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Robotic Arm Mimicry

A thesis on motion tracking and haptic feedback to control robotic machinery

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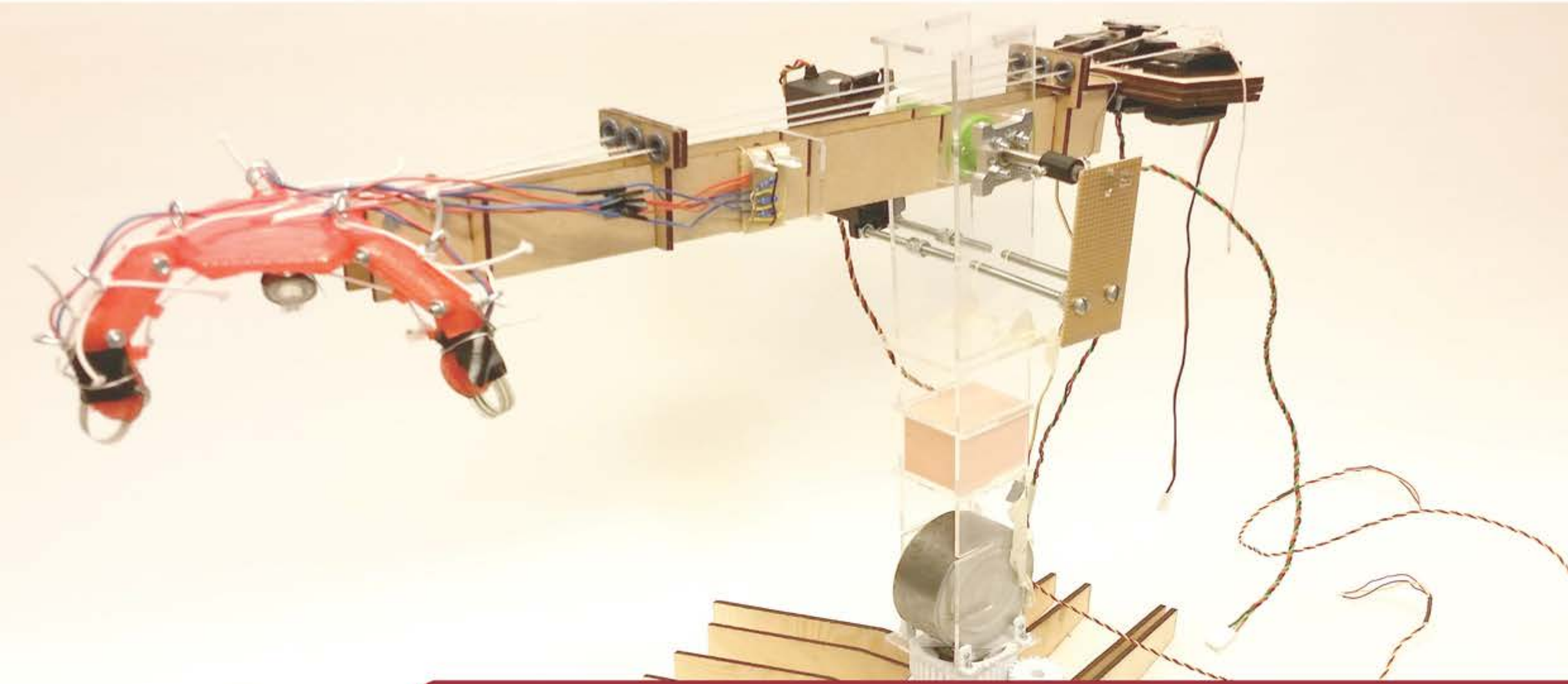

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KTH Industrial Engineering and Management

Bachelor Thesis MMKB 2016:36 MDAB097

Robotic Arm Mimicry

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ABSTRACT

This thesis considers new ways of motion tracking and the usage of haptic feedback. The purpose is to develop and test an intuitive way of controlling robotic machinery; in this case the focus is on the arm and hand.

The developing process consisted of four major steps; firstly constructing a frame for tracking the user's arm motion, secondly creating a robotic arm responding to above mentioned tracking. The third step consisted of designing a glove to track finger motion and provide haptic feedback to the user. Last step comprised the construction of a robotic hand which follows the signal by the user through a glove. Pressure sensors are integrated in the robotic hand to supply the haptic feedback in the glove with a signal.

To assess the ability of the demonstrator, two different tests are made. The first one tests the difference between the tracked arm motion (input) and the resulting robotic arm movement (output), using rotary potentiometers. The second one focuses on the haptic feedback in the glove, which allows investigating the possibility for the user to differentiate hard objects from soft objects.

Results show that the robotic arm follows the tracked motion from the user with high accuracy. However, testing of the robotic hand indicates difficulties while distinguishing between hard and soft objects.

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KTH Industriell teknik och management	**Kandidatarbete MMKB 2016:36 MDAB097** **Härmande robotarm** Henrik Strömqvist Sofia Olsson

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SAMMANFATTNING

Kandidatarbetet behandlar nya sätt att spåra rörelser och användningen av känselåterkoppling. Syftet är att utveckla och testa ett intuitivt sätt att styra robotar; i detta fall en robotarm och hand.

Utvecklingsprocessen bestod av fyra viktiga steg; först konstruerades en ram som skulle spåra användarens armrörelse, därefter skapades en robotarm som följde den spårade rörelsen. Det tredje steget innebar utveckling av en handske som skulle spåra användarens fingerrörelse samt återkoppla till användaren via känseln. Det sista steget innehöll skapandet av en robothand som följde signalerna från användarens handske. Trycksensorer integrerades i robothanden för att ge en signal till känselåterkopplingen i handsken.

Två olika tester av den färdiga demonstratören gjordes för att uppskatta dess kapacitet. Det första testet undersökte skillnaden mellan den uppmätta signalen från armrörelsen (indata) och den resulterande rörelsen från robotarmen (utdata), genom att använda roterande potentiometrar. Det andra testet fokuserade på känselåterkopplingen i handsken, genom att undersöka möjligheten för användaren att skilja på hårda och mjuka objekt.

Resultaten visade att robotarmen följde den uppmätta armrörelsen från användaren med hög precision. Däremot visade tester av känselåterkopplingen svårigheter att skilja på hårda och mjuka föremål.

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PREFACE

The chapter contains expression of gratitude to important persons to the project.

We would like to thank our supervisor, Fariba Rahimi, for frequent availability, feedback and support. We would also like to thank Staffan Qvarnström for support and help with obtaining components and Urban Olsson at SKS Sweden for supplying us with material. Lastly, we would like to thank the assistants in the course for helping us with sudden difficulties and problems.

Sofia Olsson and Henrik Strömqvist

Stockholm, May 2016

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Nomenclature

The chapter contains a list of symbols and abbreviations used in this thesis.

Symbols

Symbol	Description
d	Distance (m)
t	Time (s)
v_a	Speed of sound through air (m/s)
L	Length of frame (mm)
H	Height of frame (mm)
Φ	Diameter (mm)

Abbreviations

CAD	Computer Aided Design
PWM	Pulse Width Modulation
FIR	Finite Impulse Response
IDE	Integrated Development Environment
USB	Universal Serial Bus
PLA	Polylactic Acid

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Contents

1 INTRODUCTION

The introducing chapter describes the background, purpose, scope and method in detail for the thesis.

1.1 Background

Controlling machinery to move and lift objects, as robotic arms, excavators or cranes are often done with joysticks. Using such devices, a lack of intuition might arise as a joystick is quite far from the actual human arm and hand motion. A solution closer to a user's natural movement could for example be the usage of a human arm and hand to control machinery by tracking their motions. At the University of Rochester, medical procedures have been performed by using robotic assistance. [1] Surgeons' hands are mimicked by small gripping claws to perform surgeries with enhanced dexterity and provide a smaller invasive procedure.

To further improve the implementation of robotic assistance through master-slave robotics, some kind of haptic feedback to the user could be used to enhance the instinctive feel. At Massachusetts Institute of Technology studies have been made to increase performance of master-slave robotics by using human reflexes to stabilize the balance of a slave robot [2]. Thus the user works as a controller, instead of implementing one through a microcontroller with calculations and software. The reason behind this is that results showed that the reaction time is much shorter when the robot adjusts its balance through a human controller compared to visual feedback from on-board cameras.

The thesis will therefore try to combine these two concepts; a robot which could mimic a user's arm and hand motion and give feedback to the user who will act as a controller.

1.2 Purpose

The purpose of this thesis is to develop and test a new way of controlling robotic machinery; the focus of the dissertation is on a robotic hand and arm. Further on, the thesis also investigates the usage of haptic feedback when gripping objects of varying softness and size.

The thesis will therefore handle two different main areas as research subjects. One area concerns motion tracking and accuracy in master-slave robotics, and the other haptic feedback and determination of objects' degree of softness. The following questions are to be answered in this thesis:

How accurate can a robotic arm follow a user's arm moving in a 2-dimensional space?

How does haptic feedback behave when the robotic hand is gripping soft respectively hard objects? Is it possible for a user to assess the softness with the feedback?

1.3 Scope

The report corresponds to one semester of work with a Bachelor thesis at KTH. The time and budget limits have led to some restrictions regarding the design of the demonstrator. The movement of the human arm is only possible in a two-dimensional area, since the implementation of a third dimension would complicate the project further. The human arm motion is linear, but the robotic arm motion is spherical since servos are used to perform the robotic arm motion. This results in a limited area in which the robotic hand can reach and grip objects, namely the shell of a half sphere. Concerning mechanics in the arm, its length correlates strongly to the counter-torque needed to uphold itself with objects. The length of the arm is therefore limited, since the cost of a servo increases with the counter-torque needed.

1.4 Method

As the purpose of this thesis is based on finding a new way of controlling robotic machinery some brainstorming was done. To track a position in two-dimensional space a frame was designed in which the user's hand could move freely. The hand is attached to two wires whose varying lengths are constantly measured by ultrasonic sensors. These values are then used in an equation system to solve the x- and y coordinates of the hand in the frame. See subchapter *2.1 Positioning calculation* for further details. The ultra-sonic sensors were chosen due to their relatively high accuracy and low cost.

Next step was the construction of a robotic arm that could move with two degrees of freedom, horizontal and vertical. The applied servos in each direction were mapped to x- and y-coordinates of the user's hand position in the frame respectively. To answer the first research question regarding the accuracy of the movement, rotary potentiometers were implemented on each axis.

A glove was created to control gripping motion of a robotic hand. The glove consisted of bendable potentiometers to measure the flexing of the user's fingers. Only three fingers were implemented, due to the limitations in terms of budget and time.

To respond to the signals from the glove, a robotic hand with three fingers was constructed. To answer the two remaining research questions, pressure sensors were attached to the fingertips of the robotic hand. These were used as a feedback to the user in the form of vibration motors attached to the fingertips of the glove. Thus, a haptic feedback is created where the user can sense the amount of pressure applied to an object gripped with the robotic hand. Testing the usage of this was made through gripping objects of varying size and softness to assess whether the softness could be identified by the user.

Throughout the work, new prototypes were built subsequently to develop new functions and counter unpredicted difficulties in the construction. By conducting these steps in an empirical manner, the research questions can then be answered in a satisfactory way.

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2 THEORY

The chapter describes the theoretical knowledge that is necessary for the thesis.

2.1 Positioning calculation

The thesis investigates the possibility to track human arm and hand motion by using a two-dimensional frame with a wire of fixed length attached to two blocks, see figure 1. The human hand is attached to the middle of the wire and the hand is moved around within the borders of the frame. This results in a distance difference between the blocks and the bottom of the frame, which through calculations can describe the position of the human hand in every moment, see equation (1) and equation (2).

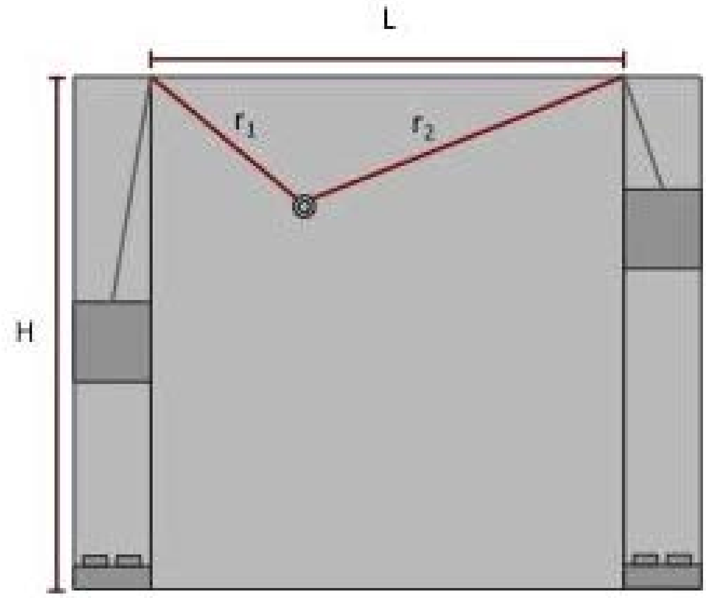

***Figure 1**. Schematic of the frame.*

The x-coordinates in the two-dimensional plane is calculated by

$$x = \frac{r_1^2 \; - \; r_2^2 \; + \; L^2}{2L} \tag{1}$$

and the y-coordinates is calculated by

$$y = H - \sqrt{\frac{r_1^2 - (r_1^2 - r_2^2 + L^2)^2}{4L^2}} \tag{2}$$

where L is the length of the frame, H is the height of the frame, r_1 and r_2 are the distances between the human hand and the frame through the wire, i.e. the length of the wire.

2.2 Ultrasonic distance measurement

The principle behind the sensor is to send short bursts of ultrasonic sound which will bounce back as it hits a surface. As soon as the pulse is sent, a receiver and a timer are turned on to listen to returning ultrasounds. When the ultrasonic wave hits the receiver, the timer stops and the module sends a digital signal which translates into the time between sending and receiving the pulse [3], see figure 2. With this information it is possible to calculate the distance according to equation (3)

$$d = \frac{t * v_a}{2} \tag{3}$$

where d is the measured distance, t is the time it takes the signal to return to the sensor and v_a is the speed of sound through air. It is divided with two since the sound wave is traveling back and forth.

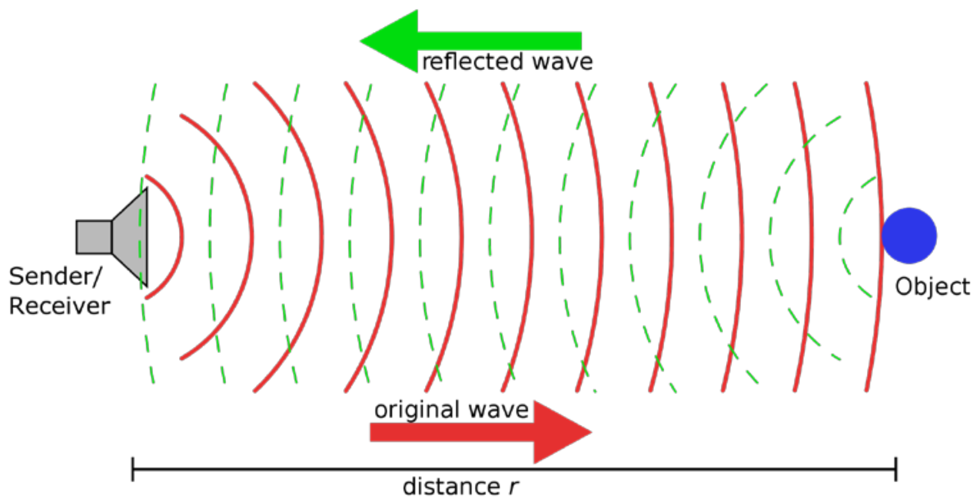

Figure 2. *The figure depicts the principle of ultrasonic distance measurement. [4]*

However a physical limit exists using this type of sensor as the sound needs to travel back and forth. This limits the sampling rate; sending out a new pulse before the previous has returned will result in erroneous samples. In this thesis the sampling rate is considered not go below 5 ms to prevent this error, as 5 ms corresponds to the double distance of H in figure 1.

2.3 Ultrasonic sensor filtering

To measure the distance differences between the blocks and the ground, ultrasonic sensors were used. Since these samples were used to calculate the x- and y-coordinates, which in turn were transferred to the servos to position the robotic arm, a stable and consistent input signal to the servos was of utmost importance. Small noise in the signal would result in vibrations, angular flickering and therefore an unstable arm motion with positional errors. To handle this, a low-pass filter was implemented that filters out high-frequency signals. This prevents the sudden deviations from the signal to be included in the positional calculations. At first an analogue RC-filter was considered, as it causes no delay in the output signal. Though as it is analogue it requires the ultrasonic module to be analogue, i.e. that different voltages are given depending on measured distances. However this was not the case with the module used, since the signal was digital. The filter which was implemented through software in the Arduino had a drawback, as it causes a delay between input and output of the signal. Therefore, code optimization is important to counter the effects of digital filter usage.

The filter implemented was a *finite impulse response filter*, also called a FIR-filter. It is a causal discrete-time filter, which is based on a moving average algorithm. The filter operates by adding N numbers of succeeding samples together with a weight; in this case the weight is the same for each value, $\frac{1}{\mathrm{N}}$ to get the mean-value, see equation (4). The calculation of the filtered signal is made by

$$y[n] = b_0 x[n] + b_1 x[n-1] + \cdots + b_N x[n-N] = \sum_{i=0}^{N} b_i x[n-i] \qquad (4)$$

where y is the filtered signal, x is the sample value, b_i is the weight of each sample value (in this case, $b_i = \frac{1}{N}$) and N is the number of samples. [5]
When the number of samples exceeds N, the process resets and starts to replace the oldest values. This way a moving average value is sent as output to the servos, which gives a more stable and consistent signal, see *Appendix A, result from FIR-filter.*

2.4 Force sensitive sensor

Force sensitive sensors are able to detect varying force, in this case pressure. They are based on conductive foam between two points which will change the resistance depending on the particle density in the foam, see figure 3. As force is applied over the surface the particle density is increased and resistance changed, the pressure is measured as an analog signal due to the change in voltage over the sensor. [6]

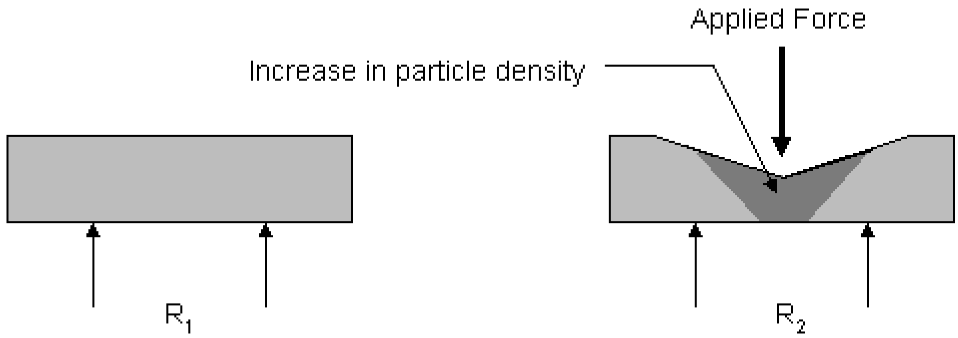

Figure 3. *The figure depicts the principle of a force sensitive sensor. [6] R_1 and R_2 are different values of resistances.*

2.5 Flex sensor

Flex sensors are made to vary resistance in a circuit depending on the amount of bending. This is implemented through conductive ink which it is layered with. As it bends the ink is thinned out and increases the resistance. It is then possible to determine the amount of bending of a finger when the sensor is attached to the glove. [7]

3 DEMONSTRATOR

The chapter describes the problem formulation, the elements of the demonstrator in terms of software, electronics and hardware and the results.

3.1 Problem formulation

Constructing the demonstrator to properly answer the stated research questions the following requirements were set:

- A well-functioning prototype is needed to answer the research questions. Therefore, prototyping is needed to be done repeatedly, as the demonstrator will consist of many subsystems and their interaction within themselves and with each other can cause unpredicted problems.

Frame

- The wire length will be longer than the height of the frame to make it possible to reach the corners of the frame.
- It is important that the surfaces used to measure distance are perpendicular to the ultrasonic sensors.
- Wires should always be fully stretched and easily moved when attached to the user's hand.

Robotic arm

- The center of mass needs to be kept at a low point to prevent tilting.
- Servos used for horizontal and vertical movement should not take axial or radial reaction forces as they are not constructed to be subjected to such stress.
- Space for rotary potentiometers is needed to confirm actual movement.

Robotic hand

- Number of fingers should be kept at a minimum to lower the complexity of the system.
- Joints should be made to only move around one axis to keep fingers straight.
- Fingers need to be big enough to be able to have pressure sensors attached on the tips.

Glove

- Flex sensors need to be attached across the fingers in a way that it properly measures a user's finger movements.

- It should be able to be connected to the wire in the frame.

3.2 Software

With each subsystem, software for the Arduino units was needed. This was developed with Arduino Uno R3 used as microcontroller programmed with the Arduino IDE-platform, able to write and compile C code directly to the unit through a USB-cable. Flowcharts of the unfiltered and filtered signal from the ultrasonic sensors are presented in *Appendix B: Flowcharts.*

The software for the hand unit is based on taking input from the analog ports A0 through A5, where A0 to A2 take input from the flex sensors on the glove and A3 to A5 taking input from the pressure sensors on the robotic hand. A0 to A2 ranging from 0 to 1023, depending on voltage given by the varying resistance in the flex sensors, are mapped to servo angles. These signals are then sent to each of the servos with wires attached to each finger in the robotic hand through the servo.Write()-function within the Arduino library [8]. The signal in A3 to A5 is mapped to a PWM-signal depending on the pressure applied on each of the sensors. Finally, the mentioned signals will be sent to each of the vibration motors in the glove as analog.Write()-function, also part of the Arduino library.

3.3 Electronics

The electrical circuitry needed to be split into two parts as the required amount of ports with analog input was exceeded by the amount on one single microcontroller. This was applied to make the software development easier and lower the stress on the microcontroller.

3.3.1 Arm unit

The electrical components that was used in the arm unit was an Arduino Uno R3, ultrasonic sensor modules, called HC-SR04, to sample the user's arm motion in the frame, two servos from Hitec; one called HS-805BB+ to rotate the robotic arm in the vertical direction and one called HS-303 to rotate the robotic arm in the horizontal direction, and rotary potentiometers to confirm the accuracy of the movement. Figure 4 shows a sketch of the electrical components related to the robotic arm unit. The two ultrasonic sensors are shown in green; the two servos are shown in blue and the two rotary potentiometers as shown in red. The black ring in the frame represents the current position of the user's hand.

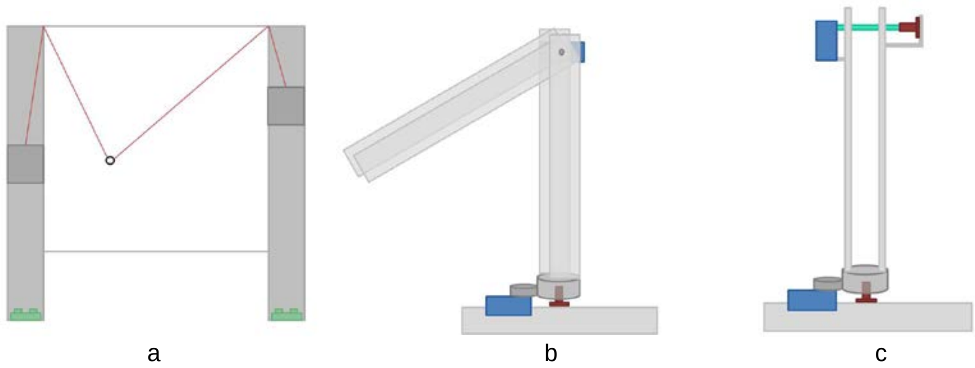

Figure 4. *Three visualizations of the electrical components used in the arm unit. The frame is in **a** and the robotic arm is in **b** (from the side) and **c** (from behind).*

The electrical wiring of these components is shown in figure 5.

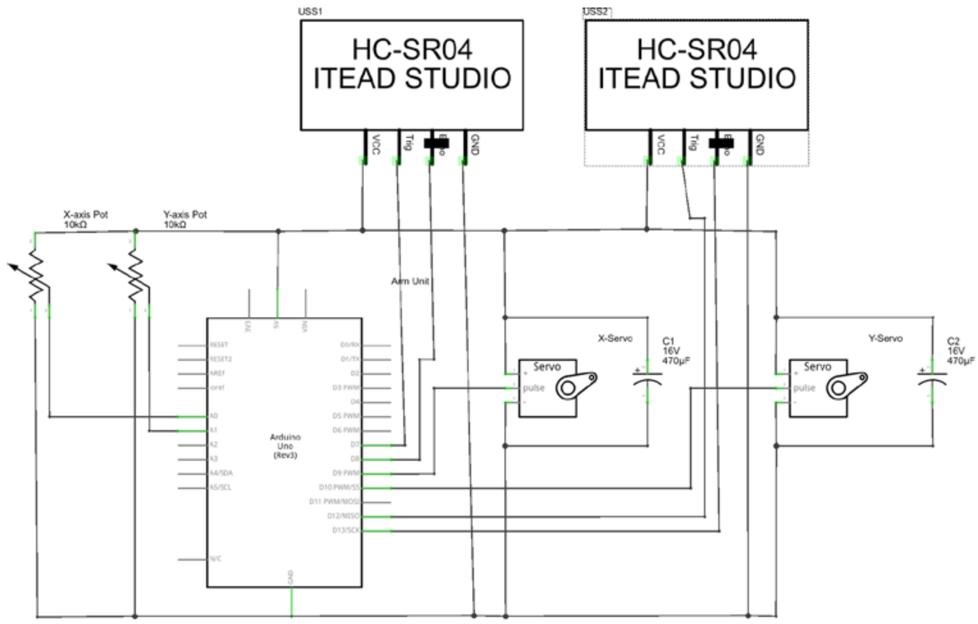

Figure 5. *The figure shows the electrical wiring of the arm unit of the robot. It consists of an Arduino Uno R3, two ultrasonic sensors, two servos and two rotary potentiometers.*

The two distances r_1 and r_2 in the frame, see figure 1, were measured with ultrasonic sensors and then used to calculate x- and y coordinates of the user's hand according to equation (1) and (2). The x- and y-coordinates were mapped to an angular position which was sent to the two servos in figure 5. To confirm the accuracy of the motion two rotary potentiometers were also implemented as can be seen to the left in figure 5. There are capacitors across each servo to prevent possible power surges in the circuit which prevents fluctuations in the current and gives the servo a smoother movement.[9]

3.3.2 Hand unit

The electrical components which are used in the hand unit is an additional Arduino Uno R3, three flex sensors from Spectra Symbol called FSL0095-103-ST [10], for sampling the user's finger movement. Moreover, three vibration motors (to send a signal using haptic feedback to the user), from Jinlong Machinery & Electronics Co. Ltd. called C1026B002F, three servos (to create the gripping motion of the robotic hand) from Hatic called HS-303 and three pressure sensors (to measure the amount of force being applied from the robotic hand), called FSR402 from Interlink [11] were used. Figure 6 shows sketches of the electrical components related to the robotic hand unit.

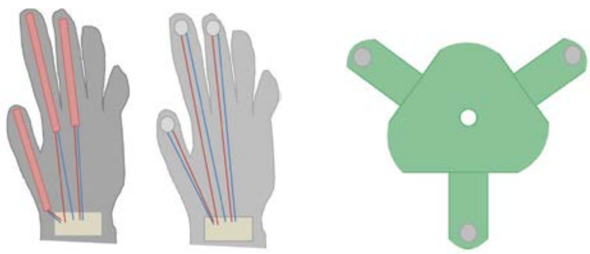

Figure 6. *The upper side of the glove is shown in **a**, with the three flex sensor in red. The palm of the glove is shown in **b**, with the three vibration motors on the finger tips. In **c**, the robotic hand is shown with the three grey pressure sensors on each robotic finger.*

Figure 7 shows the three servos in the structure of the robot and the process of adding a robotic hand on the robotic arm. The servos are shown in blue behind the axis of the robotic arm. The hand and fingers are shown in transparent green to clarify how the wires in red are directed to one servo each. When a servo gets a signal from one of the flex sensors, it rotates which pulls the robotic finger corresponding to that servo.

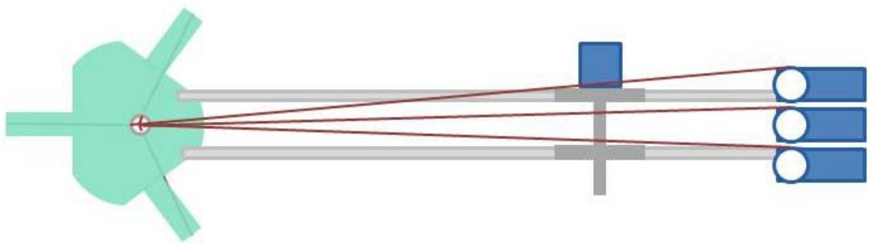

Figure 7. *The schematic of a robotic hand when it is attached to the robotic arm.*

The electrical wiring of these components is shown in figure 8.

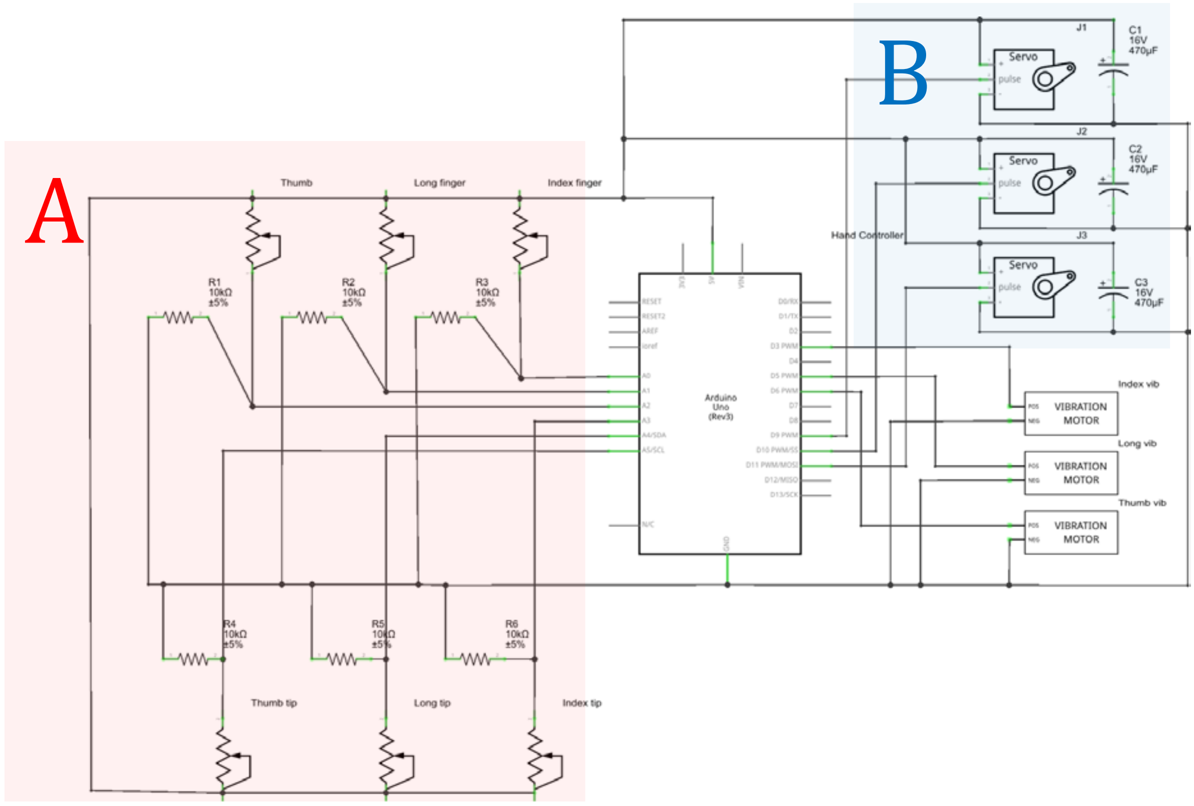

Figure 8. *The electrical wiring for the hand unit of the robot which consists of an Arduino Uno R3, three flex sensors, three vibration motors, three pressure sensors and three servos.*

The flex sensors and pressure sensors can be seen in the A-area of the figure 8 together with pull-down resistors to divide the voltage, thus making it possible to change the voltage over the analog port. [12] The flexing signal from the flex sensors is mapped to a certain angle to a servo shown in the B-area of the figure. As the servo moves, it pulls a string attached to the finger in the robot, therefore it creates a grip as the user closes its hand.
The signal from the pressure sensors are mapped to a certain PWM-signal depending on the amount of the applied pressure. This PWM-signal is then sent to the corresponding vibration motor in the glove. The robotic finger in the middle corresponds to the index finger of the user, the right robotic finger corresponds to the user's thumb and the left robotic finger corresponds to the long finger of the user. The PWM-signal goes from values 0 to 255 to set a specific duty cycle and they correspond to ground respectively 5V on an Arduino Uno unit. As the vibration motor has a nominal voltage of 3,3V, the resulting mapping went between 0 and 160 to prevent damages. Later on the 0 was changed to 20 as vibrations was not be felt by the user for values of lower than 20.

As for the arm unit, there are capacitors across each servo to prevent possible power surges in the circuit.

3.4 Hardware

The construction of the hardware of the prototype was divided into four steps. It was made in the following order; frame, robotic arm, glove, robotic hand.

3.4.1 The frame

The frame was designed big enough for the user's hand to move freely within it, which resulted in a size of 400x400 mm. The two ends of a wire with the length of 1400 mm were attached to a block on each side of the frame, while the midpoint of the wire was attached to the glove which will be explained in subchapter *3.4.3 The glove*. The tracks, in which the blocks are moving, are 700 mm high and 70 mm wide. Thus, the frame is raised 300 mm from the ground to ensure that all positions of the hand are accessible. Details regarding the method for designing the frame are displayed in *Appendix C, Construction of the frame.* The final version of the frame is shown in figure 9.

Figure 9. *The final frame, consisting of two tracks on each side with blocks attached to the wire. The ultrasonic sensors are placed underneath the blocks. The glove is later on linked with the circle in the upper part of the figure.*

The two ultra-sonic sensors were placed directly underneath the blocks in the tracks to measure the changing distance to the blocks as the user moves its hand.

3.4.2 The robotic arm

The robotic arm was designed using Solid Edge [13] and 123D Make [14]. The materials used were wood and acrylic due to their low cost and strength. The materials were shaped using laser cutting with an *Epilog Fusion M2 Laser*. The horizontal motion from the lower servo was transferred through 3D-printed gears using an *Ultimaker 2*, see figure 10. The vertical motion from the upper servo was transferred through an axis in the arm, as depicted in figure 11. Since the upper servo was placed on this height, its weight created unbalance in the vertical part of the arm. To prevent this, a weight of steel was added in the bottom of the construction.

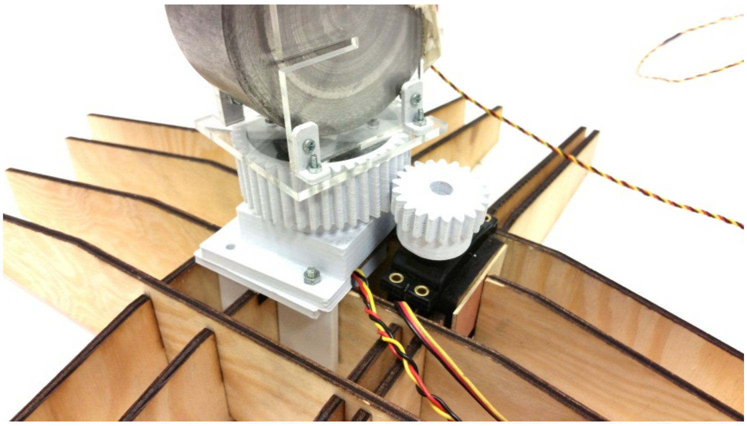

Figure 10. *The horizontal motion from the servo is transferred through gears.*

Rotary potentiometers were implemented in both the horizontal and vertical direction. The implementation of the rotary potentiometers in the design is showed in figure 4 and in figure 11.

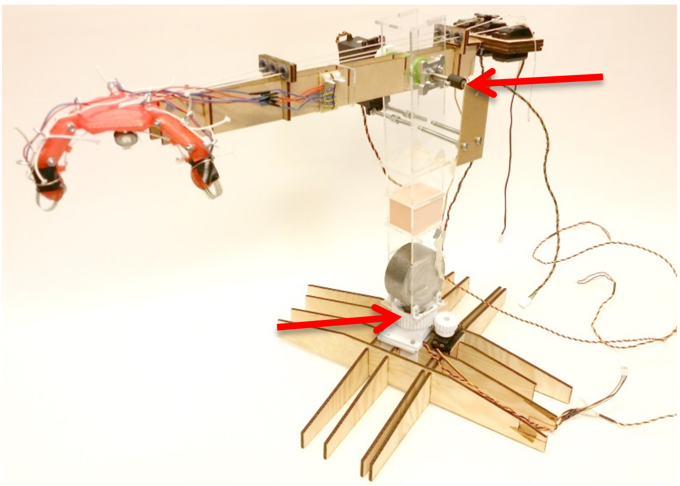

Figure 11. *The robotic arm with the robotic hand implemented. The upper servo is behind the vertical arm. The upper rotary potentiometer is in front of the vertical arm and the lower is inside the gear. Both are pointed out with red arrows in the figure.*

3.4.3 The glove

The electrical components needed for the design were attached onto a glove of fabric. Only three fingers were used for this thesis, namely the thumb, index finger and long finger. The upper side of the final version of the glove is shown in figure 12.

Figure 12. *The upper side of the glove showing three bendable potentiometers.*

The palm of the glove consists of three vibration motors on the fingertips, see figure 13.

Figure 13. *The palm of the glove showing three vibration motors.*

3.4.4 The robotic hand

The robotic hand consists of a palm and three fingers with an equal distance from each other. Each finger is connected to a servo on the other end of the robotic arm through a wire, see figure 7 and 14.

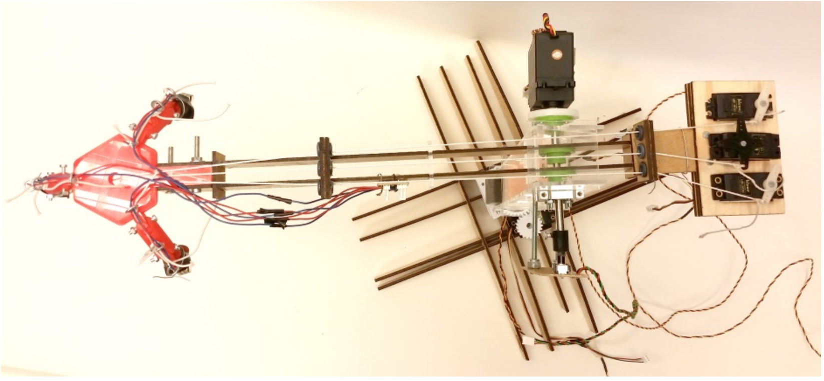

Figure 14. *The robotic hand's construction when it is attached to the robotic arm. Each finger is connected to a servo through a wire. When the servo receives a signal, it rotates to the given position. This pulls the corresponding finger.*

The design of the different parts in the hand was done in Solid Edge [13] and 3D-printed with an *Ultimaker 2* and joined with screws. Elastics were attached to loops on the upper side of the hand to make sure that the fingers were stretched out when they are not in use. The loops were also used to lead electrical wires to the pressure sensors in the fingertips. On the palm of the robotic hand, the wires and pressure sensors were attached as shown in figure 15.

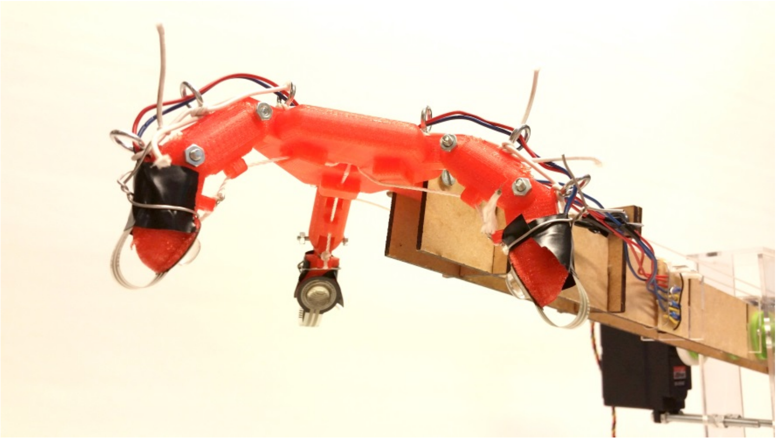

Figure 15. *The robotic hand. The wires are led through loops on the upper side of the hand. Elastics are attached to the loops to make the fingers straight when not used. The pressure sensors can be seen on the fingertips of the hand.*

3.5 Testing rig

3.5.1 Arm tracking and movement

To calibrate the rotary potentiometers, a sweeping servo between 0 to 180 degrees was used through the standard Arduino library [15]. For the potentiometers, an angular resolution of 0 to 205 degrees was satisfactory to the servo. This was mapped between analogue values 0 and 1023 in the software. As a gear is used for horizontal rotation with a ratio of 2, the max angle of the rotation will be 90 degrees. Figure 16 shows the graph with the result of mentioned calibration.

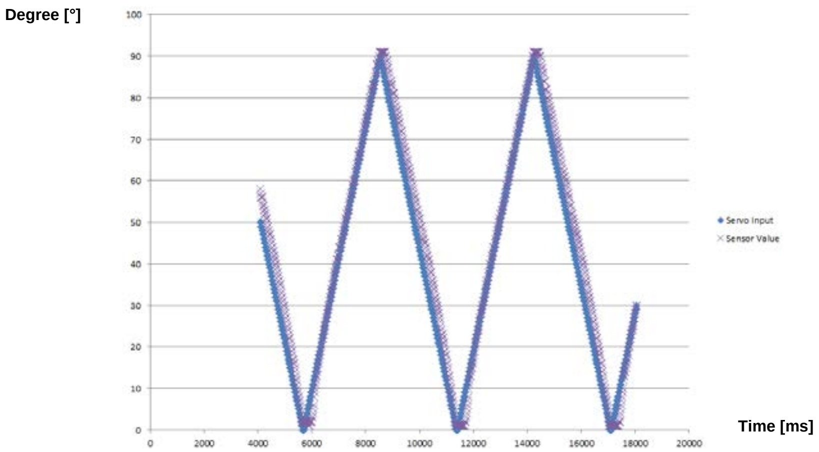

Figure 16. *Servo input and the sensor value during a sweep with a servo.*

For testing the accuracy of the robotic arm in tracking the input from the user's arm movement, two movements were considered; horizontal and vertical. This means one test for each servo axis. The process of the signal is shown in figure 17.

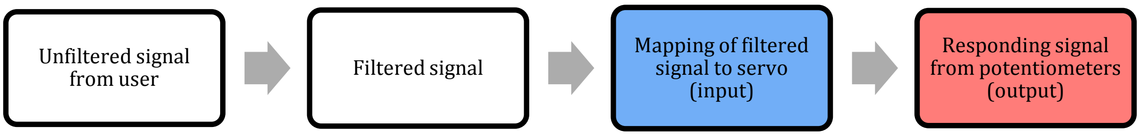

Figure 17. *The process of the signal in four steps, from the user, through the filter, to the servos in the robotic arm (in blue) and the responding output signal from the potentiometers (in red).*

3.5.2 Grip and feedback

For the purpose of testing the grip and feedback of the robotic hand, three spherical objects are used to split the pressure as equally as possible on each finger. Two of the spheres are of the same size (ϕ 85 mm) but different softness; one made of PLA plastic and one of soft rubber foam. The third is smaller (ϕ 55 mm) and is made of PLA plastic as well.

To make the gripping motion of the constructed hand as consistent as possible the software for the Arduino unit is hardcoded. Consequently, are being run at the same speed each time, in order to make the gripping motion identical for each test.

To avoid difficulties in analysing, the PWM-signal from the vibration motors is considered to be analysed instead of estimation from a human user.

3.6 Results

The following are the results from the discussion which was made in subchapter *3.5 Testing rig.*

3.6.1 Arm tracking results

Figure 18 depicts the accuracy of hand signal tracking by robotic arm. The hand motion is horizontal.

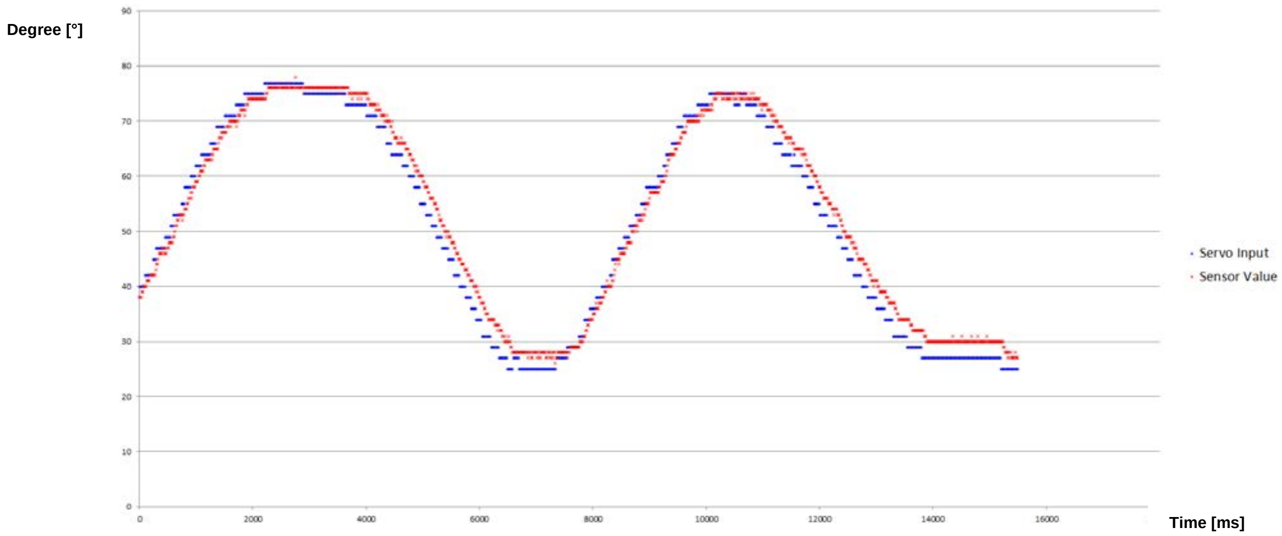

Figure 18. *Servo input and sensor values measured when the user arm moves from right to left two times in the frame.*

The second movement was vertical and the result is shown in figure 19.

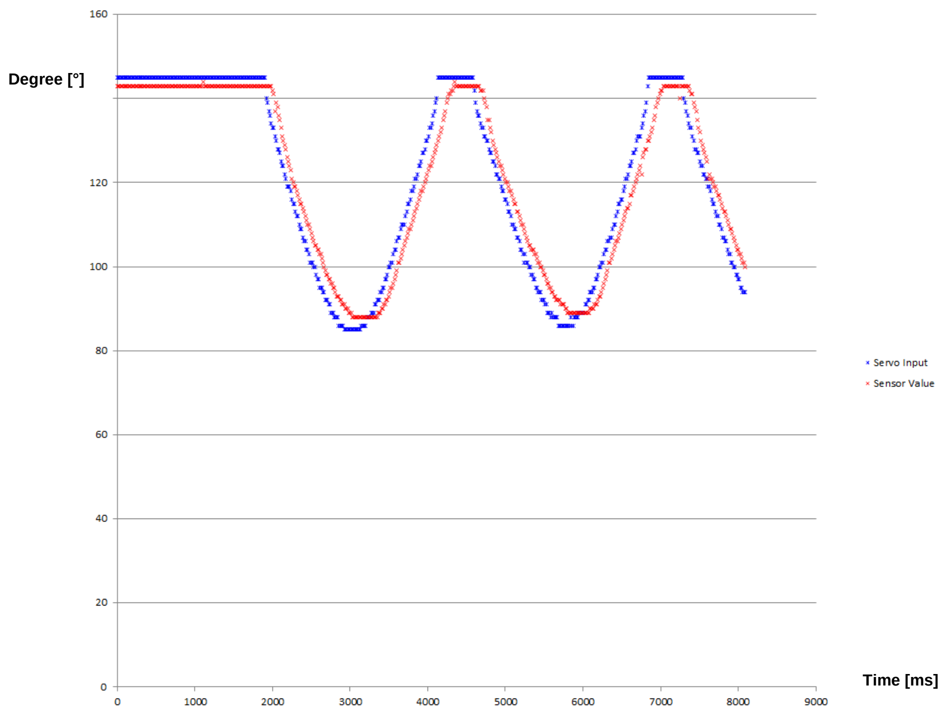

Figure 19. *Servo input and sensor values measured when the user arm is moving up and down in the frame two times, starting up and ending down.*

3.6.2 Gripping test

The following graphs in figures 20-22 show the results from testing the haptic feedback in the user's glove, as explained in subchapter *3.5.2 Grip and feedback*. The pressure sensor values are mapped to a specific PWM-signal, therefore the y-axis of these graphs expresses the amount of vibration which is felt in each finger of the glove by the human.

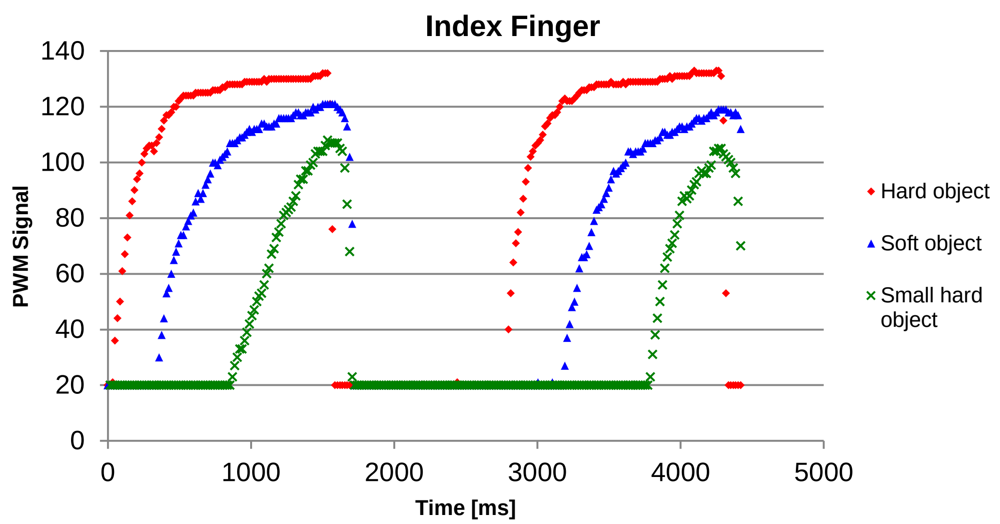

Figure 20. *The amount of vibration in the index finger of the user's glove.*

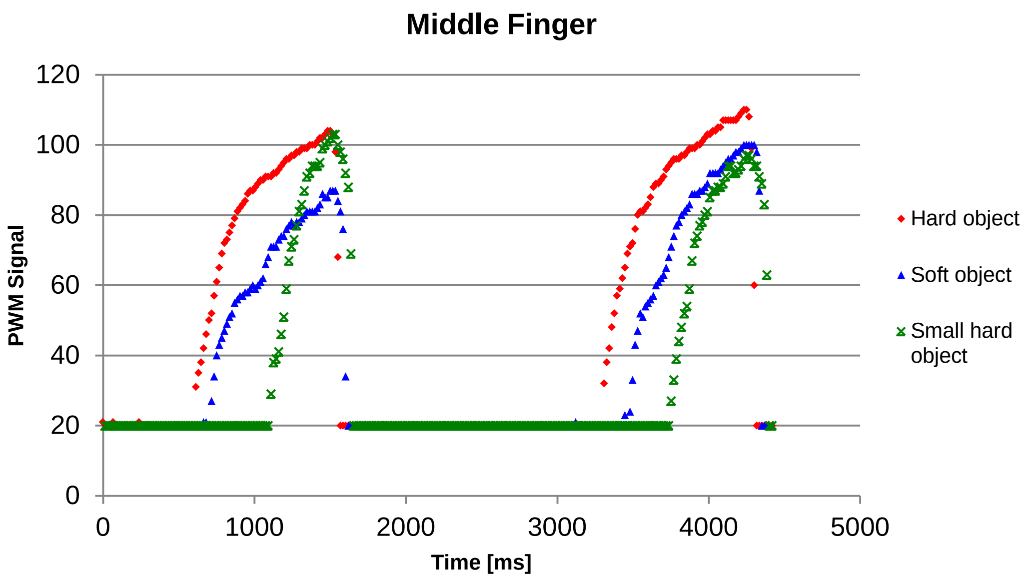

Figure 21. *The amount of vibration in the middle finger of the user's glove.*

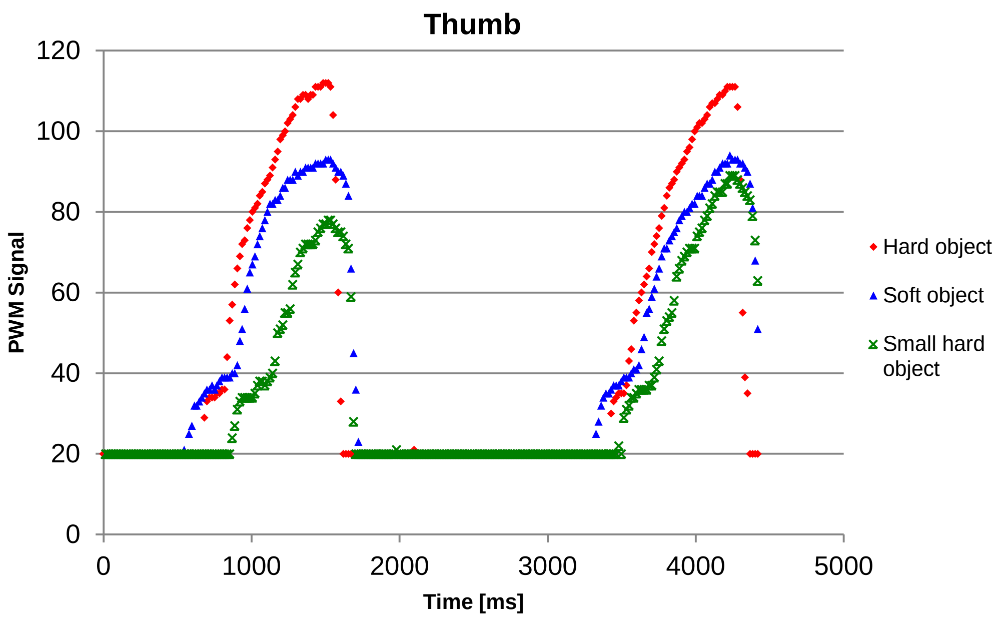

Figure 22. *The amount of vibration in the thumb of the user's glove.*

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4 DISCUSSION AND CONCLUSIONS

The chapter contains discussion about the results presented in the previous chapter and concluding answers to the research questions.

4.1 Discussion

The results from testing user arm tracking and the following robotic arm movement is showing no signs of noise in the form of overturning, which can be a result of rotational momentum or significant vibrations. However, there is a slight delay between the filtered input and the resulting output; this can be explained by the servos' speed and small delay going from one position to another. Although the delay is in milliseconds, which means that the effect of the delay on the overall system is kept at a minimum. From the design, discussions and results, it can be concluded that the delay is caused by the fast motion signal from the user in the frame. This is because of, firstly, the implemented FIR-filter in the form of a moving average requiring a few hundred milliseconds to completely replace all the values in the sampling array. Secondly, the servos can only move at a certain speed which is greatly exceeded by fast movements of a human arm. To include faster movements, a custom-made servo is necessary, although this would not be possible within the given time frame. Therefore, constructing one were excluded. However moving within slower speeds can still provide data to discuss and conclude the stated research question; how well tracking can be done within a set two-dimensional space.

The results from testing the gripping motion and haptic feedback show that the index finger's fluctuation in PWM is higher than the ones for the middle finger and thumb. This probably happens because of the design, as the wire pulling the index finger has a different angle compared to the other two, which makes the pull stronger.

The plots of the "Hard object" and "Soft object" show similarities in their respective derivatives. This means that the increase in vibration is the same whether the object is soft or hard. Compare this with grabbing an object with a human hand, where the counter-pressure exerted on the fingertips increases faster if the object is hard. A person does not need to compare two objects in terms of softness to determine if the object is soft or hard.

For the haptic feedback the plot of the "Hard object" and "Soft object" only have a difference in peak values. This means that the determination of softness necessitates that the user is aware of the size of the gripped object and can compare it to other objects which are of the same size but different softness.

To further test the haptic feedback, the results were compared to a smaller but hard object. The result showed similarity with gripping the big and soft object, particularly with thumb and middle finger. The user may then confuse the small and hard object with the big and soft object if no visual overview is provided.

A small and soft object was not tested as the results produced in previous tests indicated difficulties in separating a small and hard object from a big and soft object. The mentioned tests would therefore not provide new information about the functionality of the haptic feedback.

4.2 Conclusions

Concerning the motion tracking of a human arm, it can be concluded that tracking motion through this method of using ultrasonic sound and geometrical equation systems is indeed possible with satisfactory results. The bigger limitation lies in the maximum speed of the servos. This could prevent the usage in some areas but as the thesis inspired from robot assisted surgery and the focus on actual tracking, the speed range turns out to be unimportant to take into account.

The development of the haptic feedback and the following results showed some difficulties in differentiating soft and hard objects. This can be explained by insensitivity of the sensors. Also the peak difference between red and blue plot interpreters the voltage difference of around 0,4V which with the used vibration motor is difficult for a person to feel. Therefore the conclusion is that with this design and these components it is possible but hard to determine the softness of an object.

5 RECOMMENDATIONS AND FUTURE WORK

The chapter contains recommendations for a possible remake to improve the work and avoid mistakes. It also contains suggestions for future work, if the project would be continued.

5.1 Recommendations

Since the frame solution is a rather unique way of tracking motion, it is recommended to try out every new addition to the function before starting the next one. It is important to prove that every new concept works to see if the idea is possible. This may feel time consuming, but in the end, it is actually the opposite.

After testing new features with cheap and fast methods, it is recommended to start building well-functioning prototypes as early as possible. The extensive construction of this project takes a lot of time and should have started as fast as possible.

The upper servo of the arm needs to be a lot stronger than the lower servo as it will control the vertical lifting motion. It is recommended to calculate how strong the different servos need to be, as it can reduce the costs.

When using the frame as a tracking method, it is highly recommended to create a construction where the blocks in the frame are unable to tilt. Tilting of the blocks makes the sound waves move in the wrong direction before returning to the ultrasonic sensors.

5.2 Future work

Many aspects of the demonstrator can be improved and extended.

Implementation of a wrist motion would heavily improve the demonstrator, as the robotic hand would be more flexible and able to reach objects better. This can either be done mechanically, using a four-bar linkage for keeping the robotic hand horizontal regardless of the robotic arm's motion. It can also be done through tracking of the user's wrist motion.

A wireless transmission between the frame and the robotic arm would increase the areas of application for the demonstrator, for example transmission with WiFi or Bluetooth. Then the user and the robotic arm can locate in different areas of the world which would be efficient in controlling from far distances.

The upper servo on the robotic arm can be placed on the support console instead of the top of the vertical arm. As a result, the motion from the servo can be transferred through a driving belt. This would make the robotic arm construction steadier as its mass centre is lowered.

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APPENDIX A: RESULT FROM FIR-FILTER

This appendix contains diagrams, figure 1 and 2 show the result when using the sliding-mean-filter on the sampled values from the ultra-sonic sensors while drawing a circle within the frame. The filtered signal is sent to the servos as input signal. The sample frequency is set to 200Hz (one sample/5 ms). The window contained the last 50 values to calculate an average distance.

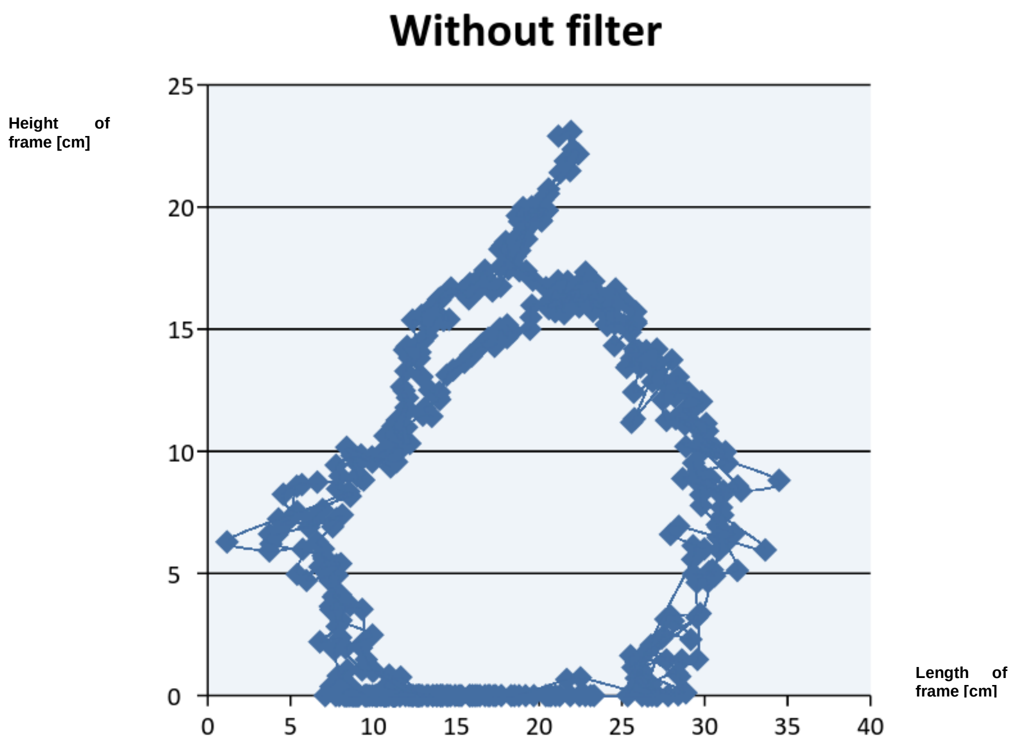

Figure 1. *The x-and y-coordinates for the unfiltered signal.*

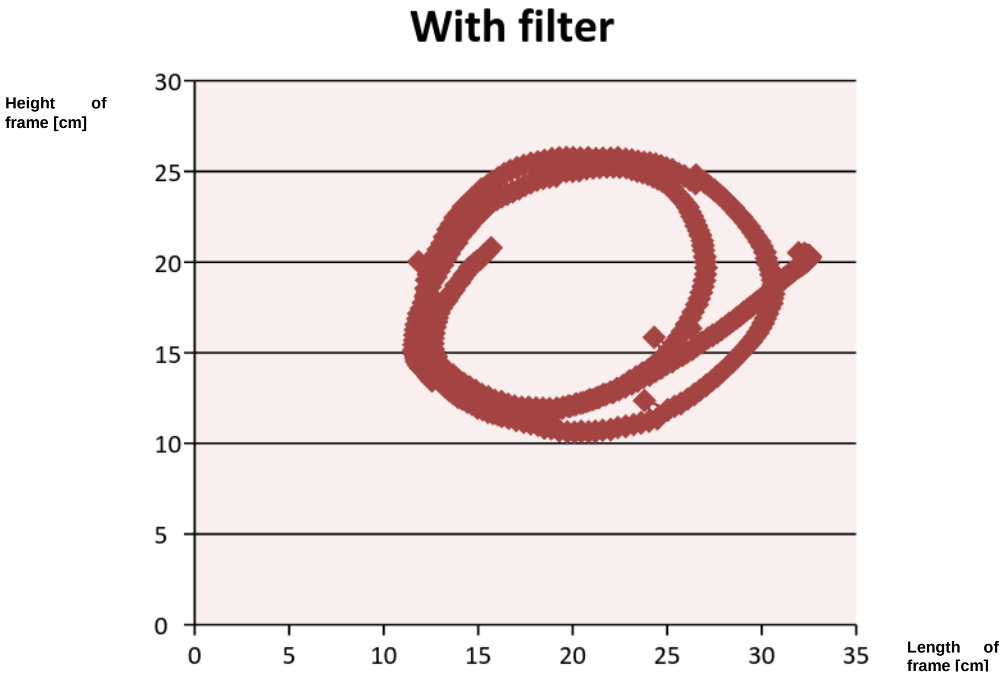

Figure 2. *The x-and y-coordinates for a moving average-filter using the 50 last values.*

APPENDIX B: FLOWCHARTS

Figure 1 shows the flowchart of the software without the FIR-filter implemented.

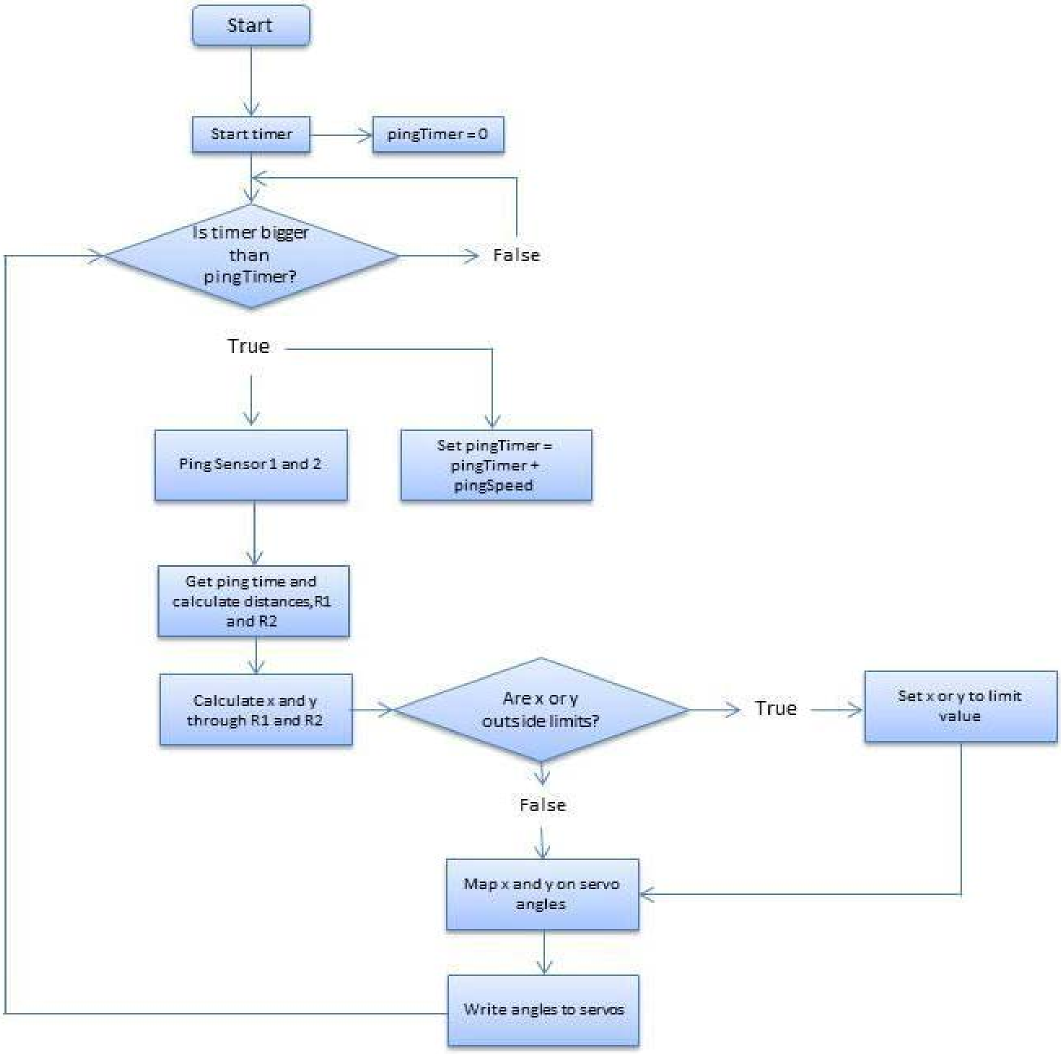

Figure 1. *A flowchart of the software that gives an unfiltered signal.*

Figure 2 shows the flowchart of the software with the FIR-filter implemented.

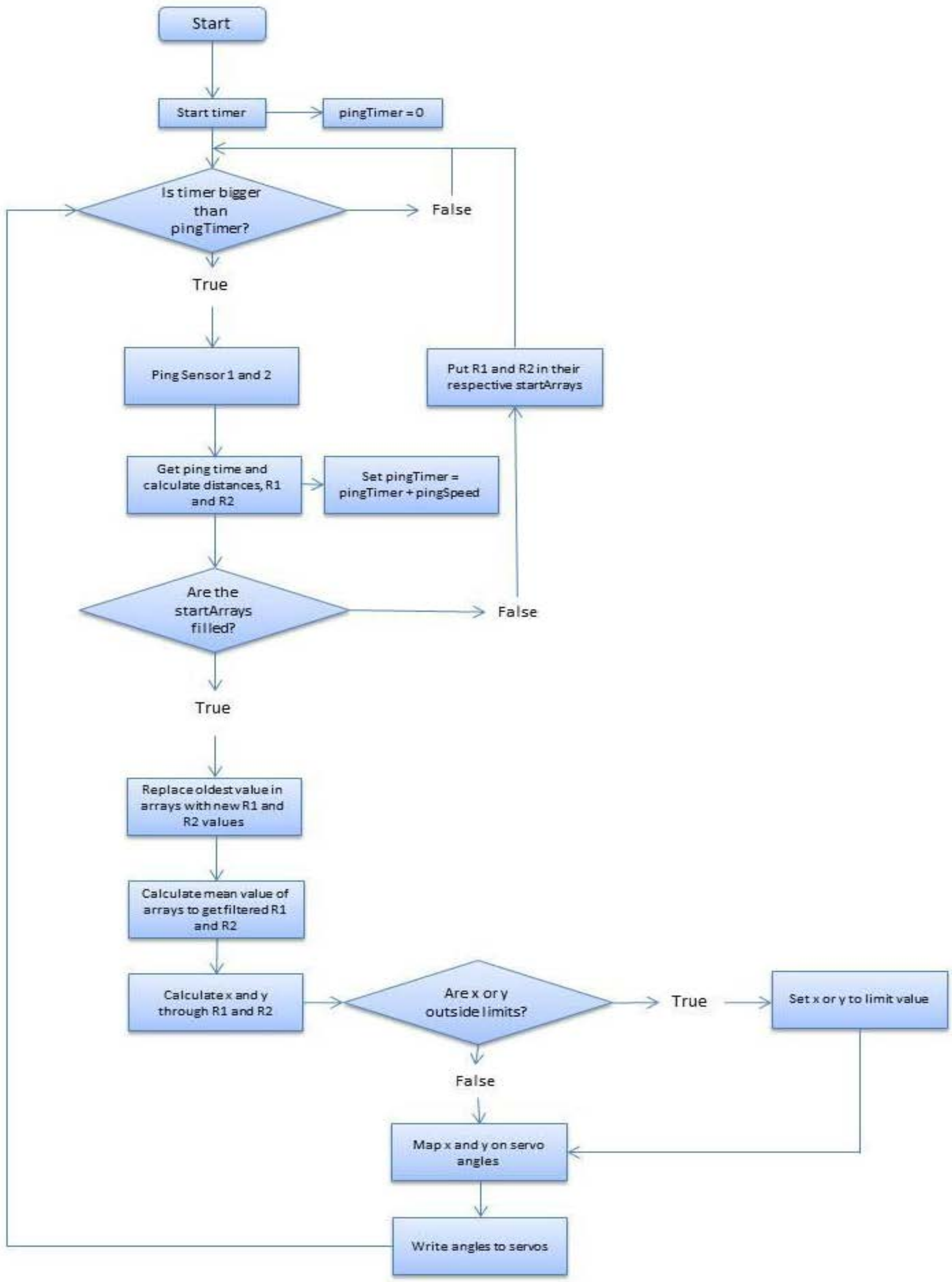

Figure 2. *A flowchart of the software that gives a filtered signal through a FIR-filter (moving average).*

APPENDIX C: CONSTRUCTION OF THE FRAME

When calculating the length of the wire and the height of the tracks for the blocks, two different extreme situations were considered. The first situation is shown in figure 1.

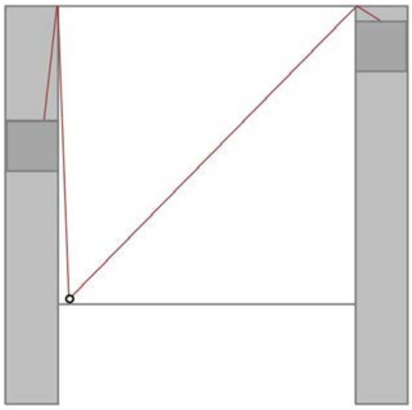

Figure 1. *The frame when the user places its hand in the lower left corner of the frame, visualized as a black ring.*

The wire has to be longer than the hypotenuse of the triangle created in the frame. The hypotenuse is calculated using the Pythagorean Theorem;

$$a^2 + b^2 = c^2$$

where a and b corresponds to the sides of the triangle and c corresponds to the hypotenuse. The hypotenuse of the triangle with the sides 400x400 mm is rounded up to 570 mm. The wire therefore has to be at least 1140 mm long.

The other situation is shown in figure 2.

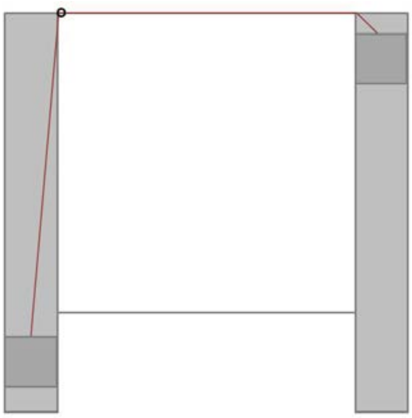

Figure 2. *The frame when the user places its hand in the upper left corner of the frame, visualised as a black ring. The left block is located below the frame.*

Since the length of the wire exceeds the length of the frame, the frame must be raised from the ground. The amount is dependable on the length of the wire. The length of the wire is 1400 mm and the frame is raised 300 mm above the ground.

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