Assignment 12T: Final Report

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Executive Summary

The problem description indicated a need for a device to aid those who have recently experienced a stroke or suffer from any grip-strength-eroding diseases like arthritis []. To do this the team has developed a robotic arm design, which makes use of a highly structured, electrically operated, and mechanically optimized system to assist with the movement of small objects. The robot has been specifically engineered for seamless movement of devices, medication bottles, and silverware, serving as a stronger extension of the user which has a full range of motion, along both the z and y-axis.

To fulfill such intentions many approaches have been considered and through meticulous testing and analysis, a final design has been produced. The final design is composed of a horizontal gearbox, set as the base of the structure, and a vertically mounted compound gearbox, of gear ratio 512:1, which was designed to allow movement along the vertical axis. The gearbox is then mounted onto the gearboxes and attached to the gripper. This gripper consists of a rack gear set between two gear-mounted, pincer-like grippers which will rotate together and grip the object as the rack gear is pulled backwards.

Many potential design options were considered, and each proved to have their own advantages and disadvantages. However, after an accumulation of sophisticated models designed to explore the structural, electrical, and mechanical integrity of the subsystems, a final design has been produced. Mechanically, the mathematical modeling and design stages are broken into two subcategories. The first of which explored the necessary vertical torque required to complete the outlined tasks. This process provided insight into the design of the gearbox which eventually led to the final arrangement of the gearbox. Similarly, the horizontal gearbox was explored in a second mechanical model, which outlined the required torque to counter friction of 1.41N within the system while still providing enough rotational force to rotate the entire robot horizontally. A third model was constructed to explore the gripper's restrictions and calculate the required torque of 114mNm – requiring a gear ratio of 5:1 to counter external forces while the gripper is activated.

Each of these subsystems have intertwined values and rely heavily on the success of one another. As a result, many tests have been designed to ensure the success of the prototypes. These highly specific tests consider multiple variables where one minor issue may have major implications on the overall function of the prototype. Some tests consider mechanical stress– designed to explore the capabilities of the gearbox contrasting each of the potential iterations of the gearbox assembly. While others consider the structural limitations of the gripper design – indicating any restrictions with the maneuverability of the system. During these tests the following six factors were used to determine the best solution- environment, human factors, safety, manufacturing, and accessibility, as well as the overall reliability of the product during each stage of the prototype.

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1. Problem Definition

1.1 Problem Description

Loss of grip strength is a common side effect resulting from conditions such as strokes, multiple sclerosis, and Parkinson's disease [1]. Due to disruption in communication between the brain and nerves in the hand, grip strength deteriorates and makes simple everyday activities, such as picking up an apple or a fork, difficult [2]. Because of how much of a struggle picking up objects becomes, those affected often need assistance from others; losing part of their autonomy. By building a robotic arm that can grip and move objects for them, this struggle can be eliminated and improve the quality of life for many. Specifically, this arm is designed to hold a mobile phone and is to be an add-on part for a wheelchair. The person will be able to remotely control the arm to lift the phone up to their face if they want to use it and put the phone down and to the side when not in use. For this arm to work, the user must be able to still move and apply pressure with their fingers as the arm will be controlled remotely via buttons. Phone calls or other tasks that require one to hold their phone can be made easier for those in wheelchairs who have poor grip strength.

1.2 Functions

This robot is designed to lift a phone, rotate it along the vertical and horizontal axis, and manipulate it to wherever is deemed necessary by the operator. Specifically, the robotic arm must grip a mass of 25 g, not scoop as mobile devices should be secure, lift the mass up 20 cm above and 20 horizontally across the original surface, and move the device in a smooth manner. The arm is to be powered purely by provided DC motors and be controlled using an Arduino which is protected by the motor control shield.

1.3 Attributes

The arm will be made up of five subsections: the gripper, the arm, the base which includes the planetary gear train and the gearbox, and the electronic section. The gripper is what is going to be holding the phone. The arm is the structure that will be pivoting along the y-axis. The rotating base allows for horizontal movement while the gearbox, mounted above the base, is where the power from the DC motor is converted to torque to lift the arm and close the gripper. Lastly, the electronic section is to guide and instruct the robot, giving the user full control over the motion along both planes. All the subsections work together in order to create a practical and effective robotic arm.

1.4 Stakeholders

For this project to be possible, there are many stakeholders who must be considered. Ms. Brouder, a famous philanthropist and known person of disability, has taken interest in the project and quickly became the leading investor. In doing so she has established herself as both a consumer and investor acting as a source of two separate forms of people with a stake in the project's success. Another important stakeholder is Mr. Galaby, the team's technical director. As the one who oversees the whole project, he is also affected by the project's outcome. If the project is successful, it could improve his reputation and gain him more projects which can further both his career. Additional stakeholders include the manufacturing companies should the technology be moved to a greater scale as well as the targeted consumers of the project. Aside from the companies that will manufacture the arm, companies that manufacture wheelchairs would also be stakeholders as the arm is designed to be fitted onto wheelchairs. Targeted consumers can be defined as wheelchair users who have limited grip strength or trouble using their arms as well as people with mobility issues. This can include people with Parkinson's disease, multiple sclerosis, cerebral palsy, impairment caused by strokes, spinal cord injuries or any other neuromuscular or orthopedic disability [1]. This can also include people who survived car crashes or any accident that has left them physically impaired. The arm is meant to allow the user to gain back some of their once-had independence and be able to lift objects around them. Groups that are associated with the targeted consumers would be another set of stakeholders. These include non-profit organizations that support people living with different conditions such as The National Multiple Sclerosis Society, the Stroke Association, as well as charities that help people affected, such as RoadPeace which helps vehicle crash victims [3]. The arm will be another way for the organizations to support people. Long term care/nursing homes for the elderly or assisted living communities would also be stakeholders as these devices could make a huge difference for their residents as well as their staff. Care home staff will have more time to focus more on the residents' mental well-being instead of spending it on menial tasks. This can be beneficial for both the staff as well as the residents.

1.5 Safety Considerations

In creating this prototype, the group hopes to better the lives of many, however, during the manufacturing process, many safety precautions must be taken to ensure that the operation runs smoothly. The motor is the main source of danger, as if not handled properly it may begin to spark and could even begin a fire if it were to overheat. It could also rotate the arm in an uncontrolled manner, which could drop or launch the phone; both of which could lead to injury of the person in a wheelchair or those around them. The arm itself could also cause harm if it hits someone or something. Additional concerns include the fact that the materials being used may react to physical and chemical changes if not handled correctly. As well the machinery being used, such as the 3D printer and laser cutters, add another level of danger.

1.Design Process Summary Resubmission

Design For Excellence (DFX) is a process used to analyze the way a product has been designed. During the design process quality, cost, environmental impacts, human impact, safety, manufacturing & assembly, and reliability were among the most important factors which each played a key role during the design process. This all-encompassing criterion has been referenced during all key decisions made throughout the project, and each of the key components has been listed below in **Error! Reference source not found.** for simplification:

Table 1 DFX Criteria Chart

Quality	This portion of the criteria considered each of the components and measured the performance of them to ensure that they meet the requirements of the system. The final prototype was derived with the project requirements in mind. It will be able to move the gripper in the x, y and z axis while gripping a 25-gram weight. Therefore, the design meets all project requirements.
Cost	This portion considers whether the cost of any additional parts is justified. Is the final estimated cost reasonable for application? The additional parts needed for the prototypes are mostly small additions like screws, axles and bushings. These are rather inexpensive and since the rest of the prototype will be made from 3D printed parts and

structural materials that come at minimal cost the prototype was able to minimize the costs

Environment

This area determines what the environmental impact would be if it were to be produced on a mass scale. The materials used for the prototype are mostly reusable and/or recyclable. The PLA plastic used for the gripper, gearboxes and joints are all biodegradable [6]. The electrical components like the Arduino circuit and motors can be removed from the prototype for proper disposal. Therefore, the prototype will have a rather low environmental impact.

Human Impacts

This portion has heavy focus on the stakeholders and people who will use the design: Concepts such as, does this address the user's needs? Must be considered. Since, the prototype is designed to help people with lacking grip strength. It has been designed to be operated using light buttons that do not require a lot of force to activate allowing the user to grip and pick up small items simply through the press of a button, simplifying an otherwise difficult task for someone lacking grip strength.

Safety

Risk = severity of consequence X probability. Identify potential risks for manufacturing and use, and approaches to mitigate each one. The prototype has a low-risk design; there are few risks if the user follows the basic instructions. The gripper closes with a rather small amount of force; it would not cause any harm if it were to close, for example, on the user’s finger. The spinning gears in the gearbox could pose a hazard if the user were to put their fingers between the gears. In order to mitigate this, clear safety instructions will be provided with the product. The gearbox will also be mostly enclosed wherever possible to limit the area where gears are exposed

Manufacturing & Assembly

During the design process the manufacturing approach for each part must be considered. The manufacturing approach used for most of the prototype is 3d printing. This allows the production of lightweight and inexpensive parts tailored to the final prototype. This process is easy to execute and is rather time-efficient; therefore, it is optimal for this prototype. When determining how the product is going to be manufactured, it is important to consider the materials being used. From a structural point of view, using stronger materials is preferred.

Reliability

What are the most likely causes of failure for the system, and for each part? How can you minimize the chance of failure? Can it be repaired/maintained? The string attached to the gearbox as well as the one attached to the gripper are most likely to be the first components to fail. Due to the precise machining of the gripper and the gearbox, they should stay intact with little wear for the longest. To ensure reliability in the strings used to move the arm, they will be constantly under tension while running along a track of grooves assuring proper alignment.

2.Final Design

Figure 1 Final prototype of the Robotic Arm which was developed to aid people in the community with grip strength

The proposed design is a culmination of many mathematical models and endless renditions to establish the best possible solution to the problem defined by the client. Each part of the prototype has been meticulously iterated to ensure the product is as efficient and practical as possible while minimizing the system's environmental and financial costs. Figure 1 displays the final prototype which is broken down into subcategories for simplification: mechanical, electrical, structural, and gripper.

2.1 Final Design of the Mechanical Subsystem

Mechanically, the proposed model provides ample power and maximizes the torque generated with the limited power of the motor using a compacted gearbox structure. The vertically mounted compound gearbox is capable of a gear ratio up to 500:1. This gearbox arrangement was determined through a thorough examination of the required torque to lift the arm vertically. Initially, a gearbox with a ratio of 400:1 was expected to produce enough torque, however, further consideration of the distance from the base for the mass and gripper suggested that 0.2N of torque was required. The selected compound gearbox arrangement maximizes the output torque using a more space-efficient method and yields gear ratio results that surpass the initially proposed requirements. This tightly compacted gearbox can accomplish such a feat by maximizing the rotational power through the gears by alternating between gears with 10, 20, and 40 teeth. Considering the limited torque supplied by the DC motor of 0.98mNm it was determined that a gearbox of 500:1 provides enough torque and despite external power loss due to friction, the torque produced was enough to manoeuvre the arm along the vertical plane with ease.

An additional requirement of the project was to allow easily controlled rotation along the horizontal axis. To meet such ambitious standards the initially produced solution was a planetary gearbox which utilized three horizontally mounted “planetary” gears which are intertwined with the sun gear, powered by the first DC motor, and an outer orbital gear designed to rotate and produce enough torque to rotate the robotic arm placed atop the orbital. However, upon modelling the system and calculating the torques required to rotate the system, it became clear this initial prototype would generate far too much friction given the estimated total weight of the arm. The planetary gearbox also imposed restrictions on the gear ratio that was obtainable; a simple, single-phase planetary gearbox can only achieve up to a gear ratio of 10:1 due to restrictions on the size of the planetary gears inside. Therefore, the second iteration of the gearbox involved a base plate rotating on a track of ball bearings. The base had 80 teeth surrounding its circumference, meshed with a five-tooth bevel gear driven by one of the DC motors. This system took advantage of a 16:1 gear ratio to rotate the base, which now generated almost no friction as the friction coefficient for a ball bearing is very small. Additionally, the design of the base plate allowed for the vertical gearbox to be mounted and secured directly to the base. While the first DC motor mounted atop the base provided vertical torque allowing for movement along the y-axis, the second DC motor provided horizontal torque through this 80-tooth gear. The vertical and horizontal gearboxes are displayed in Figure 2.

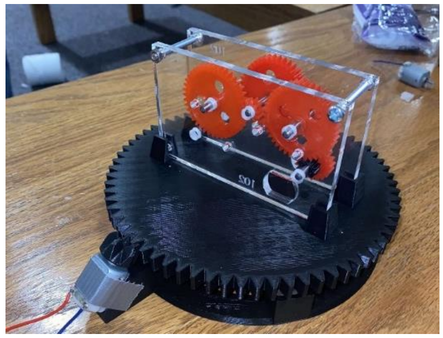

Figure 2 Final proposed design for the horizontal and vertical gearboxes

2.2 Final Design of the Structural Subsystem

The torque generated from the gearbox must be transferred to the arm. To ensure the design works it is imperative that the arm is lightweight and capable of combatting any strain which may be put on the arm by the masses to prevent any internal collapse. Initially, six popsicle sticks were used for the design as individually they provide sufficient strength and maintain a very lightweight stature while still managing to withstand the stresses and strains acting on the arm. However additional models were needed to determine a solution for deformation within the arm. These models indicated that the most efficient way to minimize vertical deflection while maintaining the length of the arm is to add additional supports to form a more structured system. This reduced the force experienced by each individual component as it created a larger surface area for the stress to be distributed to. Adding triangle trusses to the arm proved to be efficient as it strengthened the structure while having an insubstantial impact on the weight of the arm. This structure is then attached to the base of the system via the axel running through the last gear within the vertical gearbox – thus allowing for movement along the vertical axis. The end of the arm resembles that of a forklift made of popsicle sticks which were specifically constructed to hold the gripper of the arm

2.3 Final Design of the Gripper Subsystem

The gripper consisted of three main parts: the stepper motor, the gripper portion, and the gripper gearbox. The concept which was inevitably decided upon consisted of two arms whose orientation relied on the position of two attached 30-tooth gears, each turning at identical rates. The gear motion is controlled by the rack gear. When the highly tensioned string is pulled back, the rack gear accelerates backwards and transmits motion to the two 30 tooth gears in the opposite direction causing movement within the gripper. This tension is a direct result of the stepper motor-powered gearbox, gear ratio 5:1, located at the base of the system. As the motor turns the 50-tooth gears in the gearbox the tension grows within the rope and eventually, the force acting on the rack gear surpasses the force of friction between the gears of the gripper causing the rack gear to be pulled back causing motion within the individual grippers to enclose on the object. A rendered form of the final prototype is depicted below in Figure 3 and Figure 4.

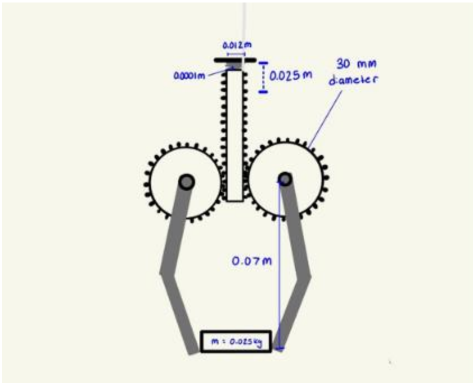

Figure 3 Final technical design of the gripper

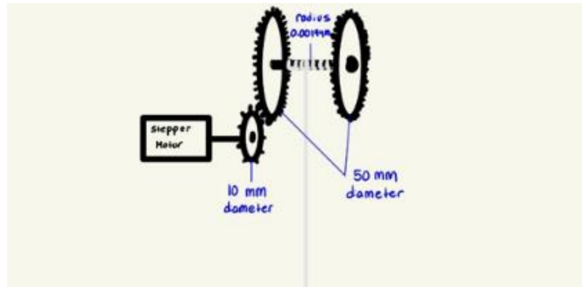

Figure 4 Technical drawing of the gearbox created to generate torque for the gripper. Featuring a 5:1 gear ratio

2.4 Final Design of the Electrical Subsystem

The electrical subsystem consists of five functional parts: stepper motor, two DC motors, the FSR, and the buttons. For every part to work the way it should, the circuit had to have an effective current flow throughout the system. The circuit board showcased in Figure 5 consisted of five buttons, each doing a specific task to control different parts of the overall system. This was executed very effectively as there was a current flow throughout the circuit resulting in all motors and the FSR (Force Sensing Resistor) performing the way they should. A resistor was put in place to measure the voltage and electric current across the circuit. This works in correlation with the FSR and compiles the correct response that it reads from the code uploaded to the Arduino. The motors are all connected to the Arduino and were able to compile the code that was uploaded. Lastly, the buttons were able to work in correlation with their motor in creating a final electric circuit that is not only effective, but efficient.

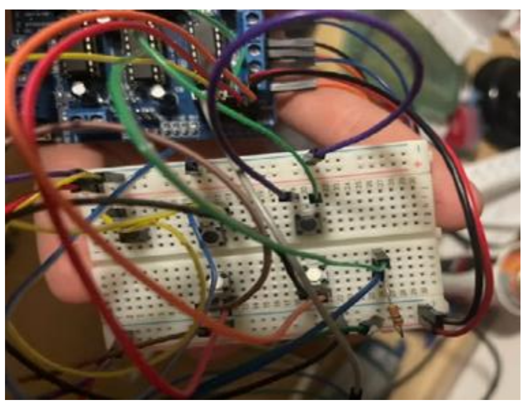

Figure 5 The circuit board used to control and provide subsequent power to each of the motors within the system

2.5 Bill of Materials

Table 2 Bill of Materials

- CRAFT STICKS: X10
- WIRE CONNECTORS: X8
- ARDUINO UNO: X1
- 40 TEETH GEARS X3
- STRING ROLL: X1
- SCREWS: X25
- DC MOTOR: X2
- ACRYLIC SIDEWALL X2
- 50 TEETH GEARS X1
- RODS X4
- STEPPER MOTOR: X1
- 10 TEETH GEARS X3

3. Testing and Evaluation

3.1 Vertical Gearbox

The vertical gearbox was one of the most important tests as the results of the gearbox tests were indicative of the capabilities of the robot. The first test was designed to consider the strength of the vertical gearbox and is specifically related to the capabilities of the mechanisms within the gearbox. Meaning that the robot needed to be able to live at a mass of 25g above the specified threshold (20cm). Additionally, despite the additional load, the mechanical torque generated must be great enough to maneuver the arm vertically in a safe and controlled manner. Through the testing phase, the results were relatively successful as the gearbox was able to generate enough torque to lift the required mass of 25g. However, it was inconsistent and relied on many external factors which eliminated any chance for controlled movement. One of the main issues found within the testing stage was the reliability of the gears. It appeared that the material used for the gears was not able to withstand strenuous circumstances; the more testing was done the more wear and tear on the gears which caused an increase in friction. Eventually, this force of friction became too great for the power of the motor to overcome, causing the gearbox to jam.

3.2 Horizontal gearbox

The main requirements for the horizontal gearbox to function properly are smooth movement as well as stability. To test the movement, the gearbox can simply be turned by hand to ensure that it rotates smoothy without interference. To test the stability, pressure can be applied to points around the circular gearbox to determine whether it affects the alignment of the gearbox. Once the gearbox was assembled, these tests were conducted, and the prototype worked exactly as intended. The base plate was able to spin very smoothly and with a very small amount of friction. When pressure was applied to the center of the base plate, it remained completely stable. However, when pressure was applied close to the edge of the base, it would tip over. This, however, was not an issue for the final prototype as the majority of the weight (and thus force of gravity) was placed near the center of the base.

3.3 Gripper

The gripper is made up of multiple parts and so testing the parts individually is crucial to determining any areas of weakness. The section of the gripper containing the rack gear, 30 tooth gears, and the arms should be tested for its gripping ability with the assumption of adequate torque. In order to do this the string was pulled by hand while the gripper was held in position in front of a battery. This test was able to demonstrate the success of the gripper system as it was able to grip the battery and remain holding it while the person moved the gripper from one location to another. Another important section of the gripper was its gear box. This is where the torque comes from. While in test 1, adequate torque was assumed, this torque needs to be tested as well because it is not guaranteed. The gear box was assembled, and the string was attached to the shaft. To test its functionality the stepper motor was turned on and it was clear that the gears turned, and the string wound itself around the shaft as intended. At the time of the test the stepper motor was functioning as intended and therefore, so was the gear box. However, the stepper motor was moving at a very slow speed and inevitably caused the gripper to close at a rate much slower than expected which caused further problems.

3.4 Electrical Test

To test the electrical component of the system, a working circuit needs to be put into place. Testing that there is a flow of electricity to power the motors in the circuit is essential. This test will be done through scratch code that will be used to test the functionality of the motors. To test the effectiveness of the motors, resistance will be added in the form of gears to see if enough torque is present in the system to have a working arm. If there is no flow of electricity in the circuit, then the motors will not activate meaning that a complete redesign will be necessary.

3.5 Structural Test

The first test was to test the arm's stability and if it could stay standing on its own without tipping or falling over. Without added weight, the arm could stand on its own and move up and down vertically. When the gripper was attached to the arm, it could also remain stable. However, it was unable to move up and down as the gearbox was not strong enough to lift the arm including the gripper. To fix this the length of the arm was shortened from the original 28 cm (about 11.02 in) to 20 cm (about 7.87 in) to ensure there was enough torque to lift the gripper. The second was testing resistance. To test the arm, coins were used for mass. After assembling attaching the gripper to the arm, coins were put on until the maximum weight. There was some deflection so supports were added to the side of the arm. Incorporating triangular trusses resulted in less deflection as there was less strain on one part of the arm as it was more evenly distributed along the trusses. By using popsicles sticks, the mass stayed light enough to not weigh down the arm but provide enough support to eliminate deflection.

3.6 Overall Test Evaluation

The prototype's overall testing process went well in some ways; however, some areas of improvement included the mechanical efficiency of the vertical gearbox and coordination between the gripper and motor. This became clear as despite each of the mechanisms within the prototype working as individual components, however, as a product the pieces did not come together effectively.

4. Conclusion

The robotic arm was required to grasp a smooth object with a minimum mass of 25g and move it at least 20cm vertically and horizontally. In doing so, the arm would be able to assist a person who struggled with grip strength to grasp and retrieve objects, specifically a mobile phone. Eventually, the goal would be to attach the arm to a wheelchair to make it more accessible. It is already designed with this intention in mind. The rotational horizontal motion allows for objects to be grasped from any angle while the arm stays stationary on the chair. A product with similarities to the current goal is Kinova's Jaco Assistive Robot [4]. The product has a market, and it can assist those with limited use of their arms, hands, or shoulders. To achieve these goals, the arm design was divided into five subsystems: vertical motion, horizontal motion, structure, gripper, and electrical system.

The final design had multiple successful elements individually, including 360° horizontal motion, greater than 20cm of vertical motion, and an effective electrical breadboard and code. Unfortunately, when all elements were integrated the system did not meet the requirements. Although the gripper was functional when the string was pulled by hand, the gear box was not powerful enough to pull said rope. The stepper motor was not moving fast enough to be effective. Consequently, the arm was unable to pick up the battery as desired. The arm's structure was strong enough to hold the gripper's mass and battery, but the connection between the structure and the gripper was unable to hold its weight.

In the future, more attention should be paid to the integration of the individual systems to decrease how they affect each other's performance. Specifically, the connection between the gripper and the end of the arm structure should be stronger. It should be stronger and should not interfere with the string. Edits to the code should be made to ensure all motors are moving at an adequate pace. Another aspect that failed to be considered when integrating the parts was the orientation of the gear boxes. The gripper gear box was attached in a way that placed gears on their sides, increasing friction and increasing required torque.

A possible improvement to decrease the friction in the gripper system would be to remove the string and gear box and place the stepper motor directly on the gripper itself. By doing this, a large amount of friction would be avoided, decreasing the overall torque required. Nylon strings such as the one used in the prototype can have coefficients of friction ranging from 0.07 to 0.2[5]. Strings can also be unreliable because they do not always move as expected because they are free to move as they wish. They often rub on other materials, do not lay flat and get tangled with themselves. This uncertainty and additional friction is unideal and should be avoided. A gear within the gripper system could connect the motor to the rack gear directly turning it and any other required gears to increase torque could also be included within the same box. If necessary, the size of the box could be increased.

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