Helping Hand: Intuitive, Tele-Operated Robotic Arm

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***Abstract*—As robotic technology becomes more prevalent in society, more intuitive control approaches will be necessary. This will make the technology more accessible to all users with little to no training. Helping Hand is a remotely controlled robotic arm using a novel human-robot interface. Helping Hand mimics the user's actions, resulting in an experience that is both precise and user friendly.**

I. Introduction

The applications and prevalence of robots in our society is expanding rapidly. Ever since the industrial revolution, man has sought to create machines that can accomplish tasks once only possible by a human. Originally, these machines were purpose-built, designed to perform only one or two highly specific tasks. However, the latter half of the previous century up until today have brought about more generalized applications. The human body is often regarded as the gold standard for general-purpose robots. This is not surprising as the human body is capable of performing a huge number of tasks. Therefore, by building a robot that is a human body analogue, or one that embodies certain elements, one can tap into this huge potential.

Of the entire human body, the most important limbs for manipulation are the arm and hand. In recent years, robotic arm technology has improved vastly and has been extended to many new areas. These range from construction site, to medical surgery robotic arms. The most famous example of the latter is the da Vinci surgical robot, which utilizes multiple extremely precise robotic arms to actually help perform a surgery. [7]

The challenges of these robotic arms are their remote-control systems; essentially, the way the operator interacts with and manipulates the robot. Currently, some of the most popular ways include using some kind of remote-control, joystick, or wearable device. While easy to implement, these methods remain complicated and unintuitive for the user. Our system can reduce—if not entirely eliminate—the amount of training needed to operate such systems.

In order to address these challenges, our team is designing and constructing a remotely controlled robotic arm using a

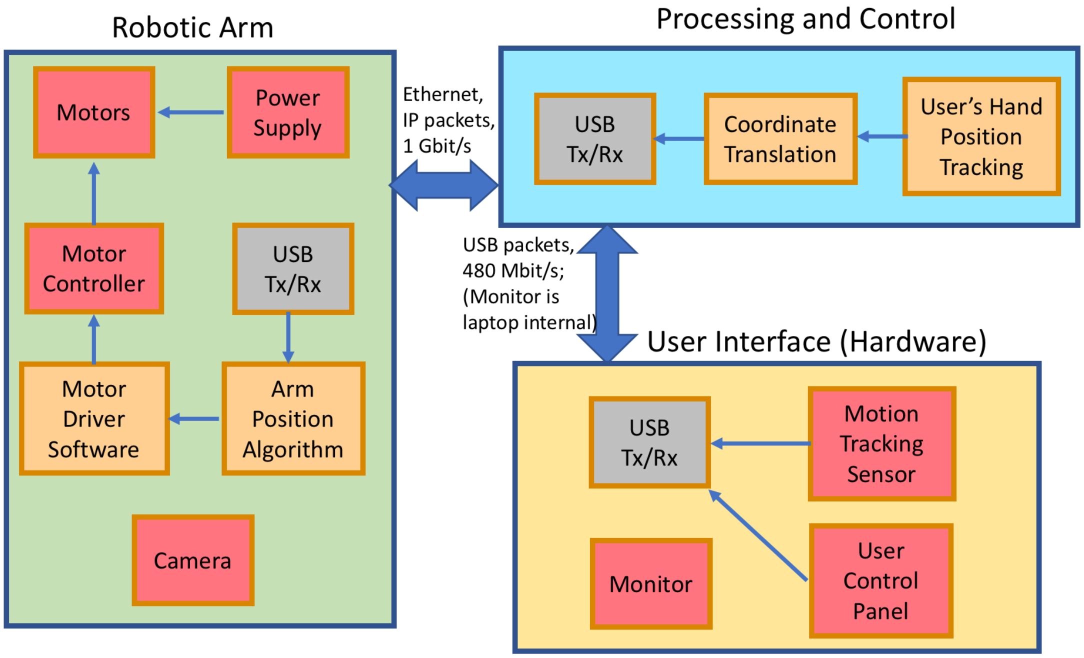

Fig. 1. This block diagram shows the organization of the Helping Hand project.

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novel human-robot interface, that will be both precise and user friendly. The arm will mainly be controlled by mimicking the user, meaning when the user moves their arm, the robot will move the same amount.

Our system requirements are mainly due to the two large linear actuators that power to two main joints of the arm. Both motors draw up to 10A maximum [6] and therefore require a 20A power supply at a minimum just to power the arm. The microcontroller and the Raspberry Pi both require separate 1A power supplies. If the microcontroller does not have a separate power supply and is instead powered off the Raspberry Pi, the input can vary slightly which causes issues when reading analog voltages using the analog to digital converter (ADC). On the user interface side, all of the power is easily supplied by the user's laptop or desktop computer. Our system has been designed to meet the specifications as shown in Table I. The functionality test demonstrates the cohesiveness of system and all its specifications.

Because of the modularity of our system, the user interface side could in theory be very easily adapted to a larger a smaller system however the arm side is not as scalable. It is possible to change the dimensions slightly (changes of less than 10 cm in arm length), however, greater changes would require a complete redesign. In order for someone else to use our system they would merely need to turn the system on and place their hand over the sensor. Since the arm mimics the user, using the arm, even for a first-time user, is extremely simple and intuitive.

II. Design

A. Overview

The way in which our team has approached this problem consists of three main divisions: 1) the user interface, 2) processing and control and 3) the robotic arm hardware as shown in Figure I. The processing and control portion of the system receives the three-dimensional coordinate of the user's current hand position from the user interface hardware. The hand position is determined using the Leap Motion controller and sent to the Raspberry Pi in the processing and control portion over Ethernet. Eventually the user control PCB will also send commands to the Raspberry Pi over the same Ethernet connection. We chose to use the Leap motion over similar technologies such as the Kinect [8] for several reasons, although we are considering incorporating the Kinect in at a later point. The Leap Motion is very accurate for hand movements, mainly because it was designed to do exactly that. In comparison the Kinect is designed to track the user's whole body. This results in decreased accuracy for reading just the hand positions and the state of being open or closed. The user control PCB will provide the user with some control from the left hand to do things such as pausing and resuming tracking and emergency stop of the arm. These controls will record using physical buttons rather than reading in the hand state with the Leap Motion.

The microcontroller receives its instructions from the processing and control portion of the system as shown in the block diagram. A Raspberry Pi model 3 is used to receive the coordinates from the user interface hardware portion of the system. The Raspberry Pi receives a three-dimensional coordinate of the user's current hand position from which it calculates the joint angles needed to reach that point. These calculations are done using inverse kinematics equations. It then sends those angles to the microcontroller. The Raspberry Pi was selected for this task because of its ability to perform the inverse kinematics equations quickly and reliably, its ability to communicate over Ethernet with the user interface hardware, and its ability to interface a webcam with it. The Raspberry Pi also allows to us add additional computations and tasks as needed without significantly affecting the performance. This portion of the system will meet the specifications of latency and movement criteria as shown in Table I.

The robotic arm system includes both the mechanical design of the arm and the electronic hardware used to control the arm. The control of the arm is implemented using an Atmel microcontroller which commands each joint angle. Using this angle, the microcontroller calculates the necessary speed to set the joint motors. This calculation is done using the desired angle and the current angle as inputs to a basic feedback system which outputs a speed and direction for each motor. The speed and direction are then given as the input to the H-bridge which actuates the motors. The Atmel microcontroller was chosen due to both the reliability and robustness of operation and its simplicity in implementation. See Figure 2. The H-bridge was chosen simply based on the current and voltage specifications for the motors.

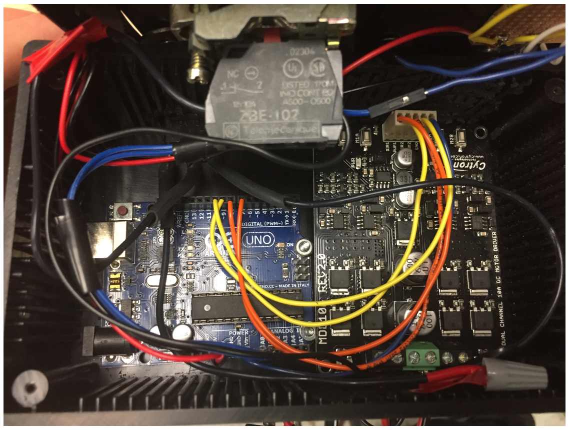


Figure 2. H-bridge and microprocessor.

The physical arm was designed from the ground up. The arm is essentially built around two linear actuators which can support up to 110 pounds while in motion [6]. These two motors provide the two degrees of freedom in the vertical plane, while a base motor provides the degree of freedom in the horizontal plane. The physical structure of the arm is constructed of aluminum which provides us with significant strength while keeping the weight to a minimum. The arm system will meet the specifications of minimum range of motion, minimum speed, latency, and movement criteria as shown in Table I.

Requirement	Specification
Lifting Strength	Should be able to lift at least 1 lb.
Range of Motion	The robot should be able to reach every point in a workspace 2' wide, 2' deep, and 1.5' tall.
Latency	Robot should move within 250ms of the user moving.
Speed	The movement of the robot should be at least 5 inches per second.
Functionality	User should be able to move five rocks from the workspace into a bowl in under 5 minutes.

Table I: List of system requirements and specifications.

B. Hand Position and Motion Tracking Sensor

These sub-blocks of the Processing and Control block and User Interface block are concerned with tracking the user's hand position in three dimensions and in real-time. The motion tracking sensor will be placed on the table in front of the user. The sensor we are currently using is the Leap Motion Controller [1]. The Leap Motion Controller LM-010 is a 3x8cm area package which consists of three IR emitters and two IR cameras and is interfaced with a computer via USB 2.0 [2]. This sensor has a tracking accuracy of less than 0.2mm for stationary positions and 1.2mm for dynamic ones [2]. It has a latency of 5ms when in High-Speed mode, and 12ms when in Precision mode [3]. It's effective tracking area is 25mm to 600mm above the sensor, with a field-of-view of 150 degrees spanning radially upwards from the sensor [1]. From our own testing, the sensor typically samples at 100Hz, although this can vary by up to 5Hz depending on CPU usage. However, all these metrics still need to be tested thoroughly, as conditions such as lighting can have a quantifiable impact of performance. Moreover, a calibration process is necessary to achieve the optimal accuracy for a particular environment, although un-calibrated performance might be sufficient for our application. This will also be evaluated during testing.

The experiment we will be conducting to measure the effective tracking area of the sensor will be to move our hand back and forth, up and down, side to side over the sensor, creating a point-cloud of tracked Euclidian (xyz) positions. Then taking this point-cloud, we will generate the convex hull. This convex hull will be the definitive volume within which hand tracking is possible. This experiment will then be repeated under a different set of lighting conditions to see if that has an effect.

If the experiment determines that the sensor does not meet our system specifications, it might be necessary to explore alternate options. One option is switching the sensor to a Kinect [8]. The advantage would be that it has a massive tracking area, as it is designed to track the full skeletons of multiple people. The downside to this is that the tracking accuracy for a hand will most likely be significantly coarser than the Leap Motion. Another option is to use multiple Leap Motion sensors placed around the tracking area. This will expand the effective tracking area to one that meets the design specifications. In fact, this seems to be a promising approach as it has already been accomplished as detailed in: *Multi-Leap Motion sensor based demonstration for robotic refine tabletop object manipulation task* [4].

The motion tracking system and processing, from sensor to Euclidian points, is handled automatically through the Leap Motion's driver, provided as part of the Leap Motion's software package. However, we perform some post-processing on the data to reduce jitter in the sensor output. Since the sensor samples at 100Hz but our system only transmits data between the user's computer and the robot's embedded system at 20Hz, we have more data than can be sent. In order to utilize it, we currently average every 5 samples together and transmit the averaged value. This is essentially a low-pass filter on the signal. Other possibilities include a median filter or just selecting the latest sample. These will be implemented next semester and whichever performs the best at reducing jitter while not impairing latency will be chosen. There is an obvious tradeoff here so a balance needs to be achieved.

C. Robotic Arm

The Robotic Arm block encompasses the major hardware component of the system. See Figure 3. The arm is constructed with three main pieces, the base, shoulder, and elbow joints. The shoulder and elbow stages sit on top of the base, which has a DC motor connected to a turntable bearing through a chain drive system. The base provides 270 degrees of rotation along a single plane, in front of the robot. The shoulder and elbow joints are both powered by linear actuators, allowing for controlled, stable motion in a single plane. By combining the capabilities of all three joints, we are able to achieve a working area of approximately 2ftx2ftx1.5ft directly in front of the robot.

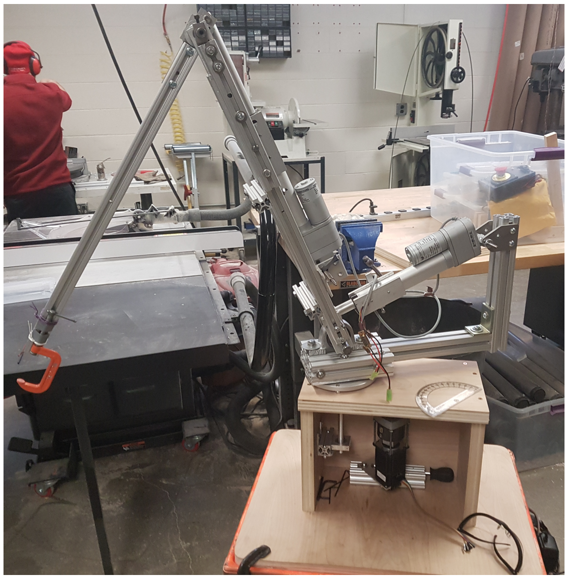


Figure 3. Helping Hand Prototype

The frame of the arm is built primarily from 1 inch 8020

T-slotted aluminum extrusion. This particular stock was chosen for its combination of strength and being lightweight. Alongside the aluminum stock, there are rotary bearings on the two upper joints to provide a smooth rotation of the joints. The entire arm is mounted on an enclosure built from 1in plywood, which provides plenty of strength to support the whole system.

To test the functionality of the arm, a manual control unit was built. The manual control unit delivers 12V in either direction to the motors from a momentary switch. This allowed for testing the arms total workspace, and for further developing the physical components of the arm.

The next phase in arm development will be the gripper. A gripper is needed to pick up objects, and in our case, ping pong ball sized rocks. We chose to use the open source, 3-D printable Mantis Gripper (see Figure 4). [9] This gripper was chosen for its combination of strength, size, and cost-effectiveness. By being able to 3-D print the majority of the parts, we will be able to make the best use of our budget.

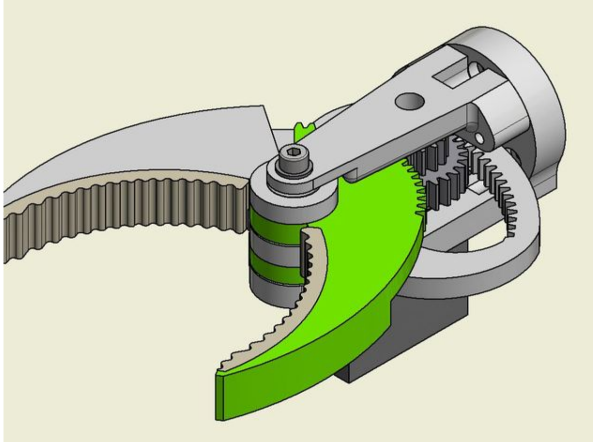


Figure 4. Mantis Gripper 3D Render

D. User Control Board

The User Control board provides additional functionality for the user, which would be difficult to control with hand gestures alone. The board is designed to be controlled with the user's non-dominant hand. The board features four buttons, which are connected to four digital pins of an ATMega328P [10]. The buttons will allow the user to stop the system in case of emergency, pause and resume the system, reset the system, and calibrate the system. The user control board is connected to the system via USB. Further development of this system will be needed as arm functionality progresses.

III. Project Management

TABLE II

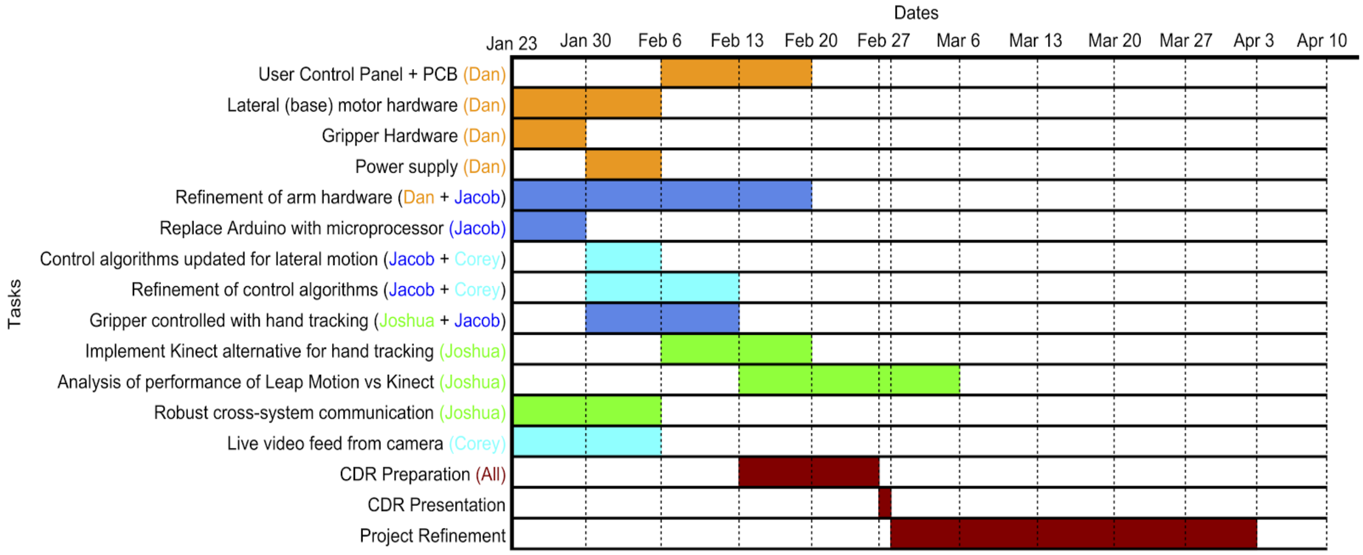
PROPOSED MDR DELIVERABLES

MDR Goal	Status
Arm movement in 3 DOF	Accomplished
Vertical movement controlled by integration of all major systems	Accomplished
Raw User Input Data Successfully received and processed	Accomplished
User Control Panel Prototype complete	Accomplished

Our team has shown a lot of vitality and perseverance since the beginning of this project, and through that we continue to learn how to work together efficiently and effectively. With communication and personal accountability as our mode of operation, coupled with frequent meetings and clearly delegated tasks, we were able to accomplish all of our MDR goals as outlined in Table II. As promised, we accomplished arm movement in three degrees of freedom, demonstrating that our design choice was sound. Also, we integrated vertical movement controlled by the integration of all major systems, which included successfully receiving and processing raw user input data. Lastly, we completed the user control panel prototype.

Even with this progress, much remains to be done. A Gantt chart of our future schedule is shown in Figure 5. The base motor needs to be integrated into the control algorithms, so the system can provide positioning in three degrees of freedom. The gripper must be integrated into the system and controlled by the user opening and closing their hand. Also, in order to provide the user with feedback, and to allow the user to use the arm remotely, a live video feed will be integrated into the system. Finally, we'll need to guarantee that the arm will

FIGURE 5: GANTT CHART



move 5 rocks into a ~3" tall bowl of diameter within 5 minutes.

Each member of the Helping Hand team has contributed important and specific aspects to the overall project and has a specific expertise. Corey Ruderman's expertise lies in software, specifically interfacing it with hardware. Corey has designed the protocol for intersystem communication, assisted with the arm control algorithms, and worked on the team website. Daniel Travis has experience building mechanical systems and designing printed circuit boards. Daniel has researched the most optimal design for our arm, and constructed the physical arm, as well as the user control panel prototype. Jacob Wyner is skilled at electronic hardware integration and embedded system programming and design. Jacob implemented the electronic arm hardware and took the lead for developing the arm control algorithms. Joshua Girard is proficient in programming, networking, and embedded systems. Joshua is concurrently developing motion tracking algorithms for both the Leap Motion Controller and the Kinect Sensor.

Although each team member had their own contributions to the project, everyone helped out to make sure that the goals that had been set were met. When it came to designing the physical arm and the protocol for intersystem communication, everyone helped to come up with an optimal solution. Whether this meant helping to troubleshoot or choosing materials for the arm design, the team was there to help when needed. Overall, it was a group process to meet all of our MDR deliverables.

To complete the various aspects of the project, the team remains in constant contact with each other via GroupMe. We continually update each other on individual progress, and meet once a week with our advisor to touch base. This meeting gives us a chance to ask questions when problems arise and get invaluable guidance. Also, we reflect on the progress that has been made and where we plan to go next. We have managed to stay on the same page through these meetings as well as email contact and will continue this practice going forward.

IV. Conclusion

Project Helping hand is proceeding on schedule. For MDR, we had proposed to have working versions of each of the three main subsystems and to have them able to communicate with one another. We accomplished this and showed significant progress towards a full working prototype.

Going forward, we plan to focus on each subsystem's functionality, optimizing motion tracking, and making the system more user-friendly. We will design and build our PCB and construct our final prototype. Concurrently, we will integrate base motor control into our algorithms, integrate the gripper into our system, implement live video feedback, and have our arm pass the evaluation metric mentioned above. We anticipate that the most significant difficulties will come from the gripper hardware. We will buy ourselves as much time as possible by developing and testing different designs so that it is completed by the time the control algorithms are ready.

Assuming all goals are met for CDR, the group hopes to experiment with extra features that will improve the usability of the system, such as reducing latency and making the hand tracking more accurate.

Acknowledgment

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