

GNG2101 -- *Final Design Report: Wheelchair Robotic Arm*

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Abstract

This report outlines the design of a hands-free, wheelchair-compatible robotic arm. The design makes use of an Arduino Uno for motor control, as well as a simple remote web application as the user interface. Function of the robotic arm ranges from picking up small, pencil sized objects and pressing elevator buttons. All of the design criteria for this project was created by interpreting the needs of patients living with arm mobility restrictions at St. Vincent's Hospital in Ottawa, Ontario. The robotic arm outlined in this document was designed for mass manufacturability, resulting in a low cost for customers in need of such a product.

1.0 Introduction

Every day, thousands of Canadians living with physical disabilities struggle to perform even the simplest activities such as brushing their teeth, eating and drinking, or turning the pages of a book. Although there are many mobility aid devices on today's market, they are often unaffordable for those with limited health care coverage. In Ontario, the government will only cover up to 75% of the total cost of mobility aids. This may seem like a good deal; however, most of the devices on the market cost dozens of thousands of dollars, and the remaining 25% of a product costing fifty thousand dollars out-of-pocket is enough to bankrupt many people.

One of the most sought-after mobility aids is the robotic arm. Some of the existing robotic arm products on the market may attach to a variety of surfaces (sometimes even directly onto the user) and have a wide range of functions. For those few people who can obtain one of these devices, performing everyday tasks is no longer a challenge; they are able to comfortably live with their disabilities.

The design of the robotic arm outlined in this report is aimed to make such a mobility aid accessible to all who need it. That is, this robotic arm is designed to be cost efficient, user friendly, and mass-manufacturable.

2.0 Research & Benchmarking

Kinova's JACO arm is an example of an existing product that satisfies most of the needs of our client. The JACO arm is able to carry out many of the day to day necessities and tasks of the user. The users of JACO are able to control the arm by using a control handle to accomplish operations such as holding cups and picking things up from the ground. Kinova provides different choices for its customers. On their official website, Kinova customers are able to customize their own arms in order to satisfy any unique and individual requirements.

The arm is built to contain 4 to 6 electric motors, 2 to 3 main arm structures, and two different grippers. Since there is only one control handle, users are able to get used to the control in a short time. Users can also "teach" the arm certain actions so that the robotic arm performs the tasks automatically. Additionally, the gripping portion of the arm is designed such that the arm can provide enough force to hold the object without damaging the object.

Instead of using conventional materials such as plastic or aluminum, JACO uses carbon fiber to build the main structure which makes the arm extremely lightweight compared to most of the similar products on the market. This makes the arm easier to install, but the use of carbon fiber significantly raises the price of the arm. This causes major issues for typical consumers given that government funding for many patients who need robotic arms is low.

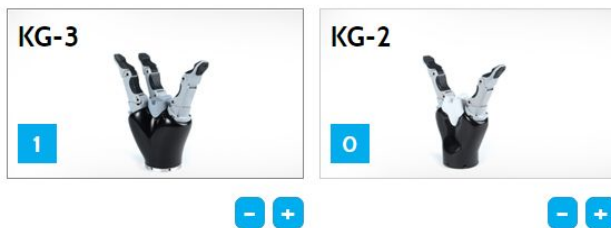


Figure 1.1: JACO robotic fingers and hand



Figure 1.2: JACO robotic arm

Based on these unique and advanced features, Kinova's JACO will be the main benchmark for our robotic arm project. It satisfies many of our user's needs including the fact that it's able to complete most of the required actions our client needs, is independent of the wheelchair (in terms of battery) and is compatible for many types of wheelchairs.

3.0 User Needs & Problem Definition

Before any conceptual designing, there needed to be a client meeting with the hospital representative Bocar N'Diaye and the patient. The patient had extreme difficulty being independent because of the lack of mobility in her arms and hands. During the meeting, the client and patient were asked many questions to extrapolate their needs and wants for the arm. The following table compiles the data interpreted from these meetings.

Table 1: A list of user statements with their respective needs and priority ratings

#	Client/User Statements, Limitations & Observations	User Needs	Priority 1-5 [where 1 is low and 5 is high]
1	Arm does not add width to table of wheelchair, nor compromise the wheelchair's structural integrity	The robotic arm is compact and is not permanently attached to the frame of the wheelchair.	2
2	Reaching items on the wheelchair tray/table is challenging	The robotic arm allows for the grabbing/picking up of items and the transportation of the items to and from the user	5
3	Limited strength and range of motion in arms/hands	The robotic arm allows for a wide range of motion (vertically and horizontally)	5
4	The user is familiar with modern technology (uses tablet, laptop, various hands free tools)	The robotic arm can be accessible easily through hands free technology.	4
5	The user operates a laptop using glasses with 3M reflective tape	The robotic arm is remotely operable.	5

6	Funding for a robotic arm is limited	The robotic arm is affordable (both manufacturing and operating costs are low).	3
7	Must be compatible with both electric and manual wheelchairs	The robotic arm does not rely on the wheelchair batteries for power and is easily customizable.	4

From the user needs outlined above, the following problem statement, which guided the rest of this project, was created:

“There is a need at St. Vincent’s Hospital for a low cost robotic arm that can be operated by patients with very limited mobility in their arms and hands to assist them pick up items and press buttons. The robotic arm must be attachable to a variety of wheelchairs and possess a power source that is independent of wheelchair batteries.”

4.0 Conceptual Designs

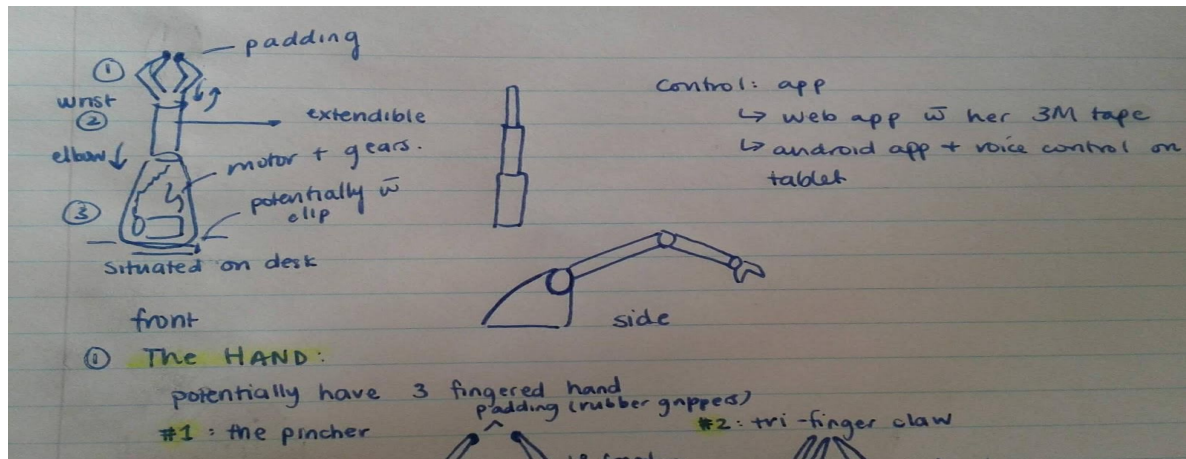


Figure 2.1: Structure of the arm itself

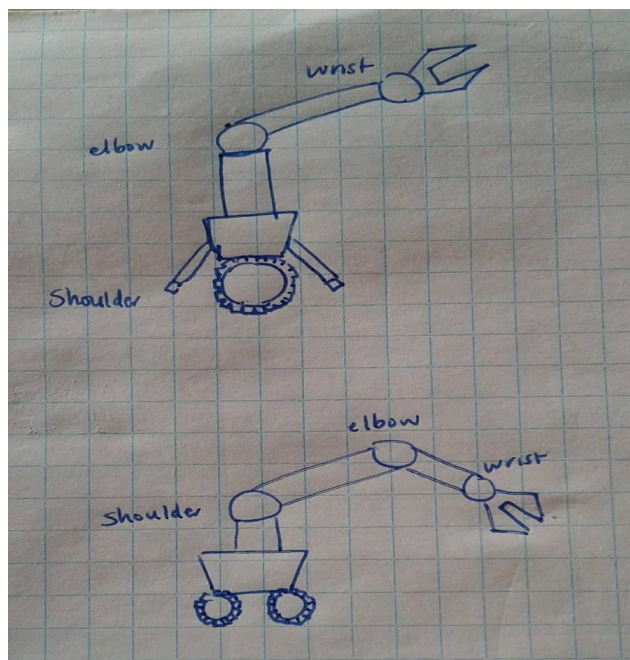


Figure 2.2: Visual representation of a design of the arm on wheels

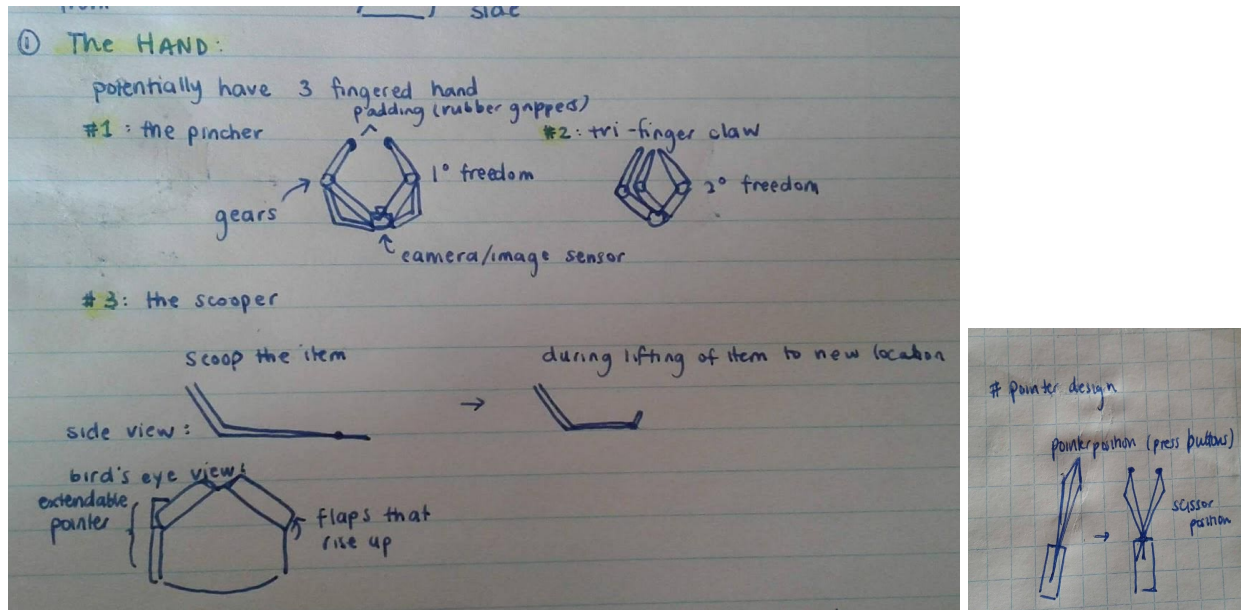


Figure 2.3: Conceptual designs of the hand and fingers

5.0 Design Criteria

After interviewing our client and the end users of the robotic arm, a list of user needs were developed. From this list, a list of design criteria that corresponds to each need was created. This list of design criteria outlines what will make the final prototype robotic arm successful or unsuccessful; hence, the design criteria is critical for guiding the project. After the design criteria were developed, a list of target specifications was developed. These target specifications would later act to determine if the prototype testing is successful or not.

Table 2: A list of design criteria translated from the corresponding user needs

User Need	Design Criteria
The robotic arm is compact and is not permanently attached to the frame of the wheelchair.	<ul style="list-style-type: none"> -The robotic arm is less than 1.5m in total length -The arm has the ability to be temporarily, yet sturdily, attached to a wheelchair tray
The robotic arm allows for grabbing/picking up of items and the transportation of the items to and from the user	<ul style="list-style-type: none"> -The arm has sufficient gripping force to grab and hold a book of approximate mass 1.5kg -The arm is able to lift a book of mass 1.5kg by 0.3m
The robotic arm allows for a wide range of motion (vertically and horizontally)	<ul style="list-style-type: none"> -The hand section of the arm can move from the wheelchair tray top to 0.3m above the tray -The arm can rotate about the base by up to 270°
The robotic arm can be accessed easily through hands-free technology.	<ul style="list-style-type: none"> -The control mechanism of the arm operates without physical user interaction
The robotic arm is remotely operable.	<ul style="list-style-type: none"> -The robotic arm can be operated by a remote device (ie. without direct user contact)

The robotic arm is affordable (both manufacturing and operating costs are low).	-The total cost to construct the arm is under \$200
The robotic arm does not rely on the wheelchair batteries for power and is easily customizable.	-The arm is powered by an independent source -The power source for the arm is variable (ie. multiple types of sources can power the arm)

Table 3: Target specifications for the robotic arm, based on the design criteria metrics

Metric	Units	Marginal Values	Ideal Values
Maximum size	m	1-2 m	Less than 1.5m
Rotational ability	degrees	Up to 360	Up to 270
Gripping and lifting force	N	Up to 1000 N	Around 500 N
Maximum distance	m	Up to 100 m	Around 10 m

6.0 Design Solution

The second (and final) prototype developed by our design team can be seen below. The main structure of the robotic arm is made of 3D printed plastic which is strong yet very lightweight. This allows for less powerful, cheaper servo motors to be used at each of the pivot points. The rectangular base of the arm is intended to be clamped to the surface of a wheelchair tray using a store-bought hand clamp.

The objective of this prototype is to provide a physical, fully operational demonstrative model of our robotic arm design. The arm should be able to rotate horizontally and extend vertically, as well as gripping a pencil-sized object between the analogous fingers. The arm should also have the ability to reach and press elevator buttons that are above and beside the surface on which the base of the arm rests.

Our robotic arm has five points of rotation -- one at each servo motor. Starting at the base, the arm sits upon the most powerful servo and rotates about the vertical axis. This gives the arm approximately 180° of horizontal range. Next, there are identical points of rotation at both the analogous shoulder and elbow joints of the arm. The servos act to raise/lower the arm, thus



Figure 3.2: Side view of the robotic arm

producing a vertical range that will allow the user to reach items on the surface of the wheelchair tray or elevator buttons that are higher up. Finally, the two servo motors at the top of the arm are attached to finger-like prongs. When these servos rotate toward each other, the fingers come together and will grip small items. To power and control the servo motors, our design team will upload a software program to an Arduino Uno. The Uno will distribute the appropriate voltages and give unique instructions

to each of the servos. To control the Uno, our design team has developed a simple web app that contains simple commands. Mobile device that use the app will connect to the Uno via

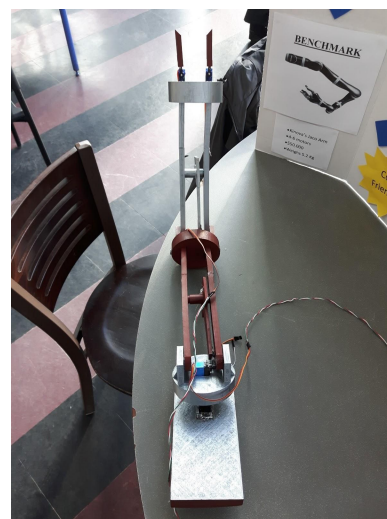


Figure 3.1: Bird's eye view of the robotic arm

Bluetooth. If the app is being used on a PC, a USB cable can connect the Uno to the operating device.

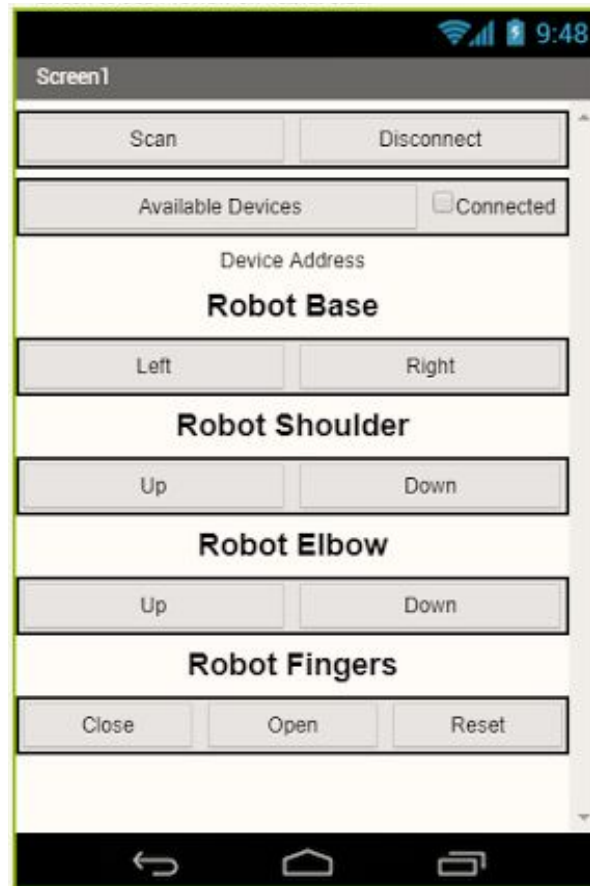


Figure 4: Android app for the robotic arm

7.0 Constraints

While doing a project of any magnitude there are always constraints that must be taken into account. One constraint for this project was the cost to make the robotic arm. Although the task to create a robotic arm that was cost efficient was difficult, it was made even harder when there was a budget of only \$200.00. It heavily affected the design because servo motors were used to power each joint and since the least expensive servos had the least torque, a light material needed to be used. This is one reason why the structural part was 3D printed. The plastic was a strong, but lightweight material that saved on the cost of servos, but also because it was 3D printed at the University of Ottawa, it was free for the team members.

From a legal standpoint, there were not be any major obstacles, given the nature of the design. For instance, it had moving parts and a few small potential ‘pinching’ points, it would be beneficial to include a warning label with our product to prevent minor injury. However, as the design was small, lightweight, slow moving, and not very powerful, this risk was minimal.

The product incorporated devices that were not made by the design team, for example an Arduino. Hence, copyright and other protection policies have been considered carefully. Since all procedures were followed in accordance to the purchased devices’ copyright statements, this also did not pose any major risk to the project.

Finally, there was a constraint on the time as the team needed to complete their arm between September 12th 2017 and November 29th 2017. Though it was not always optimal, the design team’s schedule for the project was feasible. Given the variable schedules of each individual team member, their schedule required minor changes as the project progresses. However, the time periods assigned to each aspect of the project were reasonable.

8.0 Bill of Materials

The maximum budget for this project was given as \$200, which allows for the essential components to be purchased and incorporated into the final prototype. The following table outlines what each of the direct expenses for the robotic arm are, along with a justification of each component. The total expense, calculated using the bill of materials, is \$133.90 (or \$151.31 after taxes), which is significantly under the \$200 maximum.

Table 4: The bill of materials, with item descriptions and justifications

Item Number	Part Name	Description	Quantity	Unit Cost (\$ CAD)	Extended Cost (\$ CAD)	Justification
1.	Arduino Uno	Control board for motors	1	25.00	25.00	In order for the servo motors to work, there needs to be a programmable device. The Arduino Uno provides sufficient power and its relatively inexpensive. The cost per Arduino was found on the Makerstore website.
2.	Servo Motors	Motors required for rotating the various joints	5	14.40	70.40	We need 5 motors: 1 for each of the joints (shoulder, elbow, and fingers). The source of the servos is DigiKey.ca.
3.	Web App	License to add to the google play app	1	25.00	25.00	This is needed so that an app can be used to remotely control the arm. The cost estimate came from Quora.

4.	Arm Pieces	The arm skeleton that is the structure of the arm.	>10	free	free	These can be printed on the 3D printers in the makerspace. These pieces will make for the main architecture of the robotic arm.
5.	Wire	Copper wire to connect circuits	2 metres	2.50	5.00	These wires are needed to attach the servos to the Arduino. Prices found at Lowe's.
6.	Hand Clamp	To hold the arm to the tray.	1	8.50	8.50	Found at Home Depot. This tool will attach the robotic arm to the wheelchair tray.

9.0 Prototyping & Testing

9.1 Prototype I

The objective of the first prototype was to determine the dimensions of the arm, range of motion of the arm and the installation location. As outlined in the first client meeting, the robotic arm must be able to reach both elevator buttons and objects at any point on the wheelchair tray.

Additionally, since this first prototype illustrates the basic shape and approximate size of the final product, it was useful for gathering feedback.

Table 5: Testing for product assumptions in prototype I

Product Assumptions	Description of Test Objectives
Size of the Arm	This prototype was tested to see how the size of the arm fit the user's needs. The length of the arm must enable it to reach elevator buttons and items across the entire span of the user's wheelchair tray.
Range of Motion	This prototype was tested to determine if the arm had potential areas where it is unable to reach or perform its designated tasks. Since there are multiple components of the arm (ie. the analogous upper arm, forearm, and hand) which can rest at different angles, determining the range of the arm using theoretical geometric analysis would be time consuming and would present a source of error.
Mounting Positions	This prototype was tested to determine where the optimal installation position on the wheelchair tray would be.

The first prototype was made using scrap pieces of cardboard, pencils and duct tape. The pencils act as the pivot points in the robotic arm, allowing the arm to rotate. The hand portion is represented by the top cardboard segment (as seen in the figures on the next page). A cardboard box at the bottom of the robotic arm acts as the base of the robotic arm.



Figure 5.1: Prototype I fully extended

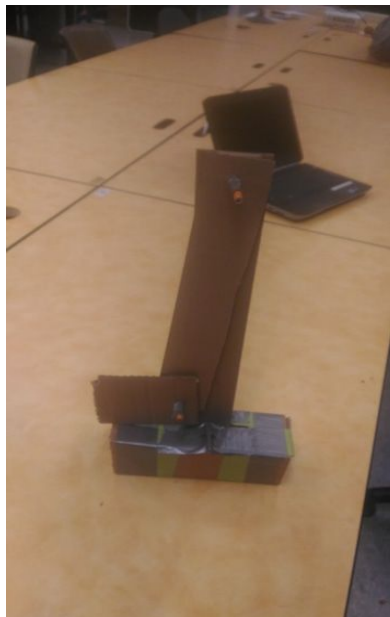


Figure 5.2: Prototype I in fully condensed position

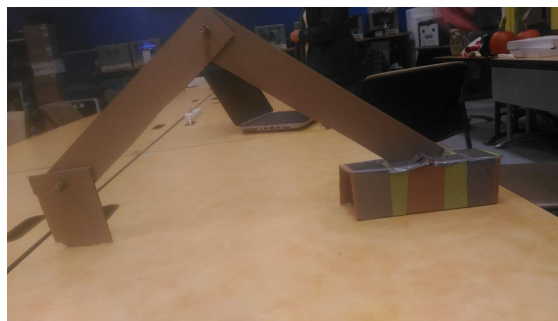


Figure 5.3: Prototype I showing full range across a surface

9.2 Prototype II

The second (and final) prototype developed can be seen below. The main structure of the robotic arm is made of 3D printed plastic, which is strong yet lightweight. This allows for less powerful, cheaper servo motors to be used at each of the pivot points. The rectangular base of the arm is intended to be clamped to the surface of a wheelchair tray using a store-bought hand clamp.

The objective of this prototype is to provide a fully operational, demonstrative model of the robotic arm design. The objective of this prototype is to be able to rotate itself horizontally, extend itself vertically, and grip a pencil-sized object between the analogous fingers. The arm should also have the ability to reach and press elevator buttons that are above and beside the surface on which its base rests.



Figure 6: Comprehensive view of prototype II

This model has five points of rotation -- one at each servo motor. Starting at the base, the arm sits upon the most powerful servo and rotates about the vertical axis. This gives the arm approximately 180° of horizontal range. Next, there are identical points of rotation at both the analogous shoulder and elbow joints of the arm. The servos act to raise and lower the arm, thus producing a vertical range that will allow the user to reach items on the surface of the wheelchair tray or elevator buttons that are higher up. Finally, the two servo motors at the top of the arm are attached to finger-like prongs. When these servos rotate toward each other, the fingers will come together to grip small items.

To power and control the servo motors, a software program is uploaded to an Arduino Uno. The Arduino then distributes the appropriate voltages and give unique instructions to each of the servos. To control the Arduino itself, a simple web app (seen below) that contains user friendly commands can be used. Mobile devices that use the app will connect to the Arduino via Bluetooth. If the app is being used on a computer, a USB cable can connect the Arduino to the operating device.

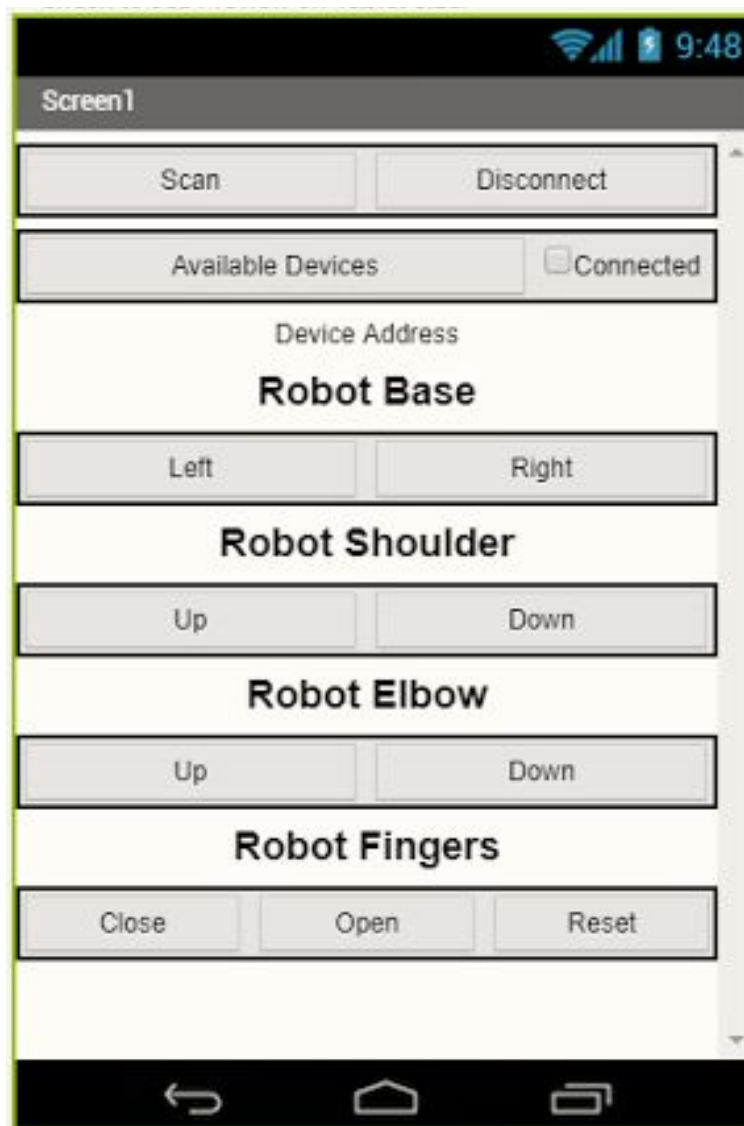


Figure 7: Android app for the robotic arm

10.0 Future Work & Recommendations

After receiving feedback from several people during the design day presentation, it is likely that a new prototype will be developed. This prototype will be more compact when it is not in use, have stronger physical connections between the servos motors and the moving sections of the robotic arm, and will require larger base pieces for mounting the servos. These were the main issues that were either inquired about by the design day judges or encountered during the assembly process. The project has great potential, given the very low cost that would make it a highly competitive product if it reaches the market; however, the second prototype does need some modification for proper, reliable operation.

For future students taking on this project, or any related projects, some of the biggest challenges encountered during the design process came from factors that were unknown until the end of the project. For instance, the size of the 3D printers that were used was not large enough to print many of our essential pieces. As a result, the initial print designs had to be split in two and attached manually. This resulted in additional weak points in the architecture of the arm. Furthermore, the method of attaching the servo motors to the robotic arm was not carefully thought out, and when the servos arrived there were several last minute changes that needed to be made. So, for the future, it would be highly recommended to get an early start on the construction of the final product. This includes ordering all of the required parts, understanding the limitations of any equipment that will be used, and accounting for all of the features in the physical architecture so that everything can be integrated smoothly.

In terms of things that did work rather well, one of the biggest reasons that this project was successful is that the designs were kept as simple as possible. That is, the minimum amount of moving parts, weak points, and other common areas of failure were implemented. This also allowed for greater flexibility when making unexpected changes as the deadlines approached. In addition, a less complicated architecture led to a more user friendly interface (the web app) as fewer commands were needed. In the case of this robotic arm, the simplicity of the design was the most successful attribute.

11.0 Conclusion

Overall, there remains great potential in this robotic arm, but given the ambitious nature of developing such a device in the given time, the final product presented during the course was successful. Although the final prototype was not fully operational, it was able to demonstrate its main functions. The client, Bocar N'diaye of St. Vincent's Hospital, was impressed and has asked for a third prototype to be completed. There has also been an offer from the Center of Entrepreneurship and Engineering Design and the University of Ottawa for further funding and support for another prototype to be made.

Given that similar products on the market that are available can cost dozens of thousands of dollars, our robotic arm (which costs around \$150 to manufacture) shows real promise to be competitive in the market. This product would also bring a much needed, affordable accessibility tool to users across the country who would otherwise not be able to afford such a device. Therefore, a third, functional prototype of this wheelchair robotic arm would achieve all of the goals defined in the beginning of this project.

Bibliography