (Professor Pranav)		1/12/24			
4.1	Budget Managment		1/15/24			
4.1.2	Delegate Build Assignments		1/17/24			
4.2	Build Protoype		1/8/24	2/16/24		
4.3	Test first Build		2/16/24			
4.4	Create List of Issues with Build and potential solutions					
4.5	Write Midterm Report Semester 2	Everyone	2/23/24			
4.6	Redesign Protoype 1					
4.6.1	Build Redesign Protoype					
4.6.2	Test Second Build					
	TBD					
	TBD					
	TBD					
	Finalize Build					
	Write EXPO presentation	Everyone	3/8/24			
	Practice/ memorize presentation	Everyone	3/8/24			
	Write Final Report Semester 2	Everyone	3/8/24			



Project Charter

4General	
Project Name:	MIE #37 Mechanical Robot Control
Project Sponsor:	Professor Pranav Bhounsule, UIC Robotics and Motion Laboratory
Project Manager:	Professor Michael A. Brown

Problem Statement
The UIC Robotics and Motion Laboratory has developed a bipedal humanoid robot primarily used for locomotion. The laboratory has plans to extend the capabilities of the robot so that it can manipulate objects through teleoperation of the upper body. The primary objective for this team is to develop a mobile upper body arm exoskeleton that can house potentiometers at each joint to wirelessly teleoperate joint movement of the user to the arm joints of the robot. While the design will be made specifically for the robot in the UIC Robotics and Motion Laboratory, teleoperation of machinery has the potential to reduce injury in workplace operations, reduce tolerancing of medical procedures, and aid in search and rescue operations across the world.

Goal Statements	
1.	Develop a wearable and mobile upper body exoskeleton that supports potentiometers at each joint.
2.	Exoskeleton must wirelessly teleoperate joint movement to arm joints of the robot.
3.	Exoskeleton must be adjustable so that both an adult and a child can teleoperate the robot.
4.	Device must be made within the given $1000 budget.
5.	

Project Charter

Project Scope

Deliverables:
A wearable and mobile upper body exoskeleton (for at least one arm) that houses potentiometers which teleoperates the arm(s) of the humanoid robot wirelessly.

Assumptions:
This team is assuming that the use of adjustable straps which will go across the back and/or chest will be the primary strategy in making the device adjustable rather than making the exoskeleton itself adjustable.

Constraints:
The device must be fully built and functional by the UIC Spring 2024 Engineering Expo. Both prototype design and final presentation must fit within the given budget ($1000).

Summary Milestones

The milestones will be kept track of via biweekly advisor meeting. The first milestone will be the creation of the first prototype design which should be completed before the end of the fall semester. The next milestone would be to finalize the design which should also completed either by the end of the fall semester or the beginning of the spring semester. The final milestone will be building the finished model and testing its functionality, which will be the group's focus during the spring semester.

Summary Budget

$1000

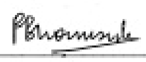
Project Charter

Success Criteria
For this project to be successful, the exoskeleton must fit comfortably on a person's arm and the device must be able to wirelessly teleoperate the human joint movements to the humanoid robot accurately.

Stakeholders & Affected Business Areas
UIC Robotics and Motion Laboratory

Core Team Members
Elena Esparza, Edward Gonzalez, Taiga Larkin, Sultan Muhammad, Paul Peretz

Project Sponsor Approval



The Arduino code used to program potentiometer movement in the joint control system is as follows:

```
#include <Servo.h>

int val1;
int val2;
int val3;
int val4;

Servo ser1;
Servo ser2;
Servo ser3;
Servo ser4;

void setup()
{
  Serial.begin(9600);
  ser1.attach(4);
  ser2.attach(5);
  ser3.attach(6);
  ser4.attach(7);
}

void loop()
{
val1 = analogRead(A0);
//Serial.println(val1);
val1 = map(val1, 137, 852, 0, 179);
ser1.write(val1);

val2 = analogRead(A1);
//Serial.println(val2);
val2 = map(val2, 216, 728, 0, 179);
ser2.write(val2);

val3 = analogRead(A2);
//Serial.println(val3);
val3 = map(val3, 200, 900, 0, 179);
ser3.write(val3);

val4 = analogRead(A3);
Serial.println(val4);
val4 = map(val4, 80, 700, 0, 179);
ser4.write(val4);
}
```

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