University Of Twente

Project Module 9

Project Bio-robotics 2020

Design and build of a prototype of a selfie robot for people with DMD

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Summary

In this report, the design of a prototype for a robot is described. This robot aims to aid people with Duchenne Muscular Dystrophy in taking a selfie. The robot should be able to move in two directions: in the z-plane, controlling the height, and in the x-plane, controlling the depth. It is controlled using three EMG-signals. The design was chosen out of three concepts and then further developed. The two motors which move the robot are located at the base, and their velocities are calculated using kinematic equations. The input for these kinematic equations is an envelope which is constructed of the EMG signals. The motors are controlled with use of a PID controller.

The finished product fulfills its aim: it is indeed possible to use EMG signals to move the phone to a desired location and take a selfie. There are several improvements to be made, such as achieving a better tilt of the phone and reducing the weight of the robot.

Contents

1 Introduction

Duchenne Muscular Dystrophy (DMD) [1] is a progressive single gene disorder which affects the skeletal muscles. It is named after the French neurologist Guillaume-Benjamin Duchenne (1806-1875), who did extensive research into the disease. It is caused [2] by a mutation in the DMD gene, which is responsible for the production of dystrophin. This protein, which is primarily found in skeletal and cardiac muscle, is responsible for protecting the muscle fibres. Due to the mutation, no functional dystrophin is produced, leading to damage of the muscles. The DMD gene is located on the X chromosome, meaning that it mostly affects boys. Approximately 1 in 3500 to 5000 [2] boys with DMD are born worldwide each year. Patients are usually diagnosed around the age of five [3]. Proximal muscles are most affected, leading to difficulties walking, running, climbing and standing up [4]. Affected children usually start using a wheelchair by the age of twelve. After the age of eighteen, cardiomyopathy often occurs. Life expectancy varies with the level of care, ranging from 14 to 40 years [5]. Respiratory complications and cardiomyopathy are the most common causes of death [4].

Due to the muscle weakness caused by DMD, people affected by this disease are limited in their ability to function in society. With help of technologies however, some of these limitations can be removed. In this report, a robot will be developed to aid people affected by DMD in taking a selfie. The robot will be able to position the users phone at a desired distance and angle and will be able to snap a picture. It will be controlled by the user via electromyography (EMG) signals.

In this report, the development of this robot will be described. Firstly, in chapter 2 the different requirements the robot needs to fulfill will be described. Then, in chapter 3, three different concepts will be described. These concepts are evaluated in 3.3, after which one concept is chosen to further develop. In chapter 4 the design of the chosen concept is described, regarding both the hardware and software. In chapter 5 the robot's performance is evaluated.

2 Requirements

2.1 Stakeholder Analysis

When designing a product it is important to perform a stakeholder analysis. A stakeholder analysis identifies the interests of all stakeholders and tries to recognize which stakeholders should be given priority when designing the product. Table 1 shows these interests and the impact they have in the final design of the robot.

Table 1: Stakeholder Overview

Stake holders	**Interests**	**Impact**
DMD Patients	Safe	High
	Easy to operate	High
	Responsive system	High
Caretakers	No extra burden	High
	Easy to set up	High
	Portable	Medium
	Easy to clean	Medium
Management Team	Affordable	High
	Innovative	Med
	Achieve Targets	Med
Engineering Team	Reliable mechanism	High
	Maintain and develop skill level	Med
	Reputation	Low
Investor	Market provider	Low
Competitors	Market monopolization	Low

It can be seen that certain groups have higher impact on the final design than others. The groups which have the most direct impact can be considered the 'primary stakeholders' and the ones which have a more indirect or less of an impact can be categorized as 'secondary stakeholders'. For this case, the DMD patients and caretakers can be considered as the primary stakeholders as they will be using the robot on a day to day basis. The rest can be seen as secondary stakeholders. Hence, the robot should be designed to incorporate the interests of the various stakeholders as much as possible with the primary stakeholders' interest being given priority.

2.2 User Requirements

In this section, the fundamental requirements which a user of the robot might want were considered and are shown in the list below:

- Move the phone to the desired location
- Take a photo
- Photo should capture the user's upper body and face
- Should work for all smartphones
- Should not drop phone
- Should not move while taking a photo
- The robot itself should not be in the picture

2.3 System Specifications

System specifications can be divided into two parts: functional requirements and non-functional requirements. The functional requirements relate to the actions that the robot must be able to perform. The non-functional requirements are requirements that are measurable and numerically define the workspace.

Functional Requirements

- Move the phone along two axes
- Take a picture instantly when user desires
- Should hold phone firmly, also while moving
- Phone should be completely still when photo is being taken
- Should hold phones of different sizes
- Front of phone should face the user
- Take a photo via a Bluetooth command

Non - Functional Requirements

- Maximal distance from user to phone should be 70 cm, similar to arm's length [6]
- Minimal distance from user to phone should be at least 30 cm, to prevent robot from injuring the user
- Time required for moving from minimal to maximal distance (in a straight line) should be ca. 5 seconds
- Distance from base of robot to user should be 110 cm (estimate from Solidworks model)
- Control should be precise enough to enable end effector to come to a stop 2 seconds after the stop command is given
- Payload: 250 grams [7]

2.4 Social Impact

Social impact can be crudely defined as the impact the robot has on altering the lives of people as they interact within society. When designing any product it is useful to consider what implications it might have on all the stakeholders as well as society in general. An analysis of this sort would ultimately help to design a robot that better fits its social environment with minimal adverse effects. To analyse the social impact of the robot, an investigation can be carried out in three parts which are outlined below. In this section, only the most important stakeholder (the DMD patients) will be looked into.

2.4.1 Conceptual Investigation

Conceptual investigation involves using existing philosophical and ethical theories to better understand what each stakeholder is looking for. When beginning to ask questions such as "what do DMD patients want from this robot?", a common ethical paradigm of thinking is that they merely want to be accepted by society. Hence, the robot being designed for this project should be made in such a way that it seamlessly integrates into society to prevent being discriminated against. For example, the robot should as closely as possible replicate taking a selfie as a person without DMD. This way people with DMD don't feel like missing out on the experience and feel like any other person who would like to take a selfie.

2.4.2 Empirical Investigation

Empirical investigation relates to actively seeking out the stakeholders' opinions and perspectives. This is commonly done via interviews and surveys. An investigation of this type helps to understand what preferences the DMD patients might have for the robot and in which scenarios they will likely be used. For example, a DMD patient in a wheelchair would like to take a selfie with a family member who is standing. If this suggestion is one that comes up often when interviewing a large sample of DMD patients, then it would be wise for the design team to add that feature. This can be done by tuning the depth level motion of the robot such that it can accommodate the two people into the selfie.

2.4.3 Technical Investigation

Technical investigation makes use of the findings of the conceptual and empirical investigations and tries to achieve a solution within the constraints of the project. These constraints can be the budget available, limitations of technology or anything else that prevents the design team from realizing their solution. An investigation of this sort brings forth the trade-offs that might have to be taken up when trying to realize the desired solution. Using the same example in section 2.4.2 of taking a selfie with a standing family member, the solution could be to increase the depth level motion of the robot and to add a horizontal motion to it. However, this might come at the cost of a more complex design that is more expensive to build. A compromise can be made by only increasing the depth level motion and not adding the horizontal motion to reduce costs. The trade-off in this case would be that the feature to take a picture with a family member still exists but can only be used effectively for a limited range.

2.5 General Risk Analysis

A risk analysis is done to identify potential problems in the robot that could harm the user or their surroundings. From this, necessary steps can be taken in the design process to remove or reduce these risks.The potential risks can be divided into a few different parts which are discussed below.

<u>Risk To User</u>

One of the non-functional requirements present in section 2.3 was that the robot should at minimum be 30cm away from the user. This requirement was preemptively chosen as it significantly reduces the risk of harm to the user. The only scenario in which they might be in harms way is if the phone is not secured tightly enough to the robot and is thrown towards the user. This can be addressed by moving the robot's arms at different speeds and accelerations and checking if the phone is still held securely. The robot is also not likely going to be placed in an environment that is exposed to water (e.g bathroom) and hence the risk of electrocution is minimal.

<u>Risk To Others</u>

Caretakers or family members who are next to the robot while it is active might be exposed to a few small risks. For example, the robot's arms might accidentally hit them while moving. One solution is to cap the speed of the robot so even if it does hit the person it would cause little harm.

3 Concepts

3.1 Function Definition

In this day and age, taking a photo on your smartphone, especially selfies, is a common activity. People with DMD however might find it an obstacle to take a selfie by themselves. A robot will be developed to aid them in this task. Essentially what will be done is to replace the stick from a selfie stick with a robotic arm. The robotic arm will be used to position the smartphone in the desired location with the use of electromyography (EMG) signals.

3.2 Concept generation

Based on the requirements of the user a robotic arm will be devised in such a way that it is able to move in two degrees of freedom and take a picture. Three distinct concepts were developed, which will be explained and analyzed taking into consideration the potential advantages and disadvantages.

3.2.1 Concept 1

This concept consists of three parts, controlled by three motors. The two motors located at the base will be used for two motions: changing the height level and changing the distance between the user and their smartphone. One of these motors is located at the left and is attached directly to the first section of the arm, allowing a rotational movement, see Figure 1. The second motor is located at the right, at the same center of rotation as the left motor. It is however not attached to the shaft powered by the left motor. The left motor rotates the second section of the arm through a belt connected to a pulley which is attached to the shaft of the first joint as seen in Figure 2. The third motor is located at the second elbow joint and is used to ensure that the smartphone is perpendicular to the user (or angled if desired by the user). Finally, the camera is actuated via a Bluetooth input.

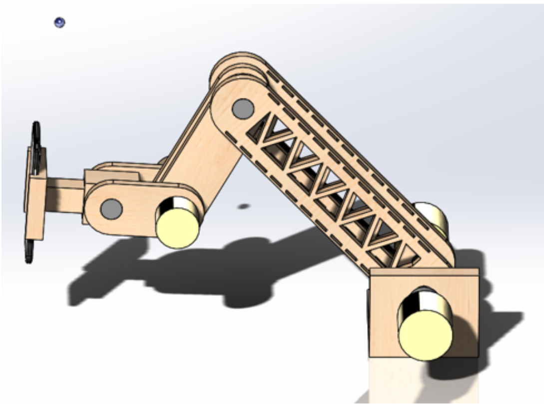

Figure 1: Left side view of concept 1. The motor at the base controls the first shaft, the motor at the second joint controls the tilt of the phone.

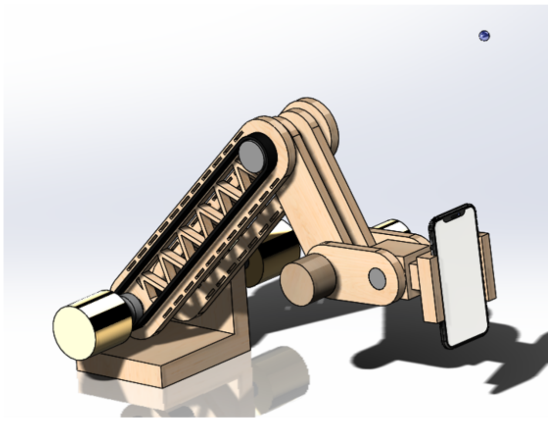

Figure 2: Right side view of concept 1. The motor at the base controls the second shaft with a belt and pulley.

In order to choose the best concept, some advantages and disadvantages are listed in Table 2.

Table 2: Advantages and disadvantages of concept 1

Advantages	**Disadvantages**
Simple design to analyse and build	Low stability at end effector
Light weight	Have to use three motors
Wide range of motion	No left-right movement

3.2.2 Concept 2

In this concept the configuration of a parallel robot is used. It is controlled by two motors in the base of the robot that run in the same axis, as is shown in Figure 3. The motor on the right of the figures allows the motion back and forward of the vertical main body while the left side motor creates a moment that it is transmitted by the large body visible in Figure 4. This makes possible the up and downwards motion. Finally, a small triangle connection is used to maintain the smartphone always in a straight position concerning the user in that way is ensure a optimal picture of the user.

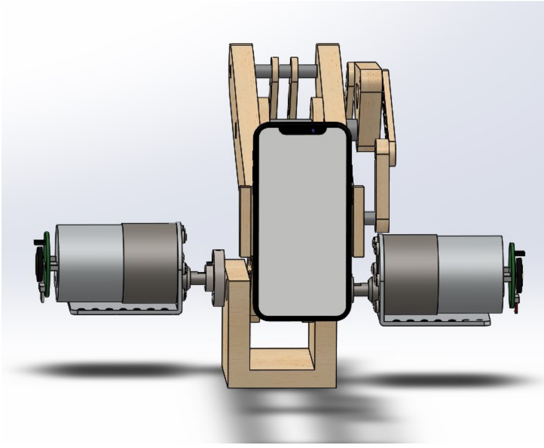

Figure 3: Left view

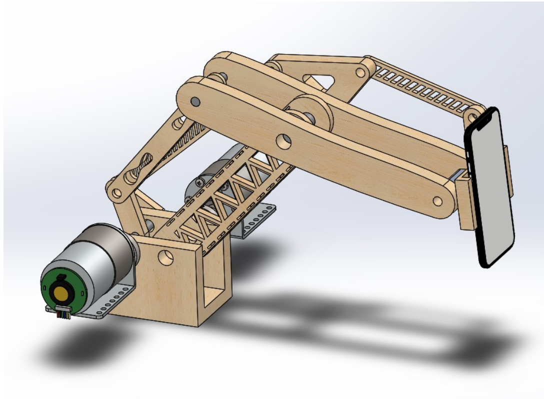

Figure 4: Front view

Table 3: Advantages and disadvantages of concept 2

Advantages	Disadvantages
Parallel connection	Possible tilt
Only 2 DC motors	Big structure
Low vibrations & noise	Complicated assembly

3.2.3 Concept 3

Concept 3 consists of three main sections and can be seen in Figures 5 and 6. These sections are the base (purple), the first section (grey) and second section (turquoise). At the base there are two motors; one that is located under the first section, with the function to rotate this section, and therefore changing the distance between the user and their smartphone and also make right-left movements. The second motor is located at the top, it controls the rotation of the second section via a belt and a pulley. Its function is to keep the front camera of a smartphone pointing towards the user. Because putting the motor directly above the first joint is not feasible, two pulleys have been placed in order to transfer motor torque to the second section of the arm. This will prevent malfunctioning in the case of directly connecting the pulley of the second joint to the motor. In order to action the camera a Bluetooth connection to a button is used.

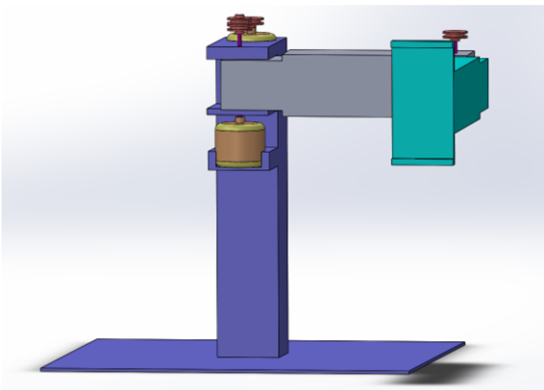

Figure 5: Front view of concept 3

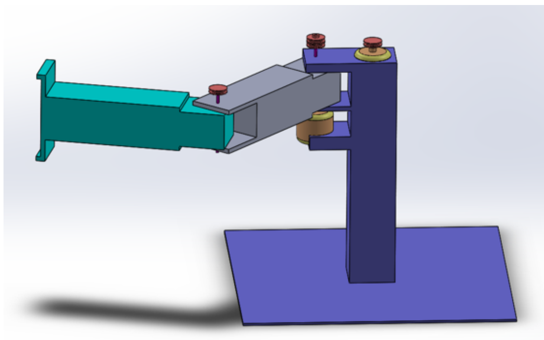

Figure 6: Left side view of concept 3

In order to choose the best concept, some advantages and disadvantages are listed in Table 4.

Table 4: Advantages and disadvantages of concept 3

Advantages	Disadvantages
Only uses 2 motors	Limited positions
Robot arm is light	Cannot perform up-down movements
Easy to assembly	Can cause difficulties with the belt

3.3 Concept evaluation

In order to select the best concept, some characteristics should be analyzed for each one. In Table 5 all three concepts are evaluated on some aspects which will be explained in detail below. For each of these aspects, a rank is given represented with the numbers 1 to 3, with 1 being the best of the concepts and 3 the worst. At the end of Table 5 a sum of all the places is shown, and the concept with the lowest number of points will be selected for being the final concept. The aspects on which the concepts are evaluated are:

- **Stability** will judge the most stable concept during its performance,low vibrations and stable during taking the picture.
- **Manufacturing** will judge the complexity of the building of the prototype and the amount of parts required.
- **Mobility** will evaluate the different positions that the end-effector can reach, where the concept with the highest number takes the first place.
- **Functionality** will judge the most realistic design that could work well in the final demonstration.
- **Safety** will judge the safety for the use during the use and the safety of the smartphone that is placed on the robot.
- **Workspace** will be evaluated depending on the size and shape of workspace of each concept, where a Cartesian space is desired.

After clarifying each of the evaluation aspects, a list with the reasons of how each rank was chosen for each of the concepts is presented below.

- **Stability:** Concept 2 got the highest rank (rank 1) because of its parallelogram shape which reduces the torque on the motors, also preventing undesired motions at the end-effector. Concept 3 got the lowest rank because when applying a load at the end-effector it will generate friction at the joints due to its horizontal motion, this will create vibrations which reduce the stability.
- **Manufacturing:** Concept 2 got a rank 1 in this aspect mainly because it does not need extra components such as pulleys and belts. While Concept 1 got a rank 3 because it additionally to pulleys and belts it also needs an extra motor.
- **Mobility:** Concept 1 wins is this aspect because of its 3 motors which allow 3 DOFs, the motor located near the end effector allow it to tilt the smartphone when desired and therefore to take selfies from above or below. Concept 3 got the lowest rank mainly because it lacks of some angle positioning, for example it can not put the camera in front of the user when it is in its rear position.
- **Functionality:** Concept 2 also wins in this aspect because its parallelogram property is more reliable than the pulley and belt of the other concepts. Concept 3 got the lowest rank due to its pulley-belt system which makes it unreliable when building it, as it will loose tension because of the reduction in length of its sections when they are in another position that is not straight.
- **Safety:** Concept 1 has the most stability as explained above and therefore was chosen to be the safer, as its stability guarantee that the smartphone do not fall from the end-effector. Therefore Concept 3 got the lowest rank for the same reason.
- **Workspace:** Concept 1 got rank 1 as it have 1 more DOF, it makes easy for rectilinear motion of the end-effector mainly front to back motion. Concept 3 has rank 3 as it has a very limited space and it will be impossible to keep the smartphone pointing to the user when changing to positions other than completely straight.

Table 5: Comparison Table

	Concept 1	**Concept 2**	**Concept 3**
Stability	2	1	3
Manufacturing	3	1	2
Mobility	1	2	3
Functionality	2	1	3
Safety	2	1	3
Workspace	1	2	3
Total of points	11	8	18

It is clearly visible in table 5 that according to the characteristics mentioned before, concept 2 has the lowest number of points (8) and therefore the higher rank, in consequence the selected idea to build will be the Parallelogram robot (concept 2).

4 Design

This chapter consists of four sections. The first section describes the kinematic model of the robot and the calculations used to make the end-effector move to a desired location. It also describes the design of the controllers used to control the motors. The second section describes several different elements of the design. This includes the mechanical design of the robot, the processing chain for the EMG-signals, the hardware that is used and the software design. In the third section, the realization of the robot is described. It mentions and elaborates on the changes that were made to the design whilst assembling and wiring it. In the last section, a risk analysis of the final realization is done.

4.1 Design Modeling

4.1.1 Kinematic Modelling

In this section a kinematic analysis will be done on the final concept to understand how the end-effector moves in relation to a predetermined reference frame.

First a simple sketch of the robot was made and is shown in Figure 7. 'm_1' and 'm_2' here refer to the two motors that are attached to the base of the robot. 'q_1' is the angle which the vertical link connected to m_1 makes with the vertical. 'q_2' is the angle which the upper horizontal link makes with the horizontal. The circles are to indicate the presence of rotation joints. The parallelogram configuration of the robot was translated into a serial arm robot for easier calculations of q_1 and q_2, which is shown in Figure 8. This transformed version can be seen as a serial robot with two rotation joints. [NOTE: The y-direction in this section is the same as the z-direction in the previous and proceeding sections]

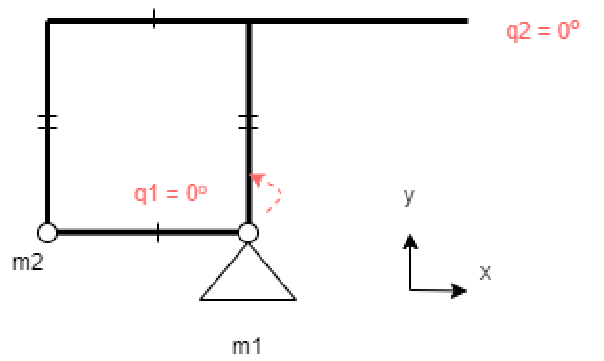

Figure 7: Sketch of final concept in reference configuration

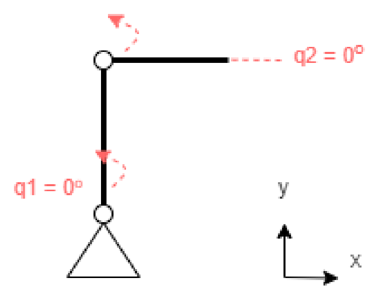

Figure 8: Transformed sketch of final concept to a serial robot

From Figure 7 and Figure 8, relations can be derived for q_1 and q_2 such that they are expressed in m_1 and m_2. The relations are shown below in equation 1 and 2

$$q_1 = m_1 \tag{1}$$

$$q_2 = m_1 - m_2 \tag{2}$$

Forward kinematics

Forward kinematics is used to obtain the end-effector position given values for q_1 and q_2. Figure 9 shows the robot in reference configuration with frames attached. Ψ_0 is the reference frame and is located on the first rotation joint. Ψ_1 is the frame attached to the first arm, Ψ_2 is the frame attached to the second arm and Ψ_e is the frame located at the end-effector.

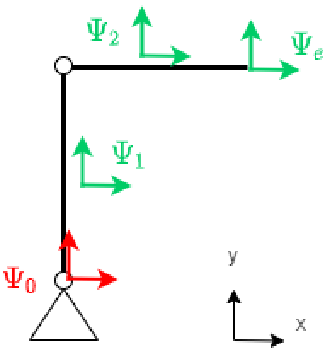

Figure 9: The reference configuration of the robot with all frames shown

To find the end-effector position in the reference configuration Brockett's formula is used as shown below:

$$H_e^0(q_1, q_2) = e^{{}^0\tilde{\hat{T}}_1^0 \, q_1} \, e^{{}^0\tilde{\hat{T}}_2^1 \, q_2} \, H_e^0(0) \tag{3}$$

with:

${}^0\hat{T}_1^0 = \begin{pmatrix} 1 & 0 & 0 \end{pmatrix}^{\mathrm{T}}$

${}^0\tilde{\hat{T}}_2^1 = \begin{pmatrix} 1 & y & -x \end{pmatrix}^{\mathrm{T}} = \begin{pmatrix} 1 & l_1 & -l_2 \end{pmatrix}^{\mathrm{T}}$

$H_e^0(0) = \begin{bmatrix} 1 & 0 & l_2 \\ 0 & 1 & l_1 \\ 0 & 0 & 1 \end{bmatrix}$

l_1 and l_2 represent the lengths of the links of the robot.

However, analysis needs to be done on the robot for a variety of different configurations besides the reference one. For this the Geometric Jacobian method can be used. The twists inside the Jacobian are found with q_1 and q_2 as variables such that simply plugging in their values for any arbitrary configuration will give the Jacobian desired. The Jacobian matrix $J(q)$ describes the relationship between the joint velocities and the corresponding twist as is shown in the following equation:

$${}^0T_e^0 = J(q)\,\dot{q} \tag{4}$$

with:

$J(q) = \begin{pmatrix} {}^0\hat{T}_1^0 & {}^0\hat{T}_2^1 \end{pmatrix}$,in which

${}^0\hat{T}_1^0 = \begin{pmatrix} 1 & 0 & 0 \end{pmatrix}^T$ and

${}^0\hat{T}_2^1 = \begin{pmatrix} 1 & l_1 \sin q_1 & -l_2 \cos q_2 \end{pmatrix}^T$

Thus with the use of the Jacobian, given a desired angular velocity of the arms ($\dot{q}$), the twist of the end-effector with respect to Ψ_o can be found for any configuration. This twist provides information on how the end-effector is moving for the given configuration.

Inverse kinematics

Inverse kinematics is used to obtain the values for q_1 and q_2 given a desired end-effector position or motion. Multiple methods are possible to evaluate this. The method of direct inverse kinematics was also done purely to check for the position of the end-effector and was not included in the microcontoller code. The direct inverse kinematics method is presented in Appendix A. The method chosen here is inverse differential kinematics with the use of a Jacobian inverse. In this method, kinematic derivations will be performed such that q_1 and q_2 can be determined when the end-effector moves horizontally or vertically in a straight line. The relations in equation 1 and equation 2 can then be used to determine how much the motors would have to rotate. A new frame, Ψ_f will be placed on the end-effector which rotates with the end-effector. This is done so that the ω of the end-effector with respect to this frame will always be zero allowing for simpler calculations. This is shown in Figure 10 below.

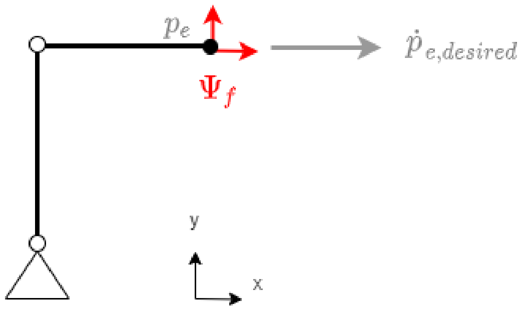

Figure 10: Robot configuration indicating presence of new frame Ψ_f and desired velocity of end-effector

To begin with, a derivation for the Jacobian inverse has to be found. Multiple steps are needed for this. First the matrix H_0^f has to be found. Since Ψ_f and Ψ_e are both located on the same point, the expression below in equation 5 can be used.

$$H_f^0 = H_e^0 \tag{5}$$

H_e^0 was found in the forward kinematics section and simply taking its inverse gives H_0^e which equals H_0^f. This expression is shown below in equation 6

$$H_0^f = (H_e^0)^{-1} \tag{6}$$

From here, $Ad_{H_0^f}$ can be calculated using equation 7 where x, y and the rotation matrix R are taken from H_0^f

$$Ad_{H_0^f} = \begin{bmatrix} 1 & 0 & 0 \\ y & R_{1,1} & R_{1,2} \\ -x & R_{2,1} & R_{2,2} \end{bmatrix} \tag{7}$$

Using the definition of an adjoint matrix as shown in equation 8 and after several substitutions, it can be seen that a modified Jacobian (J') maps the angular velocity of the arms ($\dot{q}$) to the twist of the end-effector (${}^fT_e^0$)

$${}^fT_e^0 = Ad_{H_0^f} \cdot {}^0T_e^0 \tag{8}$$

$${}^fT_e^0 = Ad_{H_0^f} \cdot J(q) \cdot \dot{q} \tag{9}$$

$${}^fT_e^0 = J'(q) \cdot \dot{q} \tag{10}$$

This modified Jacobian can hence be calculated using the expression below in equation 11

$$J'(q) = Ad_{H_0^f} \cdot J(q) \tag{11}$$

Equation 10 can be written as follows in equation 12

$${}^f\begin{pmatrix} \omega \\ v_x \\ v_y \end{pmatrix}_e^0 = J'(q) \cdot \dot{q} \tag{12}$$

Since $\omega = 0$ as Ψ_f rotates with the end-effector, the top row of the vector can be removed for simpler calculation. The top row of J' and $\dot{q}$ also have to be removed to maintain the concatenation of the matrices. The resulting 2x2 Jacobian is written as J'' to show it is of different size to J'. This is shown in equation 13

$${}^f\begin{pmatrix} v_x \\ v_y \end{pmatrix}_e^0 = J''(q) \cdot \dot{q} \tag{13}$$

For simplicity, the velocities of the end-effector can be written in point notation, as shown below in equation 14

$$^{0}\dot{p}_e = J''(q) \cdot \dot{q} \tag{14}$$

From here, simply by multiplying by the inverse of J'' to both sides of equation 14, an equation is derived that provides the angular velocities ($\dot{q}$) required to move the end-effector with a certain x and y velocity ($^{0}\dot{p}_e$). Since J'' is a 2x2 matrix, its inverse is simply its transpose. This is shown below in equation 15

$$\dot{q} = J''^{-1}(q) \cdot^{0} \dot{p}_e \tag{15}$$

To implement this inverse differential kinematics on the robot, a predetermined time step (Δt) will be used. From a given starting position of the arms ($q1$ and $q2$), the amount the arms rotate over the time step when given a desired velocity for the end-effector can be calculated as shown in equation 16

$$q_{new} = q + \Delta t \cdot \dot{q} \tag{16}$$

Equation 16 can be rewritten in vector notation to explicitly see the relations with q_1 and q_2. This is shown below in equation 17

$$\begin{pmatrix} q_{1,new} \\ q_{2,new} \end{pmatrix} = \begin{pmatrix} q_1 \\ q_2 \end{pmatrix} + \Delta t \cdot \begin{pmatrix} \dot{q}_1 \\ \dot{q}_2 \end{pmatrix} \tag{17}$$

Finally, the $q_{1,new}$ and $q_{2,new}$ found can be used in equation 1 and equation 2 to determine the new motor angles required. This is shown in equation 18 and equation 19

$$m_{1,new} = q_{1,new} \tag{18}$$

$$m_{2,new} = m_{1,new} - q_{2,new} \tag{19}$$

Hence with the inverse kinematics above, given a desired velocity for the end-effector, the angle the motors need to rotate to achieve this velocity can be determined.

4.1.2 Dynamic model

In this section, the theory of system analysis will be applied. The goal would be to obtain a nominal transfer function of the robot that can be used to design and tune the controllers. To do this, a free body diagram (FBD) has to be drawn up. Since there are 2 motors that work independently, there will be 2 separate inertias for these motors to act on. These inertias can be found from Solidworks or by modelling the robot in Spacar. There are no springs present on the robot and the friction present at the joints can be taken as viscous damping. Figure 11 shows this information. M1 and M2 are the torques of the motors while d1 and d2 are the damping constants.

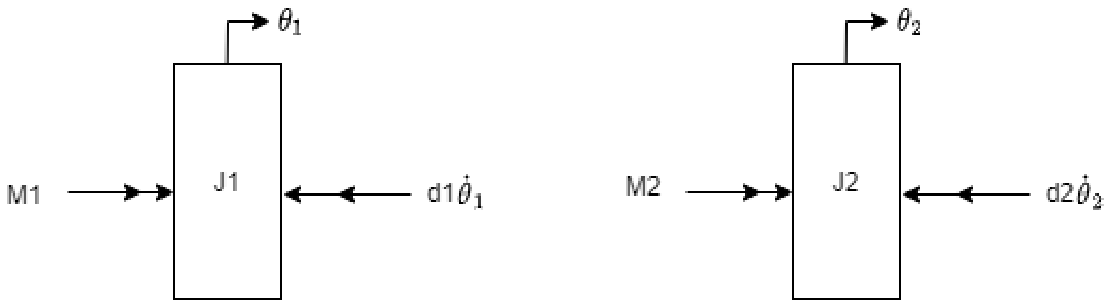

Figure 11: Free body diagrams of the two inertias. M1 and M2 are the torques of respectively motor 1 and motor 2. d1 and d2 are the damping constants.

For each FBD, an equation of motion can be derived. This equation of motion then undergoes a Laplace transform and can be rearranged to obtain the transfer function of the nominal system. The transfer functions are shown below in equation 20 and equation 21.

$$G_1 = \frac{\theta_1}{M_1} = \frac{1}{J_1 s^2 + d_1 s} \tag{20}$$

$$G_2 = \frac{\theta_2}{M_2} = \frac{1}{J_2 s^2 + d_2 s} \tag{21}$$

4.1.3 Controller model

Both motors are controlled using a PID controller. This controller consist of three parts: a proportional (P) term, an integral (I) term and a derivative (D) term. It is a mechanism that employs feedback. It continually calculates an error-value, which is equal to the difference between the reference value and the real value of the angular motor velocity. Using the P, I and D terms, the error-value is minimized. The transfer function of the PID controller is shown below and the basic schematic is shown in Figure 12:

$$C(s) = k_p \cdot \frac{\tau_z s + 1}{\alpha \tau_z s + 1} \cdot \frac{\tau_i s + 1}{\tau_i s} \tag{22}$$

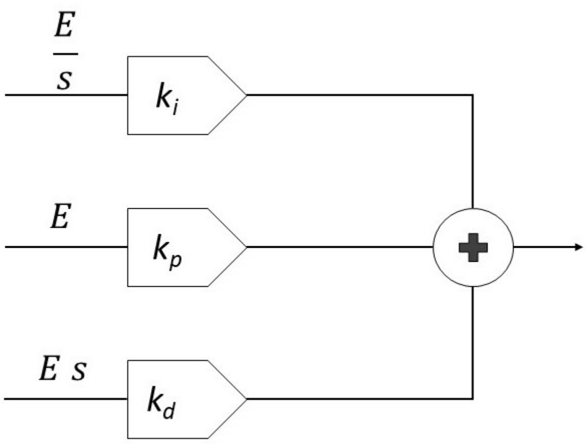

Figure 12: The parallel PID controller, with gains K_i, K_p and k_d

In order to design a correct parallel PID controller, the estimation of a nominal plant was used:

$$P(s) = \frac{\frac{\sigma}{\tau}}{s^2 + \frac{1}{\tau} s + 0} \tag{23}$$

in which σ is the Static gain and τ is the time. The values of σ and τ were calculated by giving an input sinusoidal signal and compare it with the output in the real robot, in such way that the delay and the phase change can be identified. Those values are fundamental to calculate the correct gains for the controller. The following equations were used to calculate the gains for the PID controller:

$$\alpha = \frac{1 - sin(PM)}{1 + sin(PM)} \tag{24}$$

$$\tau_z = \frac{1}{\omega_c \sqrt{\alpha}} \tag{25}$$

$$\tau_p = \alpha \tau_z \tag{26}$$

$$k_p = \beta \tau_z \tag{27}$$

$$\tau_i = \beta \tau_z \tag{28}$$

The values found in the equations above can be replaced in the equation of the PID controller to find the correct gains. Some simulations were run, until the most suitable gains for this controller were found. The values used in the controller are the following:

Table 6: Controller Gains

Gains	**Values**
k_p	0.006
k_i	$3.8171 \cdot 10^4$
k_d	2.9608

4.2 Design details

4.2.1 Mechanical Design

From chapter 3, concept 2 was chosen as the final concept. The main feature of this concept was the parallelogram structure of the robotic arm. The advantage of this feature is that it allows both motors to be located at the base, which greatly reduces the weight on the robot arms themselves. The downside is that deriving kinematic relations will be a little more complex.

A few modifications were made made to this model. Primarily, the parallelogram structure was simplified to allow for less complex parts. This is beneficial when assembling and provides easier kinematic analysis. In addition, the dimensions of the small triangle connection mentioned in section 3.2.2 were tuned such that they corrected the tilt of the phone more optimally. A proper phone holder was also designed which contains a manual screw mechanism that adjusts the gripper part. This was done so that phones of different sizes can be accommodated. A counter weight connection point was also added, in case the robot was offset by the weight of the phone. Finally, holes and slits were added wherever possible to make the design more lightweight. Figure 13, Figure 14, Figure 15 and Figure 16 below show the final model.

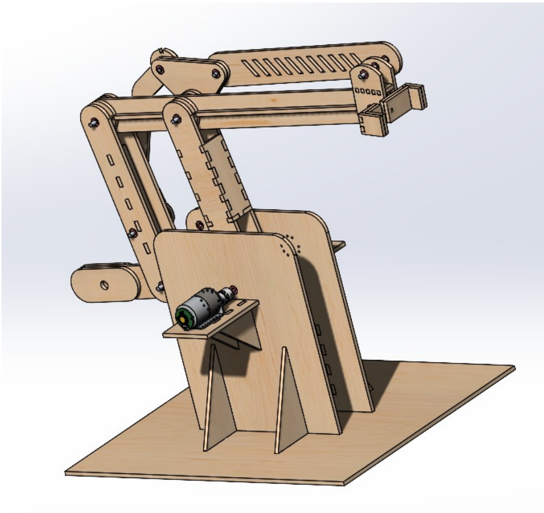

Figure 13: Final concept in "home" orientation

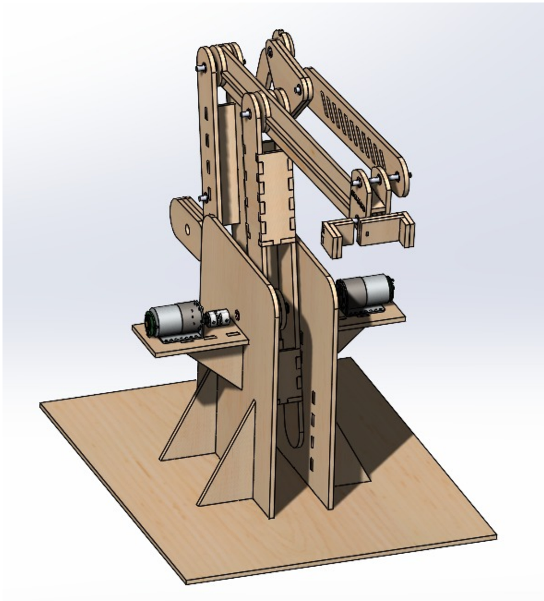

Figure 14: Final concept showing the two motors at the base

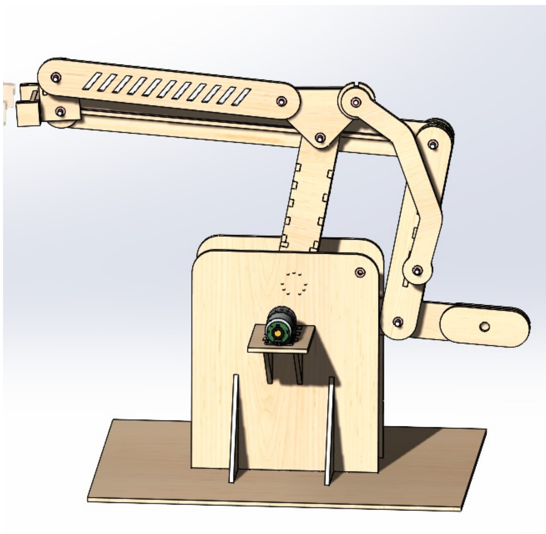

Figure 15: Final concept side view

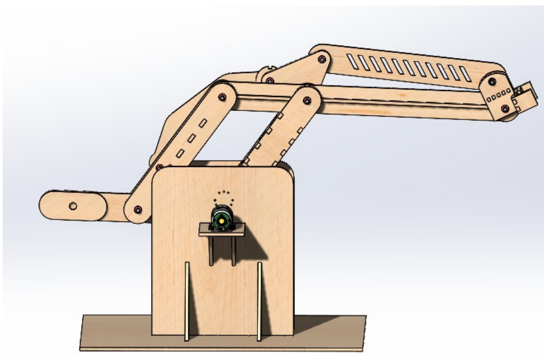

Figure 16: Final concept in extended position

4.2.2 EMG processing chain

In this section, the processing of the EMG signals from their raw form to the form they will be used as input to the PID controllers will be outlined. The raw EMG is measured at the electrodes and sent via cables to the microcontroller. In the microcontroller, the EMGs undergo several processes. The amplitude of the EMGs vary about a mean line that is offset from the zero value of the amplitude axis. In order to bring down the mean amplitude line to zero amplitude, a high pass biquad filter is used. The offset is of 0 Hz hence the cut-off frequency for the high pass filter was chosen slightly above this with 0.2 Hz. Next, the EMGs undergo rectification in which all negative values (values below the zero amplitude line) were converted to positive values. This is done as only the strength of the amplitude is required and not their direction (be it positive or negative). Finally, the EMGs are passed through a low pass biquad filter to filter out unwanted noise. A cut-off frequnecy of 30 Hz was chosen by trial and error. Figure 17 shows an overview of the process.

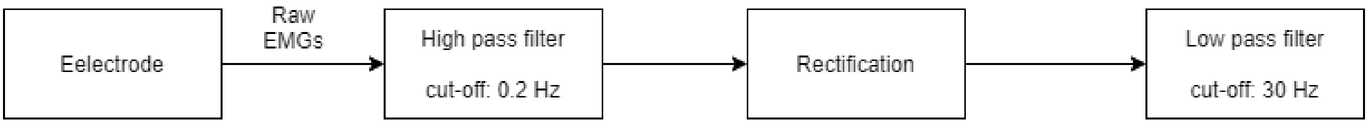

Figure 17: Overview of the processes undergone by raw EMG signals

4.2.3 Hardware

The hardware used can be divided into three categories: electrical components, electromechanical components and mechanical components.

The electrical components used were the following:

- NUCLEO-H743Z12: the controller, which serves as the brain of the robot. This is the part of the robot where the code is run.
- Olimex Shield-EKG-EMG: the EMG shield used to read the EMG signals. This robot uses three of these shields: one for each measurement signal.
- DFRobotMotorShield: the motor shield used to control the two motors. The external power supply is connected to this shield.
- Custom Biorobotics shield: a custom made shield which connects the motors to the potmeters. This is used to drive the motors without use of the EMG signals.
- Powersupply: a 9V medical grade powersupply which is connected to the motor shield and is used to drive both motors.

The electromechanical components used were the following:

- Pololu 37D Metal gearmotor: two of these motors are used in the robot. It has a gearbox ratio of 131:1 and a motor encoder on the motor shaft.

The mechanical components used were the following:

- Plywood: all of the links are lasercut from 6 mm plywood
- Shafts: the shaft used are 6 mm in diameter and are made of steel
- Bearings: the bearings used have an inner diameter of 6 mm.

The microcontroller used is the STM32 NUCLEAO-H743ZI2 microcontroller, with a custom fork for micropython.

4.2.4 Software design

<u>State machine</u>
A state machine (Figure 18) was developed to show the different states the robot can be in, and the steps it goes through to complete the task. The robot is controlled using three EMG-signals. Signals 1 and 2 control the movement in positive and negative direction, and the third signal controls the switch between moving in the x- and z-plane.

The transition guards for switching between the different states in which the robot moves are values of the EMG signals. To enter the states to move in either x- or z-direction, either signal 1 or 2 needs to pass a certain threshold, meaning either muscle connected to the electrode is contracted. To switch to moving in the other plane, both signal 1 and 2 need to be below a threshold, meaning both muscles connected to the electrodes must be relaxed. This enters the ”no movement” state. Then, another muscle, providing signal 3, is contracted. This changes the value of parameter ’S’ to 1 if it was previously 0 and vice versa. To start moving in the new plane, once again one of the muscles providing signal 1 and 2 must be contracted. The photo is taken by the use of an external Bluetooth button.

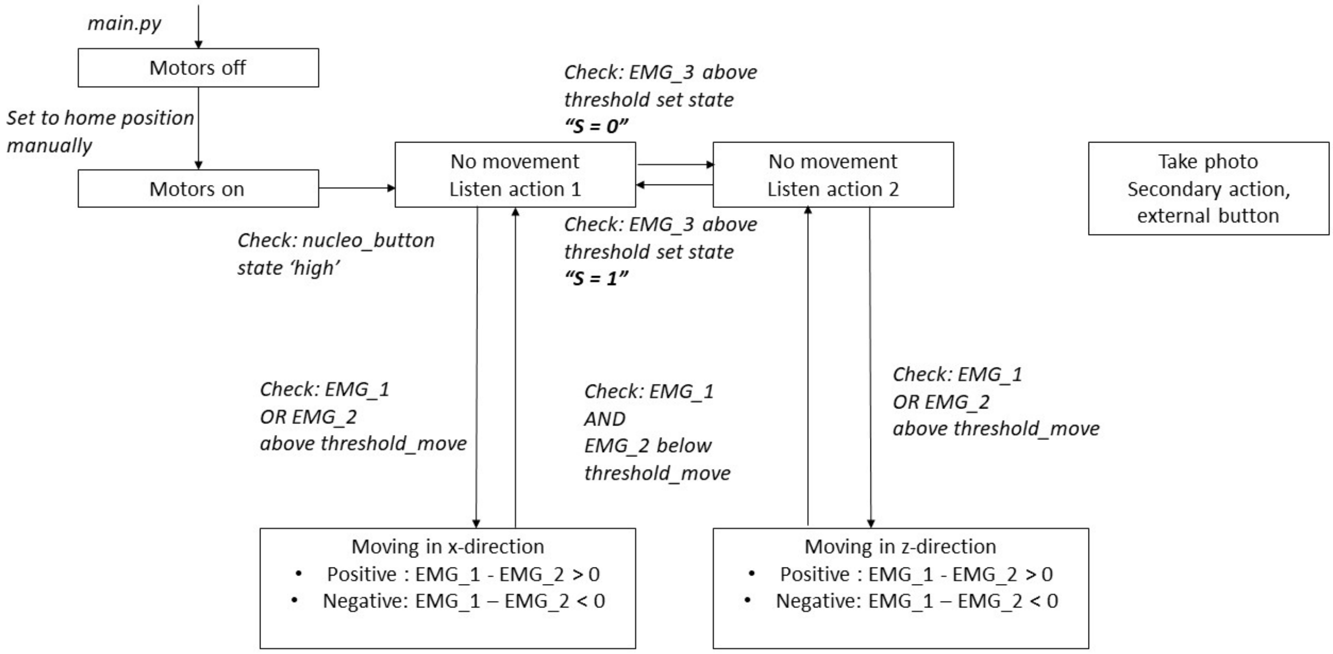

Figure 18: The state machine which describes the different states the robot can be in.

Signal flow

Figure 19 shows the signal flow. It describes how the five input signals (three EMG signals and two motor encoder counts) are transformed into the two output signals (motor velocities). The EMG signals are first filtered with a high pass filter with a cut-off frequency of 0.2 Hz, then rectified and filtered with a low pass filter with a cut-off frequency of 30 Hz. Going through these steps results in an envelope. The envelope of signal 2 is subtracted from signal 1 to provide the reference signal. This means that when the value of signal 2 is higher than signal 1, the reference signal becomes negative resulting in movement in the negative direction. The envelope reference value which acts as the input for the kinematics. As described in section 4.1.1, after the calculations the kinematics provide a reference signal for each motor given. These reference signals are fed into a PID controller, together with the values from the the motor encoders. The inner workings of the PID controllers are described in section 4.1.3.

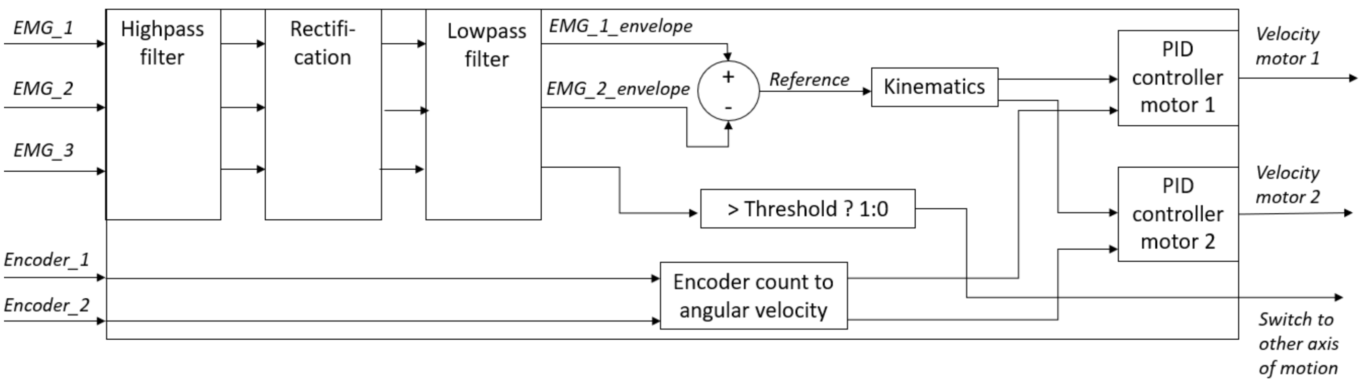

Figure 19: The signal flow of the process

4.3 Design realization

During the assembling process, some changes were made with respect to the 3D model to guarantee an adequate performance. The changes done in the design are as follows:

- The phone holder is the part with the most pieces, which makes it more complicated to assemble. The mechanism used in this part turned out to not be efficient enough to achieve its purpose. Therefore, it was decided to 3D print a phone holder.

- The 3D model was designed with press-fit connections for the bearings. These did not work as expected. To solve this problem, glue was used to get a better fit between the bearing and the wood.
- A counterweight of approximately 200 grams was added to balance the arm.
- After some tests, it was clearly visible that the input torque of the motors was not enough to drive the robot. A new gear system was used to raise the torque, which decreases the rotational speed of the motor. The same gear system was added to both motors, with a gear ratio of 1:6.

The final version of the assembled robot is shown in Figure 20.

Figure 20: The selfie robot after assembly. The added gear system is clearly visible, as well as the 3D printed phone holder. The same gear system is also present on the other side of the robot. On the left, the added counter weight can be seen.

4.4 Specific risk analysis

All the established requirements were met with the exception of the mechanism that keeps the telephone in a vertical position. Therefore, no new risk were presented to the user.

The risk for people around the robot remains minimal, since the speed at which the robot's arms move is quite low. It is therefor unlikely for it to seriously injure someone. The gear system is exposed and can be considered a hazard, but the motor is not strong enough to hurt someone.

5 Evaluation

In Chapter 2 a list of requirements was given. In this chapter, tests will be described which quantify whether the robot meets the technical requirements. Furthermore, this chapter includes an ethical reflection on the design.

5.1 Requirements evaluation

Regarding the non-quantifiable requirements, it can be concluded that the robot is able to firmly hold phones of different sizes. It can instantly take a photo by pressing an external Bluetooth button, resulting in a photo which captures the users upper body and face and does not include the robot itself. However, the phone does not capture the user's face and upper body in all possible robot configurations. This has to do with the dimensions of the triangular mechanism, which is in place to control the tilt of the phone. Because of this, the workspace within which it is possible to take a selfie with the user's upper body and face in it is limited. The malfunctioning of this triangular mechanism also at times limits the robots ability to move to the desired location. When contracted, the mechanism rotates too much, blocking further movement. It needs manual user intervention to solve this problem.

To determine whether the finalized robot meets the quantifiable requirements, a set of tests is done. The requirement regarding the distance between the user and the phone are easily met by simply placing the robot at the right distance.There are three quantifiable requirements that can be tested:

- Requirement 1: Time required for moving from minimal to maximal distance (in a straight line) should be ca. 5 seconds

- Requirement 2: Control should be precise enough to enable end effector to come to a stop 2 seconds after the stop command is given
- Requirement 3: Payload: 250 grams

Requirement 1
Although the robot is able to position itself at the minimum and maximum distance required, due to improper design of the tilt-correcting mechanism, it is unable to travel from the minimum point to the maximum point in a straight line. Hence, it was not possible to test this requirement.

Requirement 2
Due to a lack of time, rigorous testing was not done for this requirement. However, when looking at the movie presentation demonstration, it can be seen that once the muscle is contracted, the end effector moves in the desired direction for the set time interval and comes to a stop in about 2 seconds.

Requirement 3
Originally, the robot did not meet the payload requirement. However, after a counterweight was added, this requirement was met.

5.2 Ethical reflection

The selfie robot was designed with the goal of assisting people with Duchenne Muscular Dystrophy in taking a selfie. Although taking a selfie might seem like a trivial action, not being able, or having to use significantly more effort than most of society, to parttake in this part of pop culture can alienate people from society. The prototype of the selfie robot presented in this report enables users to take a selfie without having to keep their arm in an outstretched position. However, the prototype is not very mobile, which limits its applicability. It also has no rotation possibilities, limiting the workspace and thereby the possible photo angles.

The prototype does not appear to be useful to everybody, since taking a selfie without the robot is easier and quicker. So, although it helps people with DMD, users of this robot still need to put more effort into taking a selfie than most people.

Users of this robot would most likely stand out, since there is little reason to use it if you can take a selfie without assistance. This can be seen as a negative. However, if presented in a positive way, the robot could be regarded as a cool device. Giving the users the option to custom design their selfie robot would be a way to give the users control over how much they want to stand out.

6 Conclusions

The robot fulfills its main purpose: the user can take a selfie. It is also possible to control the end-effector's movements in the x- and z- plane using EMG-signals. However, the vertical position of the phone is not guaranteed in all robot configurations, limiting the positions from where a good selfie can be taken. Also, the starting position of the robot has to be obtained manually. Manual help is also needed when the robot is contracted, since its configuration then blocks further movement.

In terms of design there are several points to improve:

- One improvement would be to reduce the weight of the arms to eliminate the need of adding a gear system. The weight of the arms can be reduced by changing the dimensions and/or making holes where possible.
- Another point to improve, is to define the initial position without the help of a person, so that the user is more self-sufficient in using this robot.
- Finally, the dimensions of the triangular mechanism that allows the phone to always face the user should be improved. With the current dimensions, it does not ensure the right position for the phone.

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A Appendix

Inverse kinematics

In Figure 21 a schematic drawing of the robot in an arbitrary configuration is shown. Given ${}^0P_e$, all lengths of all sides of the triangle are known. Using the law of cosines, α, β and γ can be calculated. Since the desired values are q_1 and q_2, only α and γ need to be calculated. θ is equal to $\arctan(\frac{y}{x})$, in which y and x are the values for y and x in ${}^0P_e$. From Figure 21 it can be derived that $q_1 = \theta + \alpha$ and $q_2 = \gamma - 90°$. These values for q_1 and q_2 can be used to calculate m_1 and m_2, using equation 1 and equation 2.

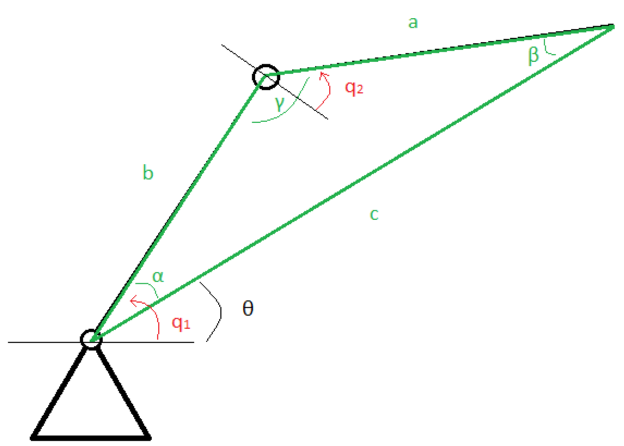

Figure 21: Sketch of the robot in an arbitrary configuration. In green a triangle is drawn, which connects joint 1, joint 2 and the end-effector. The angles of this triangle are named α, β and γ. Also shown are q_1 and q_2, the joint angles.

The law of cosines describes the relation between the sides of a triangle and the cosine of an angle. For the angle γ, it states that:

$$c^2 = a^2 + b^2 - 2ab\ \cos\gamma \tag{29}$$

For α, the equation becomes:

$$a^2 = b^2 + c^2 - 2bc\ \cos\alpha \tag{30}$$

These equations can be rewritten to find γ and α as follows:

$$\gamma = \arccos\frac{a^2 + b^2 - c^2}{2ab} \tag{31}$$

and

$$\alpha = \arccos\frac{b^2 + c^2 - a^2}{2bc} \tag{32}$$

The values for a and b are constants in this equation, they represent the lengths of the two links of the robot. The value of c is dependent on the position of the end-effector, ${}^0P_e$. It can be found using the following equation:

$$c = \sqrt{x^2 + y^2} \tag{33}$$

in which x and y are the values for x and y described by ${}^0P_e$.