Hovedoppgave

NTNU
Norges teknisk-naturvitenskapelige universitet

Ingebrigt Stamnes Reinsborg

Improving design of robot for extracting dead fish roe

Hovedoppgave i Kybernetikk og Robotikk, 5-årig master
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TTK4900 Masters Thesis: Improving design of robot for extracting dead fish roe

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Abstract

The cultivation of fish roe is an essential part of raising fish for food. However, in this phase the roe is vulnerable to infestations of fresh water fungus that will establish itself on dead biological material and then spread to healthy roe. It is therefore essential to remove as much of the dead roe as possible to prevent further losses. At Norwegian Fish Farms Tydal, there are several tanks used for roe hatcheries, which must be manually cleaned of dead roe by human workers. It has been in the interest of the company and the workers to create an autonomous device that will perform this work for them. This masters thesis details the work done to accomplish this goal by designing and writing code for controlling a parallel manipulator-type mechanism that will use a stereo computer vision-based technique to identify and localize dead roe for extraction. During testing it was found that the parallel manipulator robot can easily be controlled by a computer running the developed python code and has a high level of accuracy and repeatability. However it does not yet have a sufficient method for calculating the correct actuator lengths to reach the desired endpoints. Implementation of the stereo vision module remains to be performed because of delivery issues with the stereo camera hardware. An alternative test environment consisting of a square bucket, with a 30x30cm copy of the roe tank inlay pattern structure and using white plastic pellets, was found to function well with a previously made computer vision model, but may need adjustments if used with stereo camera imaging.

Preface

So this is it. As of writing this I'm only days away from finalizing 18 years of education. I knew early on that if I were to have a chance at a good life and escape the slums (having an ordinary job) I'd have to do well in school and study to become an 'engineer'. Now I'm here, only days away from finishing, and finally realizing my dream of studying literature instead.

Unlike my peers, I have decided not to use Grammarly, as I am under dire financial stress. So if you spot any grammatical errors, no you didn't.

This masters thesis would not have been possible without great help and support from my supervisor, Morten Omholt Alver. I would also like to direct a great thanks my family, for being supportive in trying times and encouraging me to keep going, even though I wanted to do everything else. Lastly, I would like to direct a huge thanks to all the wonderful people I have had the pleasure of meeting during my time at NTNU. Words cannot describe how important you have all been in my life, I have changed so much, grown to unexpected heights and learned a library worth of stuff that will follow me for the rest of my life. The curriculum of the courses is but a drop, compared to the ocean you have taught me.

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Chapter 1

Introduction

The aquaculture industry is a growing source of food for humanity and is expected to grow further in the years to come [1]. Towards 2050, the world population is expected to grow to around 9.6 billion, and marine sources of food will be essential to fill the nutritional needs of the population, since fish and other aquatic sources of food are extremely rich in essential vitamins, protein and fat, while also being far easier and less demanding to produce than land based meat. Aquaculture in and of itself has existed for some thousands of years [2], however, modern aquaculture as an industry is still relatively young and is in need of new technology to tackle central challenges. This is why, in recent years, the need for engineers and developers has become more evident than ever before. If the aquaculture industry is to be a viable part of future food production, then steps towards better animal welfare, less climate impact and improved efficiency has to be made.

In recent years, so called RAS-facilities (Recirculating Aquaculture System) has gained more attention due to the relative ease of controlling environmental parameters, low water consumption, lowered risk of spread of disease and less escapes due to the tanks not being in direct contact with sea water. The drawback being that they require land surface area and have a higher production cost, while per tank is far more shallow and can hold less fish than a normal sea based fish cage. However, built in old industrial areas and near a source of water, they can be a sustainable addition to aquaculture production. Certain newer RAS-facilities also use extremely low amounts of water, so that they could potentially be placed in more arid places of the world. [3]

These RAS-facilities also open up for better ways to produce fresh water species of fish, rather than rearing them in small ponds in relatively uncontrolled conditions. Species such as trout, char, carps or catfish are typical fish in freshwater aquaculture, but crustaceans and molluscs are also of interest. One such inland freshwater aquaculture facility in Norway is *Norwegian Fish Farms Tydal*, which specialize in production of arctic char. The facility is as of writing this still a small scale production facility, but the intention is to increase both size and capacity [4]. To accomplish this, several technical challenges has to be solved.

One of these challenges is in the developmental phase of the char roe where they have been treated with cold water, so called *shocking*, and is awaiting to be hatched. During this phase, the roe is very sensitive and must be handled with care. The problem arises when some of these roe become non-viable or dies, they will then become growth media for a type of fresh water fungus called Saprolegnia [5], which will grow mycelium that attacks healthy roe. If the dead biological matter is not removed, then entire batches of roe may be lost. It is therefore necessary to continuously remove dead roe and other biomatter throughout the hatching process.

This work is in present day normally done by people who do manual picking with pincers or plastic tubes, sometimes also using formalin to combat the Saprolegnia. This is a very monotonous, and by use of formalin, also dangerous work assignment that last for several hours each day, so the industry is motivated to acquire an autonomous solution for this problem.

This conceptual autonomous roe-picker must be accurate, careful to not damage healthy roe and must be able to perform picking in a satisfying rate with few to no operational stops. To achieve this goal, a general idea of a robot using computer vision has been developed as part of two separate masters assignments by Marius Tjore [6] and Edda Solem [7] and then as a project assignment by Ingebrigt Reinsborg [8].

The current plans for the robotic setup is having a platform connected to three linear actuators that by varying their lengths will vary the angle of the plate, and a fourth linear actuator orthogonaly mounted in the plate that will extend down to the roe and perform picking by suction through a tube. This mechanism will hang from a variable length arm placed on a central axis rod that can rotate, so that the mechanism can be placed above any position in the roe hatching tank. To detect and localize dead roe, a stereo computer vision system has been proposed.

The goal of this masters assignment is to establish a working stereo computer vision system that accurately identifies and locates dead roe, and to finalize a robotic mechanism that can extract the roe based on location data from the stereo vision system.

Chapter 2

Theory

This project will require some background theory in computer vision and stereo vision positioning, since the intention is to use these techniques to accurately find the position of the dead roe. Then, using these positions, a robot based on a parallel manipulator mechanism will be used to perform the extraction. To be able to successfully maneuver the robot, the kinematics will have to be defined.

2.1 Stereo Computer Vision

2.1.1 Computer Vision and Convolutional Neural Networks

The idea behind computer vision is to have a computer be able to analyze a given picture and find information of interest automatically. There are several different ways to accomplish this, and computer vision as a field of research is multidisciplinary.

A basis for computer vision is machine learning on sets of images that contain annotated data about what information a neural net is supposed to identify. A type of neural net called a Convolutional Neural Net (CNN) runs convolutions on labels in the image to produce predictions and then checks the accuracy of these predictions over several iterations until it has *learned* what to look for. A convolution is a mathematical operation on two functions that produce a third that tells the user how the shape of the first is altered by the the second. In linear algebra and particularly the field of computer vision, the centre element of a *kernel* is convoluted over each or some of the pixels in an image [1], such that each overlapping element in the two matrices [2] produces a product by multiplication that is then added together with all others and put as a value in a new matrix or image, so called pooling[3]. A convolution can be thought of as correlation, done pixel by pixel it is sometimes called a sliding window approach. The new pooled

[1] Depending on level of stride

[2] Pictures and kernels are matrices

[3] Sometimes only the greatest value is pooled, this is called max pooling, there also other types of pooling, they all downsample input images.

matrix can then run through more of these kernels and convolutions, or *convolutional layers*, to detect more and more abstract features. Typically, the CNN can start with simple geometries, such as vertical or horizontal lines (Sobel kernel), and then progress further to shapes, circles, mammal, quadrupeds, horse-shaped animal and finally zebra, as an example. These convolutional layers and kernels are developed automatically by the CNN-algorithms and this process is a part of how the model *learns*.

To illustrate how these convolutions affect images, an image of the authors cat *Gordon* has been performed several different convolutions on.

Figure 2.1: Original Image

1. Sobel kernel for amplifying vertical lines.

$$\begin{bmatrix} -1 & 0 & 1 \\ -2 & 0 & 2 \\ -1 & 0 & 1 \end{bmatrix} \tag{2.1}$$

Figure 2.2: Image of Gordon convoluted with a vertical Sobel kernel

2. Sobel kernel for amplifying horizontal lines.

$$\begin{bmatrix} 1 & 2 & 1 \\ 0 & 0 & 0 \\ -1 & -2 & -1 \end{bmatrix} \tag{2.2}$$

Figure 2.3: Image of Gordon convoluted with a horizontal Sobel kernel

3. Diagonal kernel

$$\begin{bmatrix} -2 & -1 & 0 \\ -1 & 0 & 1 \\ 0 & 1 & 2 \end{bmatrix} \tag{2.3}$$

Figure 2.4: Image of Gordon convoluted with a diagonal kernel

4. Sharpen kernel

$$\begin{bmatrix} -3 & -1 & 0 & -1 & -3 \\ -1 & 1 & 3 & 1 & -1 \\ 0 & 3 & 5 & 3 & 0 \\ -1 & 1 & 3 & 1 & -1 \\ -3 & -1 & 0 & -1 & -3 \end{bmatrix} \tag{2.4}$$

Figure 2.5: Image of Gordon convoluted with a sharpen kernel

When these convolutional layers are combined, the neural net can extract more and more abstract features. For example, a combination of several convolutions of straight line-features, could be used to determine if there is fur in the picture, and then highlight this for further layers in a CNN that is supposed to identify cats.

As the network progresses towards the output sequence, it is typical to see a global average pooling where the output feature map is pooled to a single value parameter which is then input to one or several fully connected layers. In these layers, each input is mapped to every output with a learnable weighting. The last layer usually has as many nodes as there are potential classes to be identified. [9]

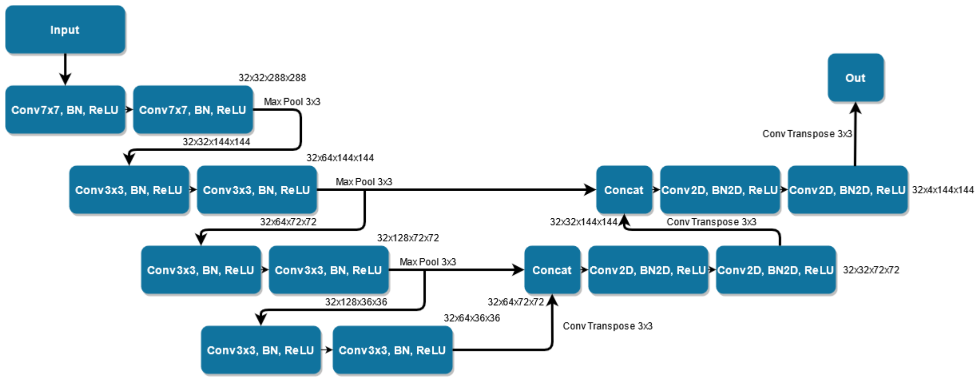

Figure 2.6: An example of how a CNN can be structured. Taken from the authors main group project in TDT4265 Computer Vision and Deep Learning

Marius Tjores work is based on such a technique. The data used for training the CNN consists of large images taken above the hatching tanks, were the optimal training input was determined to be 10x10 pixel segmented images of the dead roe. The structure of the network is based on VGGNet [10] which is a common network architecture, typically having 16 or 19 convolutional layers and relatively small convolutional filters. The model created by Marius Tjore is intended to be tested with a stereo vision camera solution and an artificial environment that emulates the actual roe inlay.

2.1.2 Stereo Vision

A common problem in the field of computer vision and robotics is to be able to determine the location of an object in the picture. Typically, this can be used to allow robots to know where an object is in relation to its own point of view, so that the robot can successfully interact with it, or in some cases avoid it. It is also possible for the robot to use location data on several different objects in its field of view to estimate position and provide navigational input, as an alternative to using e.g. an IMU or radar. In the case of this project, it is important to know the exact location of the dead roe, so that an extraction mechanism can reach it without touching the healthy roe or missing the target.

A common way to solve this problem, is to have two or more cameras with a known location and geometry that have the object to be localized in their field of view. By comparing the two images it is possible to find the position of the object bry triangulation and stereo matching. This is the same as what is found in nature, having two eyes is for the purpose of depth perception or seeing distances.

Some considerations are needed when placing the cameras. Placing the cameras in very diverging angles to each other will provide a high accuracy in placing common points in both images, however it will also mean more points will only be visible for one of the cameras. If using roe as an example, there might be dead roe lying near a small pile of healthy roe that might obstruct the view from one of the cameras. Placing the cameras at a small angle from each other will ensure a larger percentage of roe is seen by both cameras and can therefore be localized, however this provides less accuracy in terms of the mathematical 3D reconstruction done in software.

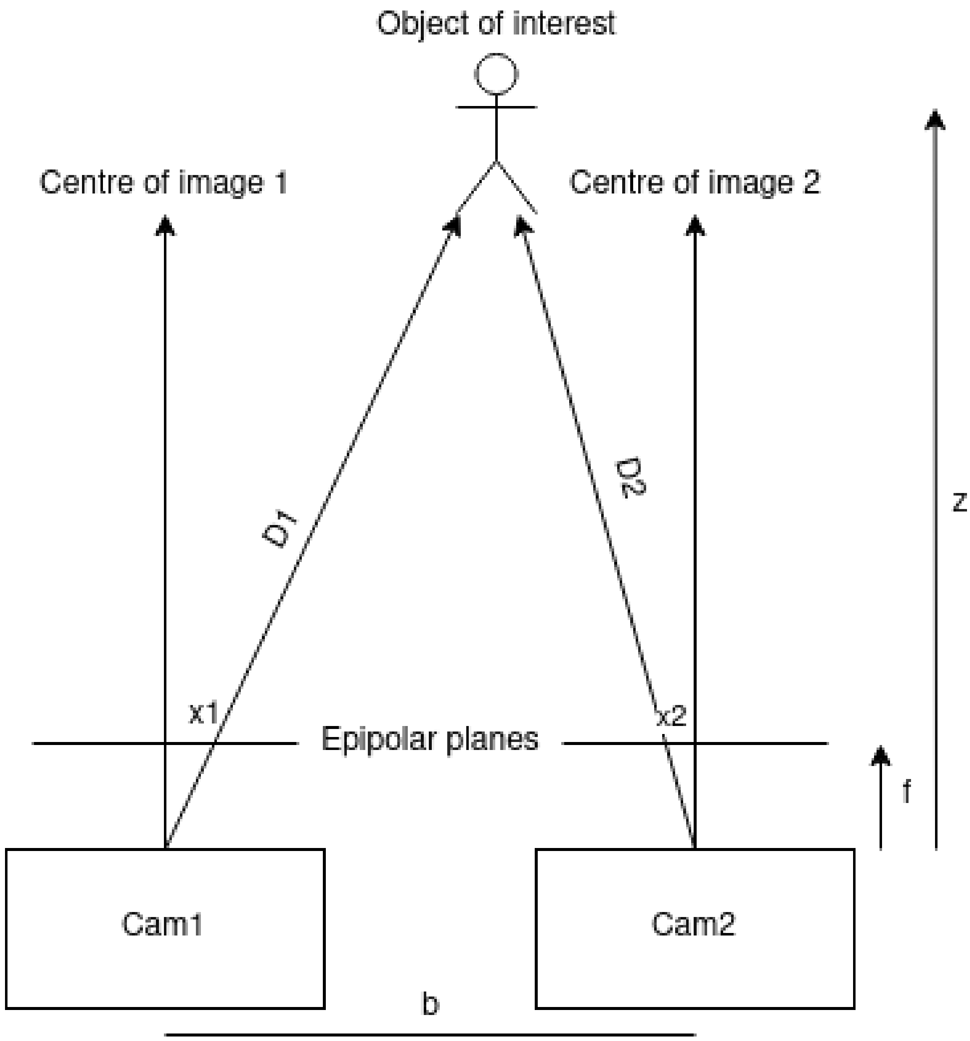

Figure 2.7: A sketch of a stereo vision setup

To estimate the depth from the camera input, the objects of interest must be mapped in both images to an epipolar plane and corresponded between each other. Then the disparity (d) between the placement of the object is found by calculating:

$$d = x1 - x2 \tag{2.5}$$

Then the depth (z) can be calculated using the known geometry of the camera setup and the epipolar planes [11]:

$$z = (f * b)/d \tag{2.6}$$

This data is then combined with XY-coordinates to give full 3D information about localization of objects.

2.2 Stewart Platform/Parallel Manipulator

2.2.1 Kinematics

A Stewart platform is typically made up of six linear actuators connected between two plates, that can change their lengths to produce different translations between the two plates. Such a platform can come in many forms, such as 6-6, where six linear actuators is connected to six points on both platforms, or 6-3, where one platform has six points of contact, while two and two are connected to three points in the other. There are many configurations that will give different qualities [12].

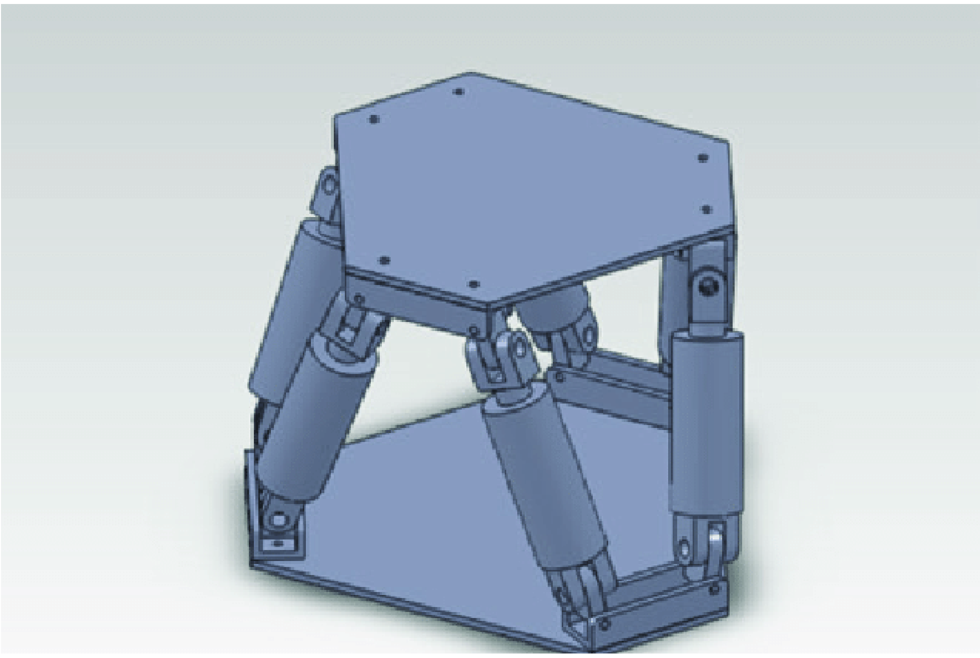

Figure 2.8: An example of a 3-3 "Stewart Platform" mechanism. Picture taken from [13]

Generalized, these types of mechanisms are called parallel manipulators, and are characterized by having two or multiple movable joints connected between two 'nodes' in the mechanism. This type of robot is generally thought to be fast, rigid and accurate compared to serial manipulators, which would make them quite relevant for this project, as the need for precision is high.

The Stewart platform generally has six degrees of freedom (6-DOF), the plate can be moved in XYZ-directions and can also be rotated along all axis. If for some reason the user would require less mobility and simpler design with a 3-DOF mechanism, it is also possible having three linear actuators connected between the plates, meaning it can move in Z-direction and rotate around the X- and Y-axis (roll and pitch).

Below is a detailed overview of the kinematics of this type of mechanism has been provided, which could be adapted for use in this project.

The universal joints of the base and platform can be represented in coordinate systems centered around each plane:

Upper base:

$$^{B}b_1 = [r, 0, 0]^T \tag{2.7a}$$

$$^{B}b_2 = [-\frac{1}{2}r, \sqrt{\frac{3}{2}}r, 0]^T \tag{2.7b}$$

$$^{B}b_3 = [-\frac{1}{2}r, -\sqrt{\frac{3}{2}}r, 0]^T \tag{2.7c}$$

Platform:

$$^{P}p_1 = [R, 0, 0]^T \tag{2.8a}$$

$$^{P}p_2 = [-\frac{1}{2}R, \sqrt{\frac{3}{2}}R, 0]^T \tag{2.8b}$$

$$^{P}p_3 = [-\frac{1}{2}R, -\sqrt{\frac{3}{2}}R, 0]^T \tag{2.8c}$$

Where r and R are the radii of the base and platform respectively.
Since rotation around the z-axis or yaw is not considered as an ability of this system, we can consider just pitch and roll (rotation around x- and y-axis). Intuitively, it is possible to see that no configuration of the linear actuators will facilitate a rotation around the z-axis.

In the thesis of D. K. Brecht [14], it is provided a general rotation matrix $^{P}R_B$ that is to be used in a transformation matrix $^{B}T_B$ that relates from the base reference frame to platform reference frame.

$$^{P}R_B = \begin{bmatrix} \cos\theta\cos\phi & \cos\theta\sin\phi & -\sin\theta \\ \sin\psi\sin\theta\cos\phi - \cos\psi\sin\phi & \sin\psi\sin\theta\sin\phi - \cos\psi\cos\phi & \cos\theta\sin\psi \\ \cos\psi\sin\theta\cos\phi - \sin\psi\sin\phi & \cos\psi\sin\theta\sin\phi - \sin\psi\cos\phi & \cos\theta\cos\psi \end{bmatrix} \tag{2.9}$$

$$^{B}T_B = \begin{bmatrix} ^{P}R_B & q \\ 0 & 1 \end{bmatrix} \tag{2.10}$$

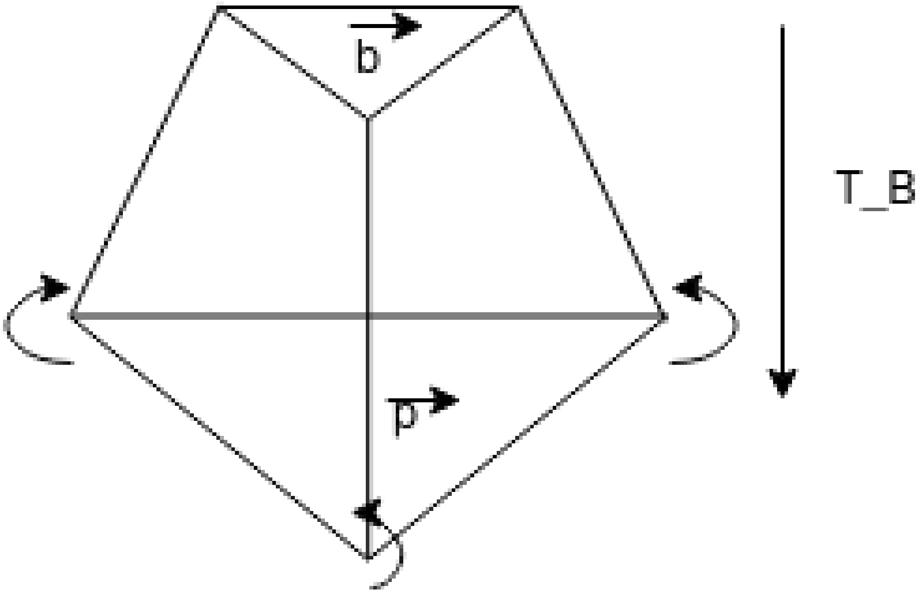

Figure 2.9: Illustration of frames

The q-vector here is the vector from origin in base frame to origin in platform frame. If the linear actuators are extended to equal lengths, then this vector only has a negative value corresponding to height since the origins are directly on top of each other. While in different configurations, this vector will have non-zero values for X and Y as well.

By using:

$$_P \begin{bmatrix} P_i x \\ P_i y \\ P_i z \\ 1 \end{bmatrix} =^B T_B^P * \begin{bmatrix} p_i x \\ p_i y \\ p_i z \\ 1 \end{bmatrix} \tag{2.11}$$

One can translate from the platform reference frame to the base platform frame. By using the difference between the corresponding coordinates of the universal joints, one can calculate the euclidean distance between them, giving us the lengths of each motor.

$$l_1 = \sqrt{(P_{1x} - b_{1x})^2 + (P_{1y} - b_{1y})^2 + (P_{1z} - b_{1z})^2} \tag{2.12a}$$

$$l_1 = \sqrt{(P_{2x} - b_{2x})^2 + (P_{2y} - b_{2y})^2 + (P_{2z} - b_{2z})^2} \tag{2.12b}$$

$$l_1 = \sqrt{(P_{3x} - b_{3x})^2 + (P_{3y} - b_{3y})^2 + (P_{3z} - b_{3z})^2} \tag{2.12c}$$

This should, according to D. K. Brecht [14] in his thesis, be enough to determine the required length of each actuator as long as we are provided with the desired angles and position of the platform origin in base reference frame.

So far this section detailing the kinematics of angle control of the platform has been taken from the project assignment report and adapted for use here [8].

If there is a size difference between the plates, this will lead to a gearing of the rotation between them. This can be used to adjust the rate of angular change if there is need for more accuracy at the cost of speed, or more speed at the cost of accuracy. For example, if you need high accuracy in controlling the angle of the plate in question, it would have to be bigger than the other. An intuitive way of imagining this is moving a lever by gripping and pulling a constant distance, close to the axis of rotation or further out. If gripped closely, the angle of the lever changes a lot; if the grip is further out, the angle changes less. If one analyzes the system consisting of a single linear actuator connected to a rotating plate, it is easy to see that the movement of the linear actuator will correspond to an arclength of movement around the axis of rotation, which divided by the distance to this axis will correspond to a change in angle. Increased radius means less angular change.

$$\Delta angle = \frac{\Delta arclength}{radius} \tag{2.13}$$

2.2.2 Finding correct angles

Before the actuator lengths can be calculated it is necessary to know what angle the platform has to achieve. This problem requires spatial information about where the roe is in relation to the robot, which will be obtained by the stereo vision module described earlier. Once a roe position is obtained in relation to a predefined origin of the robot, length can be obtained by using Pythagorean length calculation:

$$l = \sqrt{x^2 + y^2 + z^2} \tag{2.14}$$

The angles (pitch and roll) can be found by looking at the differences dx, dy and dz from origin to the roe position and calculating the angles by trigonometry [15]:

$$pitch = \arctan(\frac{dy}{\sqrt{dz^2 + dx^2}}) \tag{2.15}$$

$$roll = \arctan(\frac{dz}{dx}) \tag{2.16}$$

This is then used to find the actuator lengths described in the kinematics of the parallel manipulator.

Chapter 3

Materials

3.1 Cylinder Robot

In a previous masters assignment, a cylinder robot has been designed and produced. The general idea was to make a robot that could move an arm across the entire area of the circular substrate inlay and move an extraction tube straight down to the dead roe. The construction consists of a crossbeam where a DC stepper-motor has been placed at the centre, rotating a rod going straight down. Another crossbeam has been horizontally mounted on the rod, and the extraction tube with mechanics for moving in Z-direction can move across the length of this crossbeam. The volume defined by all reachable points of the extraction tube is defined as a cylinder.

Figure 3.1: Illustration of the cylinder robot from top

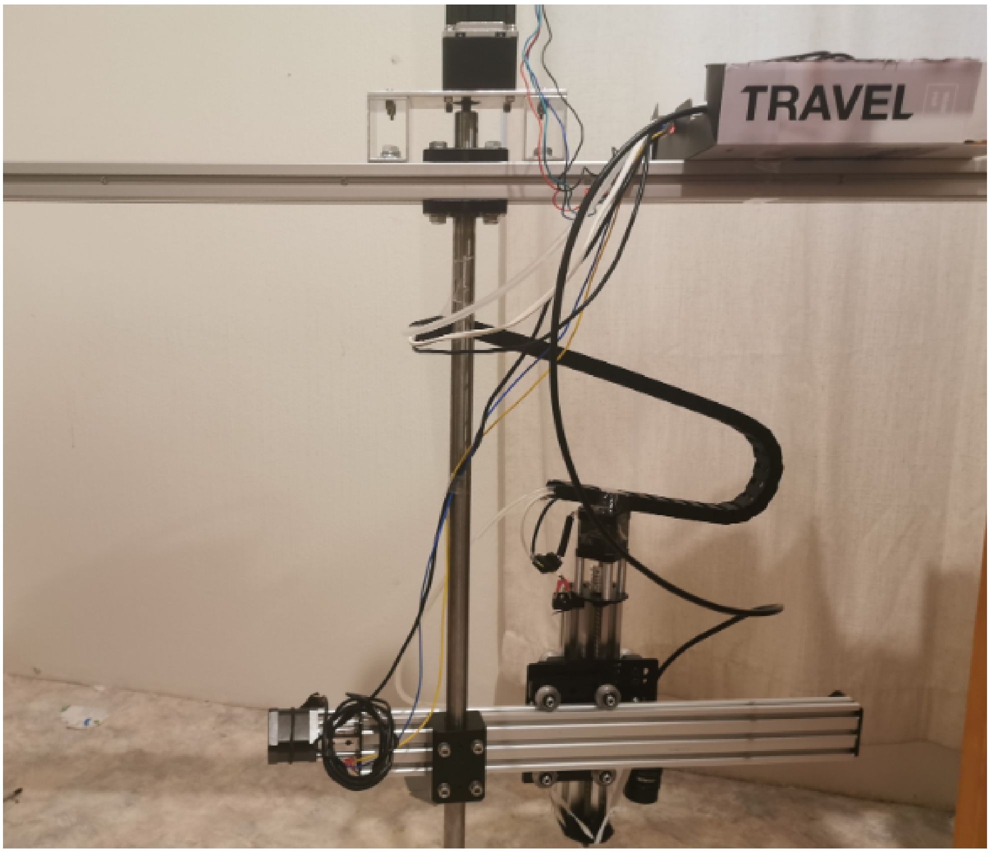

Figure 3.2: A picture of the cylinder robot

Testing done by Edda Solem [7] showed that the robot performed well, but did not quite have the accuracy to be a robust solution. A central weakness in the design is that the DC stepper-motor controlling the central axis has to be extremely accurate to provide the required accuracy when the extraction tube is at the outer edge of the inlay.

3.2 Parallel manipulator mechanism

3.2.1 Geometry and construction

This section is taken from the project assignment.

The final idea was to use a mechanism similar to a Stewart platform. For our case, it is not necessary with 6-DOF, only pitch, roll and extractor length need to be controlled in order to reach the roe. Reducing the amount of linear actuators to three, spaced 120 degrees apart will provide these 3-DOF that are needed. However, although they provide control over height (extension and retraction of all actuators), it will be better to also have a fourth linear actuator going orthogonally through the centre of the roll-pitch-controlled platform to be aimed towards the dead roe, allowing it to extend and extract. This allows the three platform-connected actuators to be solely focused on correct roll and pitch, and the fourth for radial length. This technically gives the mechanism a 4-DOF functionality, but for simplification one could design a control algorithm with a constraint such that the height given by the three platform-connected actuators never diverge from a set value.

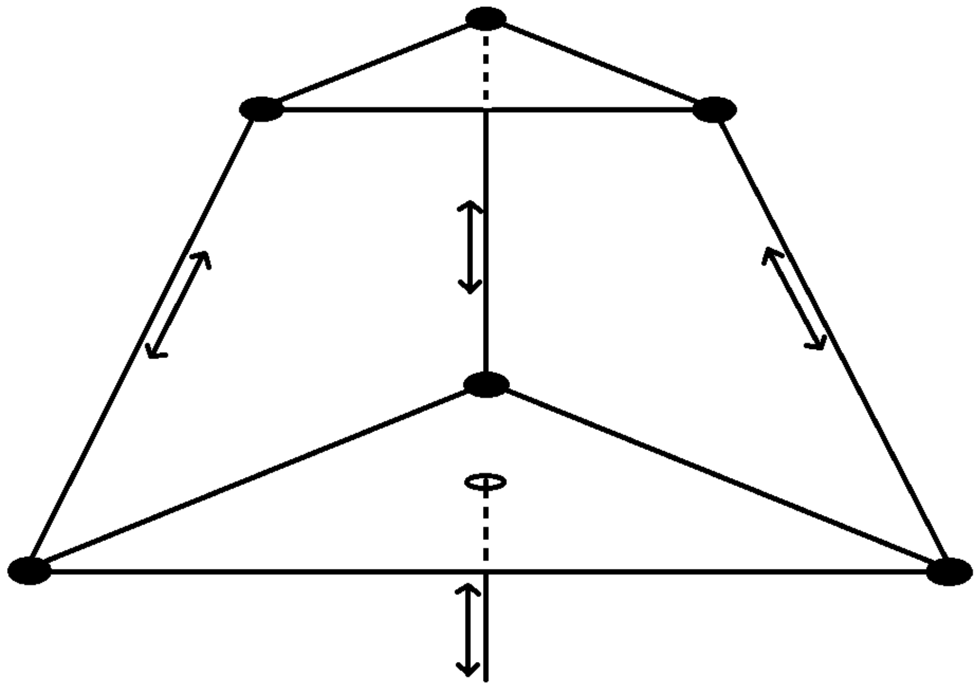

Figure 3.3: Sketch of the Stewart Platform-Inspired Mechanism

By adjusting the size of the base compared to the controlled platform, it is possible to adjust the level of angular change per change in length for the linear actuators. If the base is smaller than the platform, any movement by the linear actuators will give small angle changes. If the base is bigger, the angle of the platform will change more per movement of the linear actuators. Since this task requires high accuracy, it is appropriate to set the size of the base smaller than the platform.

The base and platform plates were cut from steel plates in roughly equilateral triangular shapes. The platform was made to be approximately three times the size of the base and given several sets of mounting holes for the universal joints connecting to the linear actuators, which will allow for further testing to determine the most fitting size ratio between the base and platform. The SP was built by ITKs Mechanical Workshop.

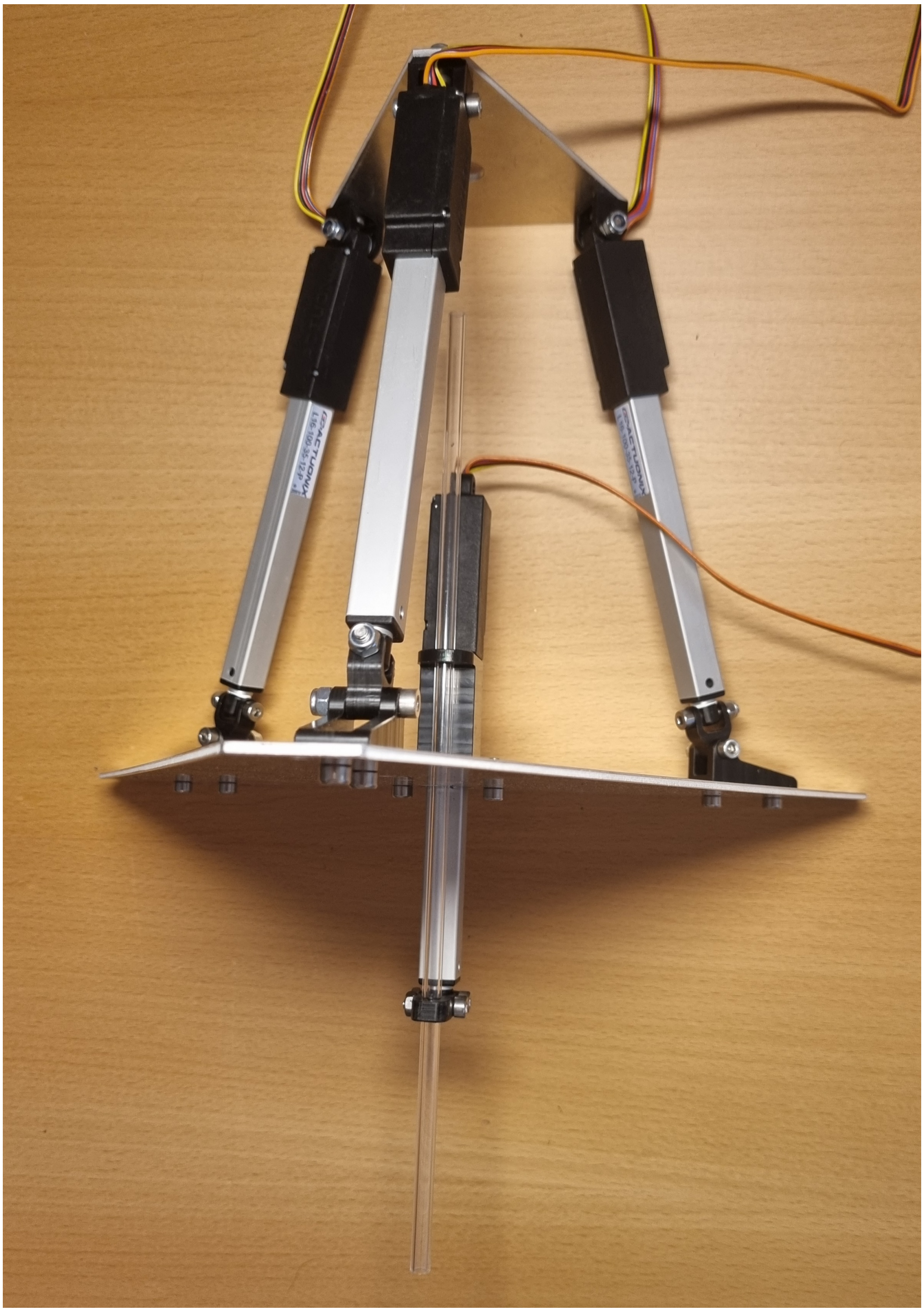

Figure 3.4: The Stewart Platform-Inspired Mechanism

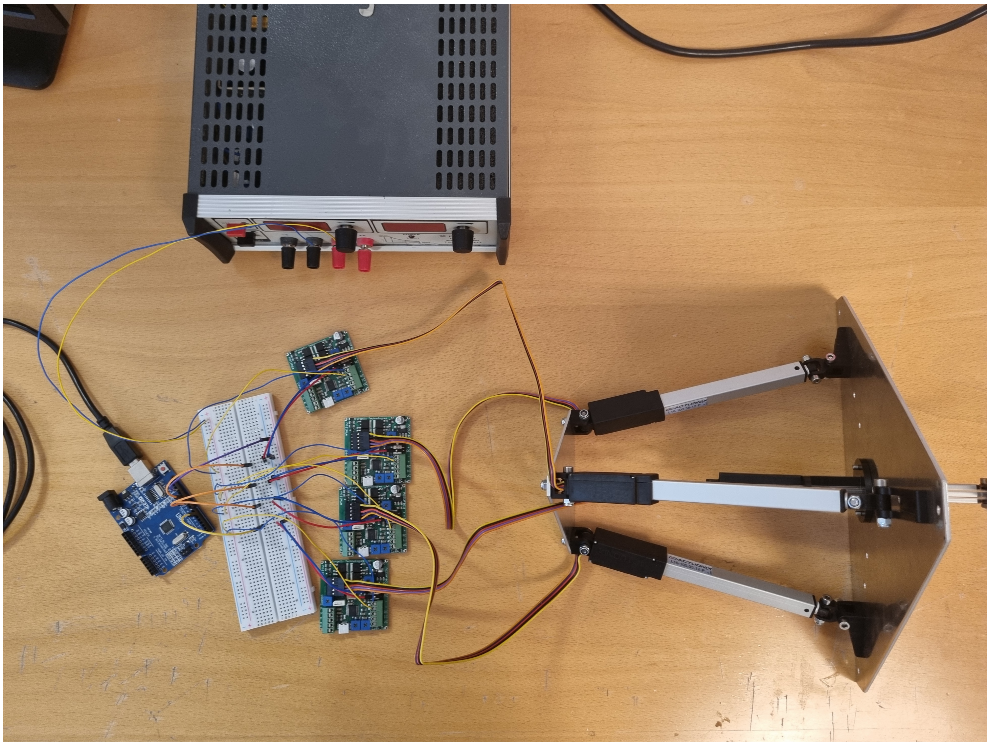

Figure 3.5: The electronic setup

A similar robot has been considered for use in pipeline restoration and has been explained thoroughly in the masters thesis of Derek K. Brecht at The University of Western Ontario [12]. The kinematics of this robot are detailed in 2.

This following bit is not from the project assignment.

Once angular control of the platform has been established, the next step is to implement another translation for the fourth actuator that will extend the extraction tube to the dead roe. This poses a challenge since the three actuators controlling the angle would also affect the height, and therefore distance to the dead roe, meaning there would be several solutions for calculating a set of actuator lengths to reach the roe. This could also be grounds for posing an optimization problem for finding the most energy effective solutions, but will add complexity that can not, for practical reasons, be considered for this assignment. To simplify, it is proposed to add constraints to the solutions so that the height of the centre of the platform is a constant. Intuitively, this constraint can be defined as the average length of the actuators having to be constant. In the 2D case, if a beam is balanced on two legs, the height of the centre of this beam will be the average of the height of the legs. The same can be seen for the height of the angled platform, if one views the legs pairwise. It is important to note that this is to be considered an assumption made by the author, there might be unconsidered reasons as to why the 2D case would not translate to the 3D case, but nevertheless, this will most likely not affect movements within small angles of the platform.

By assuming that the centre of the platform is stationary, the fourth actuator will only correlate to a change in length in the Z-axis in the reference frame of the platform. By construction, this transformation matrix will be:

$$T_{la4} = \begin{bmatrix} I & \begin{bmatrix} 0 \\ 0 \\ \delta L \end{bmatrix} \\ 0 & 1 \end{bmatrix} \tag{3.1}$$

3.2.2 Actuonix Linear Actuators

The linear actuators used in this project are of the type *Actuonix Linear Actuator L16-100* from Actuonix, which have a stroke length of 100mm, variable speed and several different ways of giving input for control. To control these, *Linear Actuator Control*-boards have been procured. These boards provide a simple way to ensure proper positioning and control by transmitting a PWM-signal from a microcontroller or computer. [16]

3.2.3 Arduino UNO

The microcontroller used in this project is a standard Arduino UNO [17]. This provides an easy way of creating a driver for the robot that accepts UART messages [18] consisting of the four values for the actuator lengths.

3.3 Hatching environment from NFFT

To provide an adequate environment for testing, Stian Aspaas at Norwegian Fish Farms Tydal has provided a hatching tank with plastic inlays and substrate. The tank is approximately 1x1x0.5 m^3 and the substrate covers a circle-shaped section of the tank. The substrate where the roe sits is a perforated pattern with oval-rectangular holes, so that the roe do not fall through, but once they hatch, the fry can swim down to the next layer.

Since the tank is quite big and impractical to fill in an office environment, it was decided to make a copy of the substrate pattern and make a 30x30 cm^2 lasered version in 3mm grey plastic which would then be put in a large bucket with water. There has also been provided a large quantity of plastic pellets that can mimic roe for use in experimental images or testing of extraction and positioning.

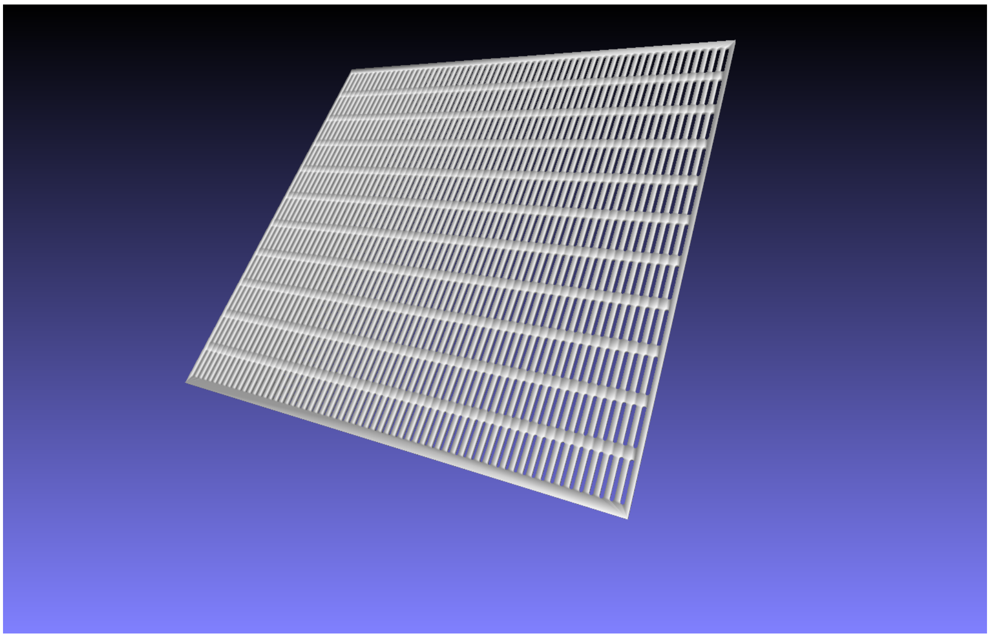

Figure 3.6: 3D model of the 30x30 roe inlay grid

3.4 Robotic hardware

The cylinder robot from previous masters assignment by Edda Solem [7], the Stewart platform, and also parts for the copy of the hatching environment was produced by Glenn Angell at ITKs Mechanical Workshop.

3.5 Luxonis OAK-FFC-3P

Luxonis [19] is a company that provides solutions for robotic vision, in particular open-source stereo vision camera solutions and software. The idea is that the customer buys one of the camera solutions and can then use the provided software and python API to produce a simple solution for a computer vision system that can discern spatial locations of objects of interest.

For this masters assignment, the *Luxonis OAK-FFC-3P* was chosen as a suitable embedded solution for the robot, since this gives the user more freedom to choose where and how the cameras should be mounted and aimed. The kit consists of the OAK-FFC-3P-chip and several lenses and cameras, in particular two stereo cameras and one RGB camera. Since the work done by Marius Tjore [6] was mainly based on monochrome pictures, the two stereo cameras provided will probably perform adequately, but the RGB camera might be useful if extra accuracy for positioning is needed.

Chapter 4

Methods

4.1 Control Algorithm and Code

4.1.1 General description of functionality

A description of the code functionality can be seen in the UML sequence diagram provided below. The general idea is that the robot initializes on a set position above the circular roe substrate inlay, take a stereo picture, analyse the image set and calculate the position of the dead roe. These locations are stored in a list which will be provided to the motor controller, the extraction tube is placed above each roe and a pump is activated which sucks the roe out through a tube. This repeats for each dead roe in the area covered by the images, until all roe has been picked. When this happens, the cylinder robot moves the platform to the next segment of the substrate inlay.

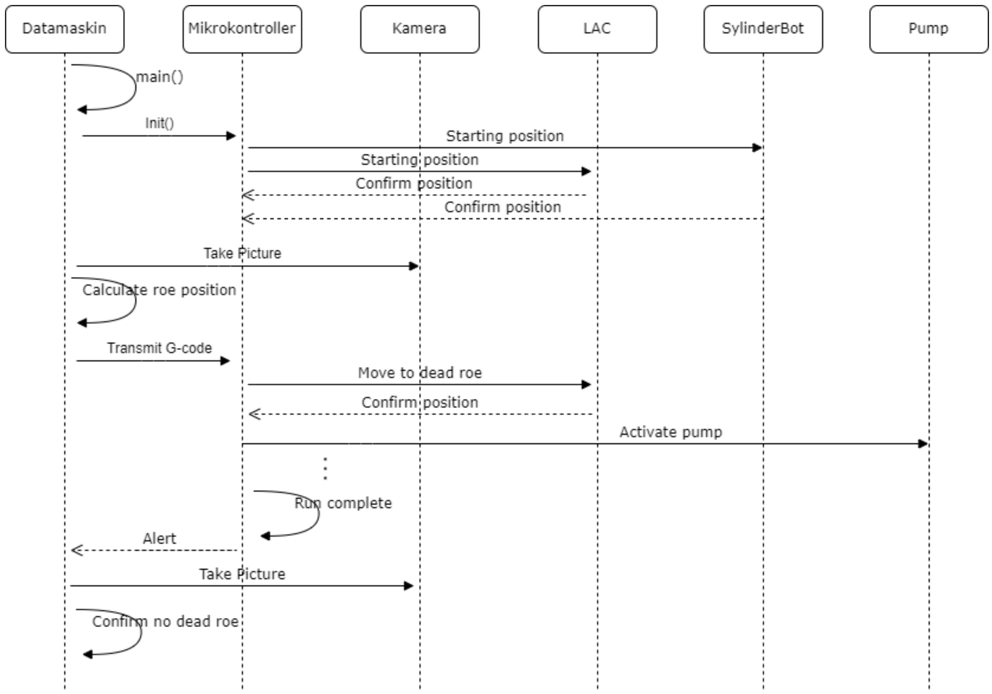

Figure 4.1: Sequence diagram of code functionality

The code for transforming XYZ-location of the roe into linear actuator positions will be written in python. To begin with, the code will utilize the computer vision program and training data written and obtained by Marius Tjore [6] and functions for kinematic calculations made as a part of the project assignment [8] to produce a list of four dimensional vectors containing the position for each of the linear actuator corresponding to the position of each detected dead roe, based on an input image and measured camera geometry. These values will then be transmitted by UART over a USB COM-port to the Arduino which will set the actuators to the correct lengths.

To begin with, the code will utilize single images taken directly above the artificial roe by phone camera as input to produce the list of actuator positions, the third variable for depth or height, will be set as a constant until work on implementing the stereo vision system can begin.

4.2 Testing Accuracy for Positioning

To test the accuracy and repeatability of the Stewart platform, a test route consisting of an origin and a set of points along a square 15x15cm orbit and a height from plane to camera of 10cm has been implemented.

These inputs are transmitted as an array via $serialtransmit()$ which then transmits the actuator positions line for line to the arduino motor controller over USB COM-port.

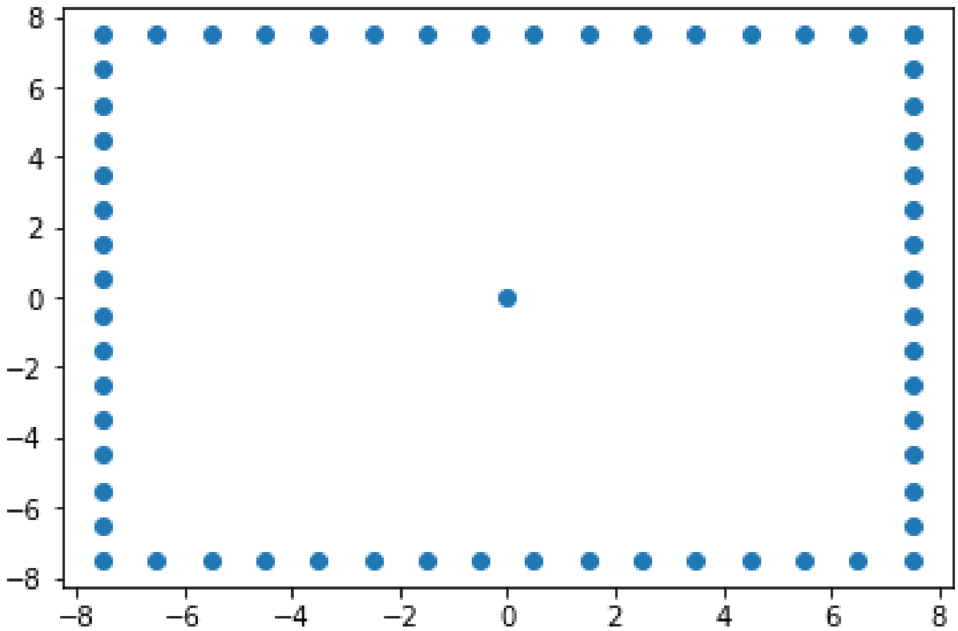

Figure 4.2: 15x15cm square test route with origin

To be able to see if the platform angle moves according to the square pattern, a laser diode is mounted so that the ray shines along the same axis as the tube connected to the fourth actuator which will then shine down on a piece of paper. For every movement, the position of the laser is tagged with a marker on the paper. If the calculation of the three actuator lengths for each set of directions is correct, there will be a square projection onto the paper. Assuming the correct calculations have been made in the code, the distance between platform and paper will not matter, this should only affect the size of the square. The accuracy of the fourth actuator can simply be measured by checking the length for a set of test points.

To have a measure of repeatability of movements, it is proposed to run the square route several times while noting a pattern drawn by the laser on a see through material such as baking sheets or clear plastic sheets, alternatively to use different colors of marker for round 1, 2, etc. By measuring the distance between corresponding points for each run of the test route, it will be possible to give an estimate of mean average variation and whether or not this will be problematic.

4.3 Testing different computer vision solutions for stereo vision and artificial environment

The imaging done by Marius Tjore [6] for making the dataset used in training the CNN was taken further above the pool than is intended in the adjustments and implementations proposed in this project. The current proposition is to move the camera just below the water line to avoid disturbances made by the surface and movements of the robot. It might also be better to have each stereo camera at an angle towards the middle to achieve better differentiation of height. The images will therefore contain fewer, but larger and more detailed segments of roe. For this reason, it might be beneficial to test different approaches to making a computer vision model.

Another thing that must be determined is how well the CV-model performs on the artificial environment and how well it detects the white plastic pellets for dead roe. It does not need to be perfect, but if the amount of detections is relatively close to the number of pellets, then at least the artificial environment makes a good enough substitute.

Chapter 5

Results

5.1 Code Functionality

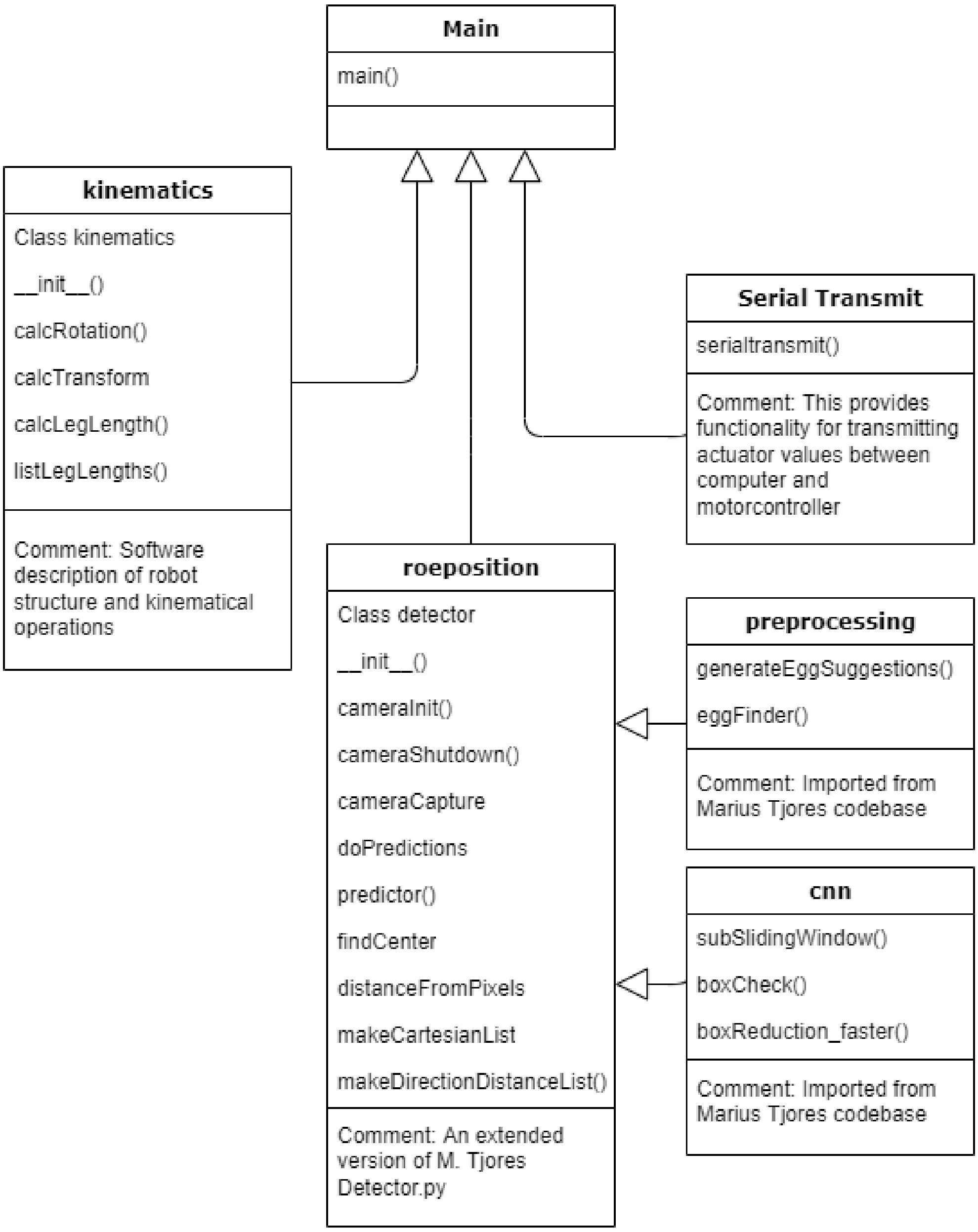

Figure 5.1: Class diagram of code

The code for roe localization by computer vision and robot control has been developed according to standard development practices. The types of functions and classes have been separated into categorical modules and each function is atomic in the way that they only perform one thing. Some of the code has been imported from the work of Marius Tjore and adapted to better fit new functionalities. All of *kinematics*, $distanceFromPixels()$, $makeCartesianList()$ and $makeDirectionDistanceList()$ from *roeposition* and *Serial Transmit* have been made as a part of this project and provide an easy framework for testing robot geometries and different kinematical approaches.

Initializing an instance of the $detector$-class in main allows for importing images or capturing from camera, and using the pretrained CV-model from M. Tjore one can pinpoint dead roe and export the positions. These lists of positions can then be used as input to the kinematical functions to create output to the actuators. The actuator positions are transmitted using $serialtransmit()$ over a UART COM-line over USB cable to the arduino working as a motor controller. The code is made so that rotation matrices and different approaches to calculating actuator positions can easily be replaced.

5.2 Accuracy of Extraction Mechanism

5.2.1 Initial tests of rotation of the platform

After implementing the kinematics described in 2, the initial testing of the code by use of the square test route, yielded these calculations for what the corresponding directions and distances, and actuator lengths should be for each point:

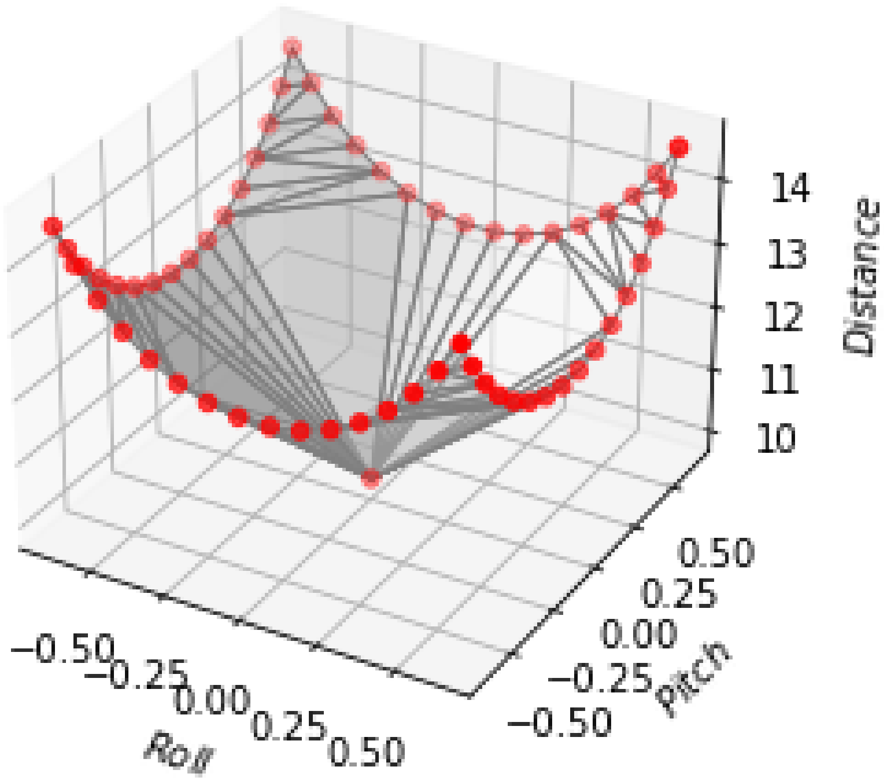

Figure 5.2: Direction and distance for each point in the square test route

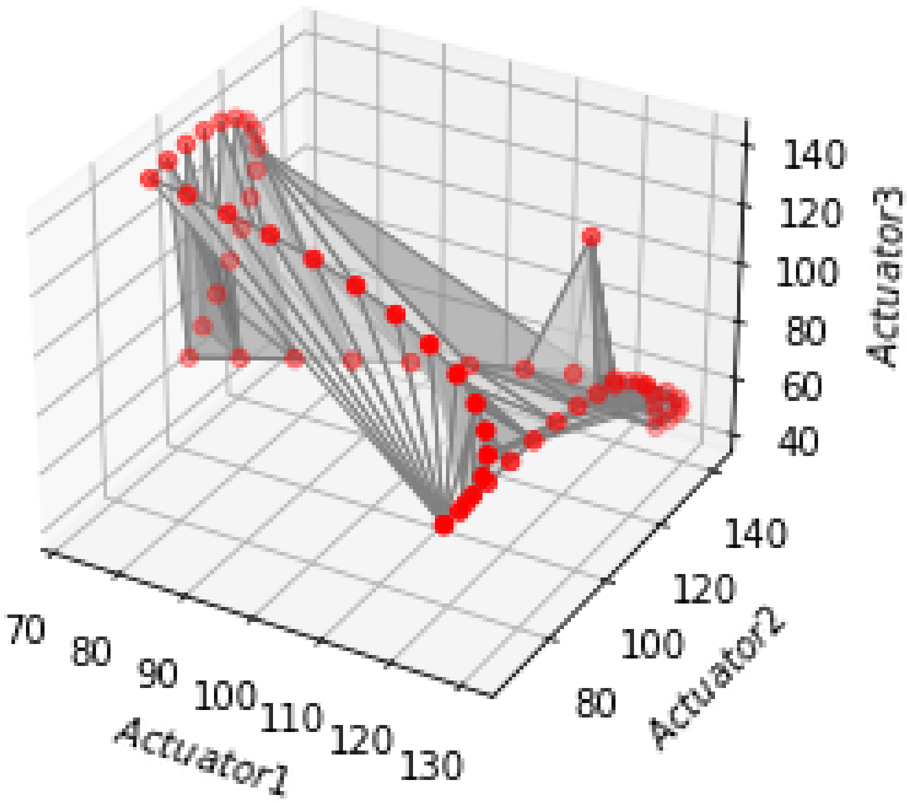

Figure 5.3: The calculated lengths of each of the three directional actuators required to achieve the correct angle

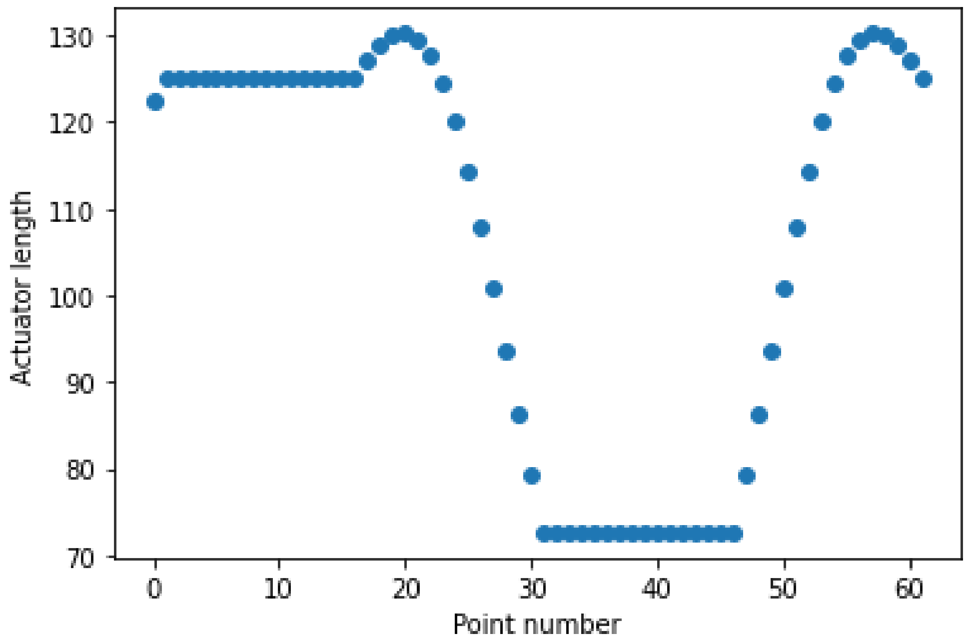

Figure 5.4: Actuator 1

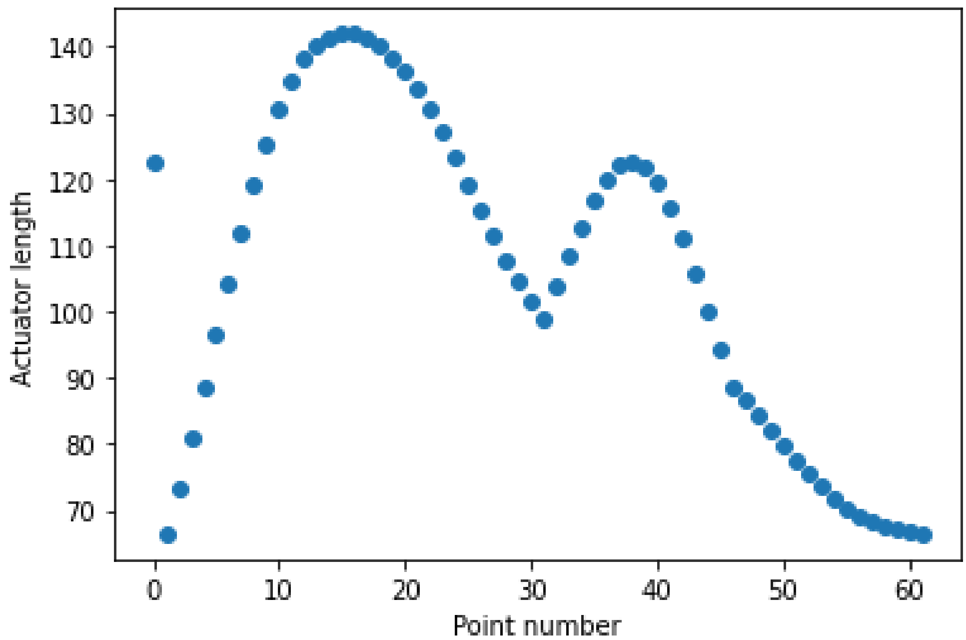

Figure 5.5: Actuator 2

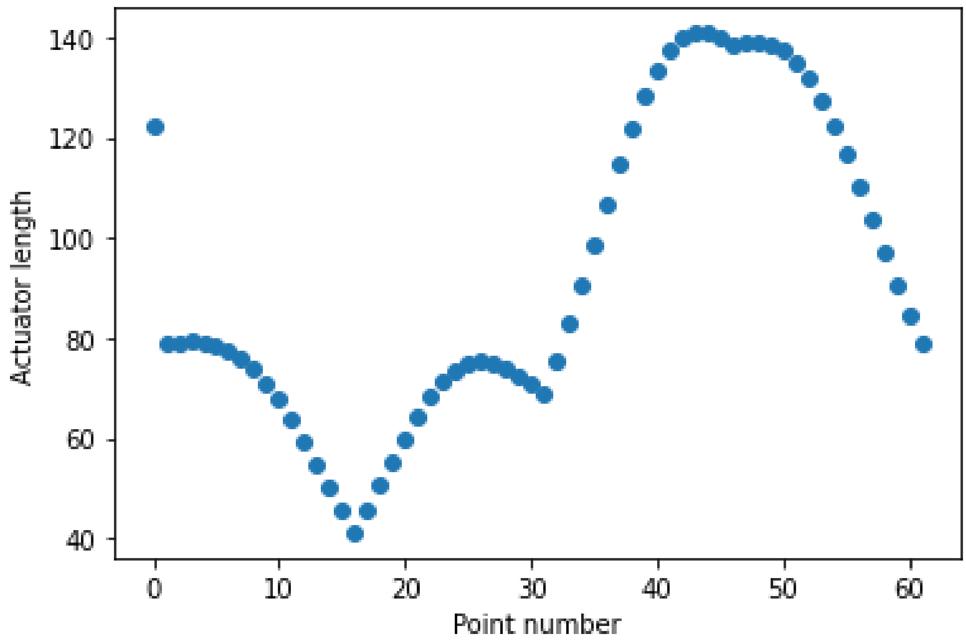

Figure 5.6: Actuator 3

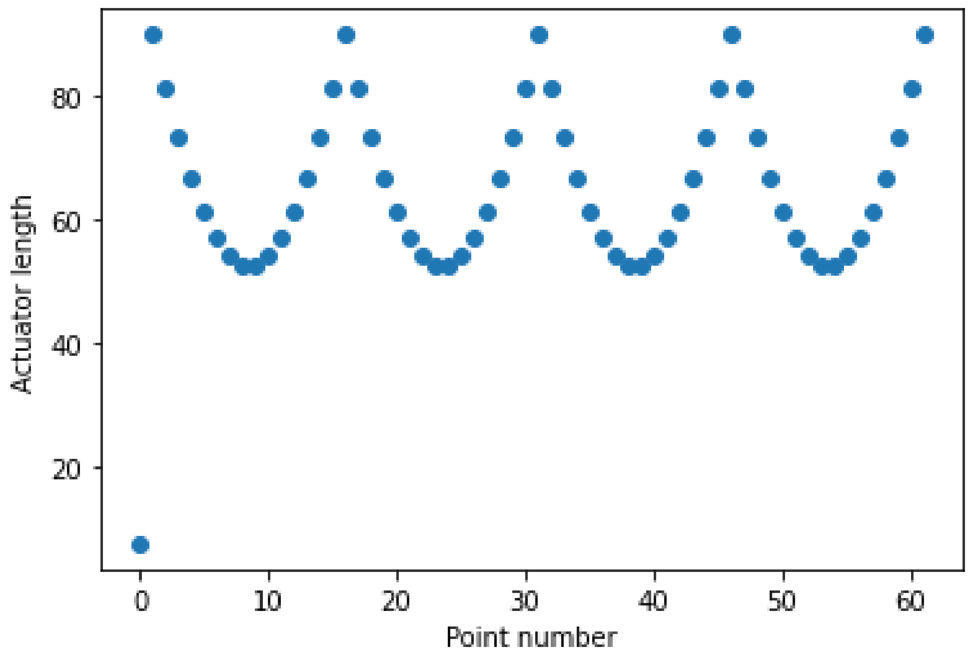

Figure 5.7: Actuator 4

To test if these calculated inputs were meaningful, the projection made by the platform on the floor plane was recorded using a laser, marker and paper, as described in 4. The projection can be seen in 5.8.

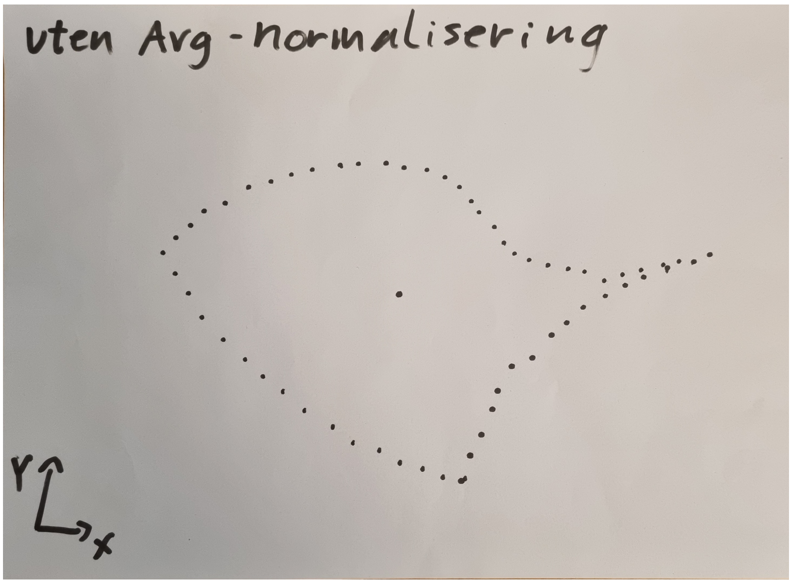

Figure 5.8: The first attempt at drawing a square

This was obviously not the desired shape, meaning that something was wrong with how the actuator lengths were calculated. As a note, it is still possible to observe some of the structure of the square in the figure, there are four corners and the 'sides' are roughly the same length. As an observation, it might look like the square has been transformed by some non-linear transformation similar to what has been illustrated in 5.9.

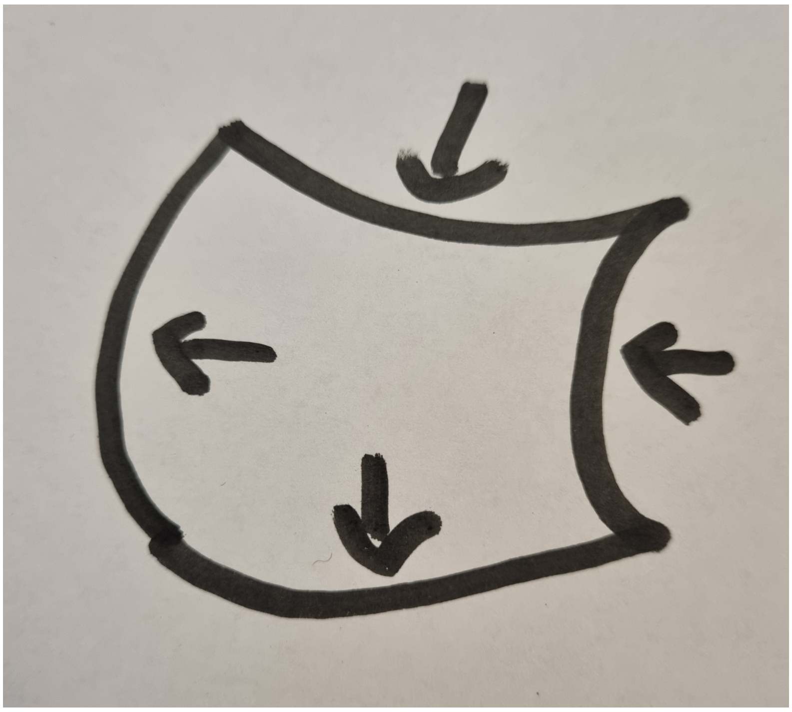

Figure 5.9: Illustration of a nonlinear transformation

An initial hypothesis for why this happened was that the actuator lengths had not been normalized so that the average extension was constant, so that the origin of the plate would hold a stationary height. Implementing these constraints in $calcLegLength()$ gave new values for the actuator lengths.

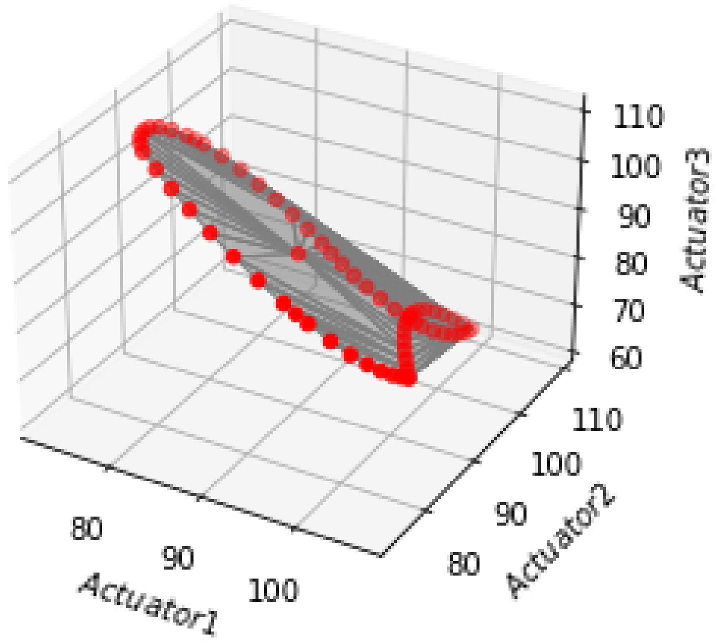

Figure 5.10: Calculated actuator lengths after implementing constant average around half of full length

These values were then fed to the motor control for laser plotting, which gave the following:

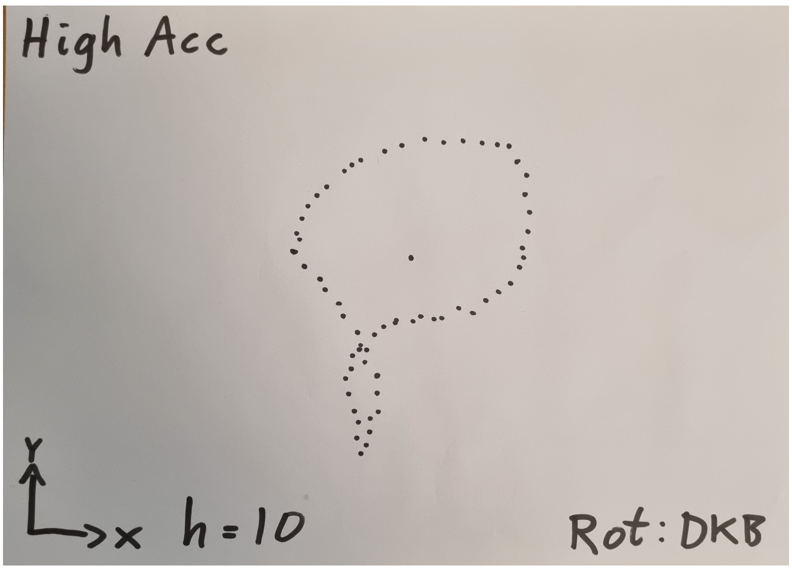

Figure 5.11: Square route with height constraint, height = 10, high accuracy on LAC

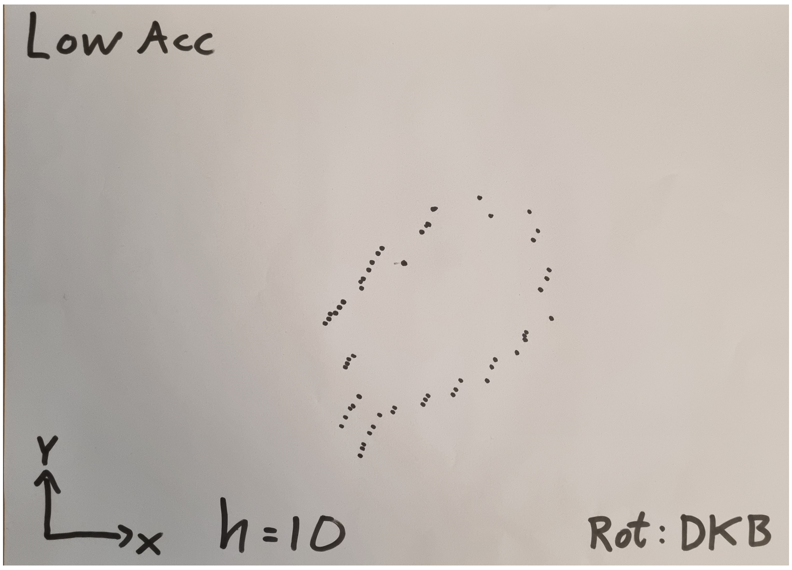

Figure 5.12: Square route with height constraint, height = 10, low accuracy on LAC

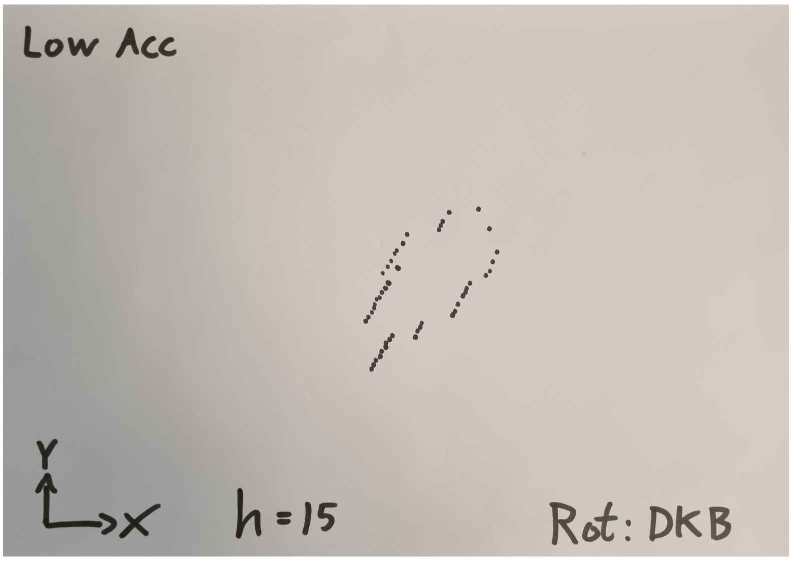

Figure 5.13: Square route with height constraint, height = 15, low accuracy on LAC

This did not seem to fix the problem, if anything it seems to have made the sides curve more. It is therefore something else in the calculations or assumptions made that is the cause of the issue.

To create a better understanding for what the situation might be, it was decided to try to run the robot in a pattern corresponding to a tilted circle in the graph for the actuator inputs. As one can see in 5.10, the shape of the structure is reminiscent of a circle, but with a slight extra loop, giving it an 8-like form. It was therefore suggested to simply create a normal circle in roughly the same shape and size. This was done by making an array of vectors where each point was calculated by a cosine function with a 0, 120 and 240 degree displacement. This produced the figure seen below.

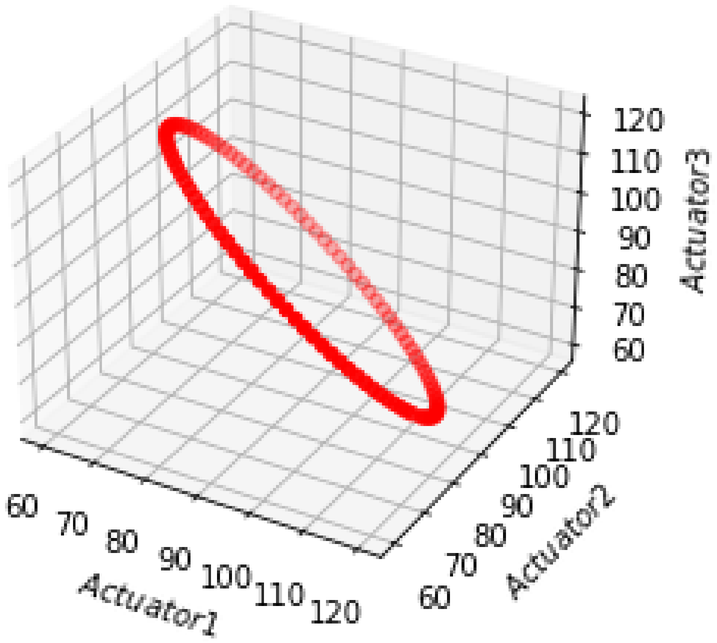

Figure 5.14: Circular pattern in the plot for actuator lengths

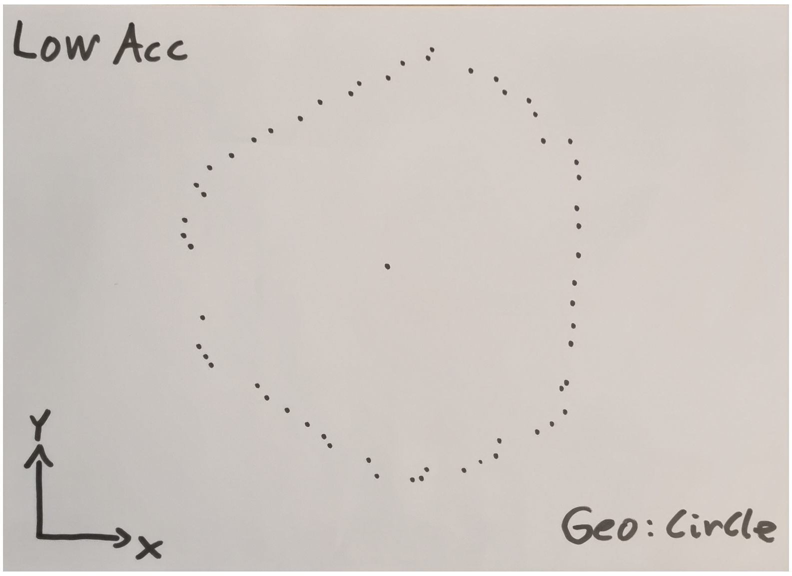

Figure 5.15: Pattern drawn when using a circular pattern as input, LAC on low accuracy.

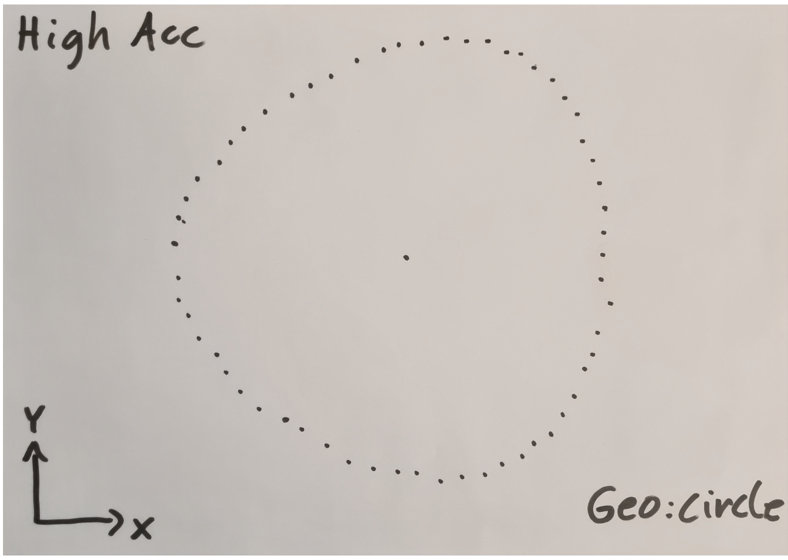

Figure 5.16: Pattern drawn when using a circular pattern as input, LAC on high accuracy.

When running the robot using these values, a circle-like pattern can be observed in the laser plots. These can be seen in 5.15 and 5.16. The 'dents' are opposite from where the actuators are fastened.

5.2.2 Second attempt using alternative implementation

In an attempt to debug what was happening, Morten Andreas Nome made an attempt at describing the kinematics in an alternative manner. The MATLAB-script can be seen in B

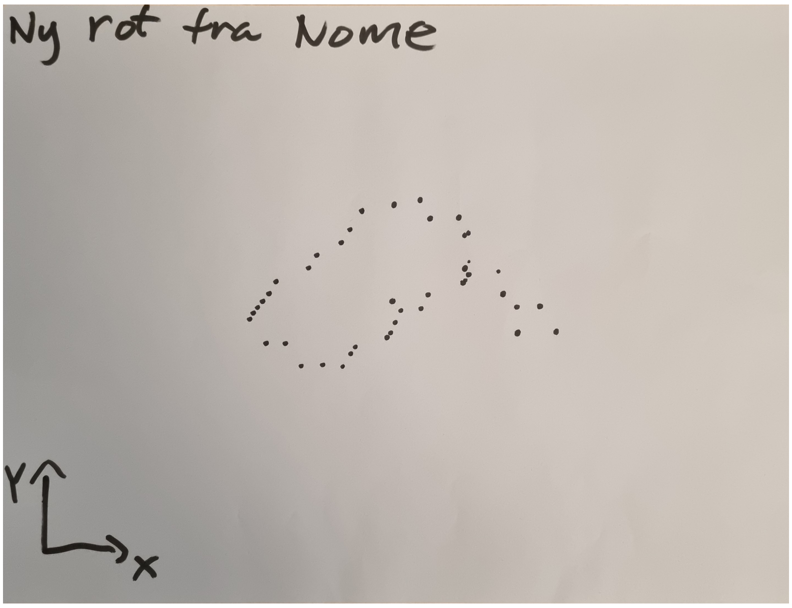

Figure 5.17: Pattern drawn when using the method proposed by Morten Andreas Nome.

The result of running the square test route by using this method can be seen in figure 5.17.

5.2.3 Third attempt by using numerical optimization

Another method to calculate actuator lengths and transformations was to rather use numerical optimization to find the platform-orthogonal vectors that would point in the direction of the dead roe. This method was devised using MATLAB and can be seen in B.

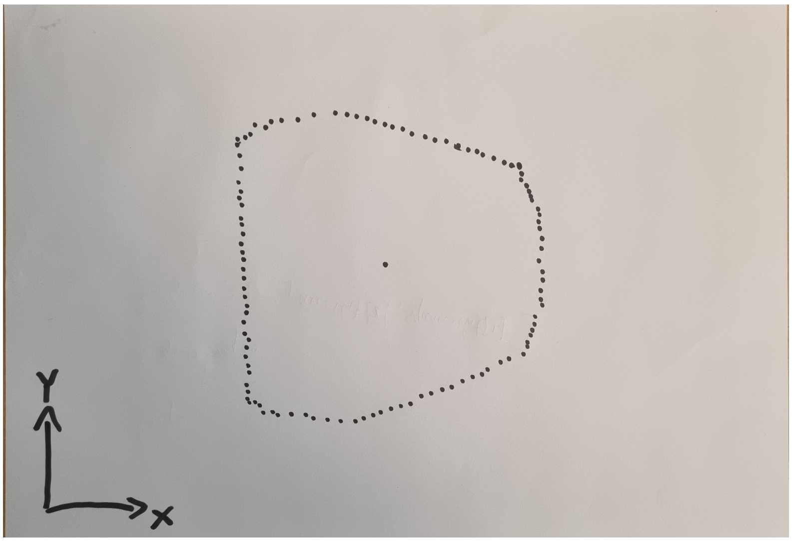

Figure 5.18: Pattern drawn by robot when using actuator values calculated by the numerical method by Morten Omholt Alver.

As one can see in 5.18, this is far closer to being a square than what has been observed so far.

5.2.4 Manual tuning of the Linear Actuator Control boards

As can be seen in 5.12, 5.13 and 5.15, there are distinct lines in the structure. This is caused by the tuning of the LAC boards, where the accuracy setting has been turned down to reduce shaking and oscillations. The actuators will only move if the difference in set value and current value is above a threshold controlled by the accuracy setting. The lines arise when only one or two of the actuators have enough difference in these values to move, when in reality two or all were supposed to move.

When the accuracy tuner is set to maximum the plate had a tendency to move the laser $\pm$ 2 mm around the points on the paper when the height between the plate centre and floor was approximately 30cm. The other plots have been made while having maximum accuracy and plotting at the approximate centre of the oscillations.

The ideal setting for accuracy will probably be just beneath maximum.

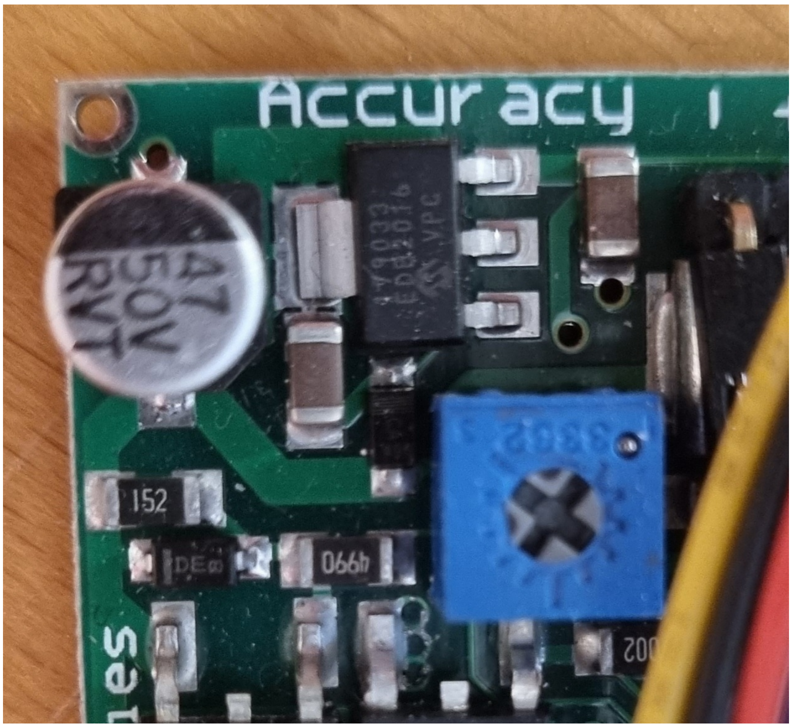

Figure 5.19: High accuracy setting for LAC

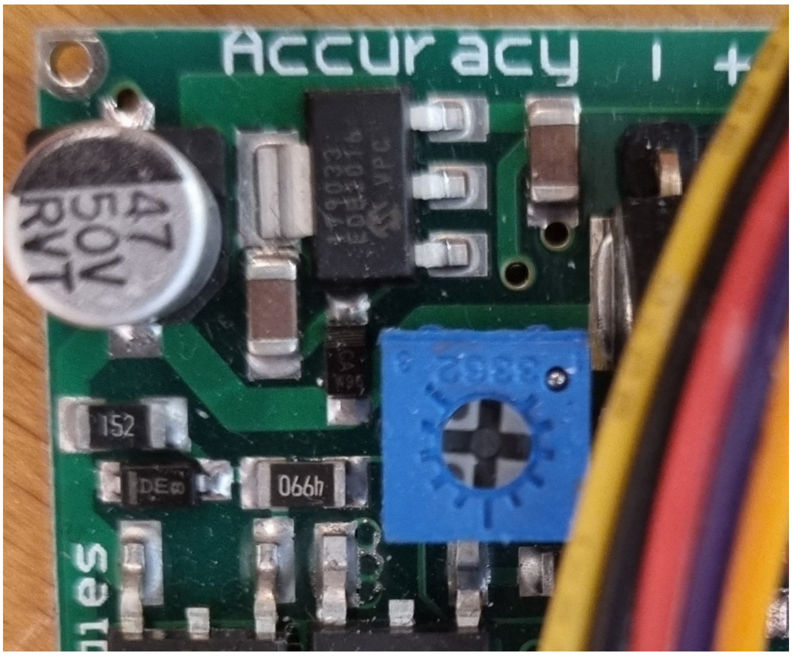

Figure 5.20: Low accuracy setting for LAC

5.3 Accuracy of computer vision solutions on test environment

Since there was no availability of actual roe at NFFT during the course of this project and testing period, the system would have to rely on an artificial environment with plastic pellets.

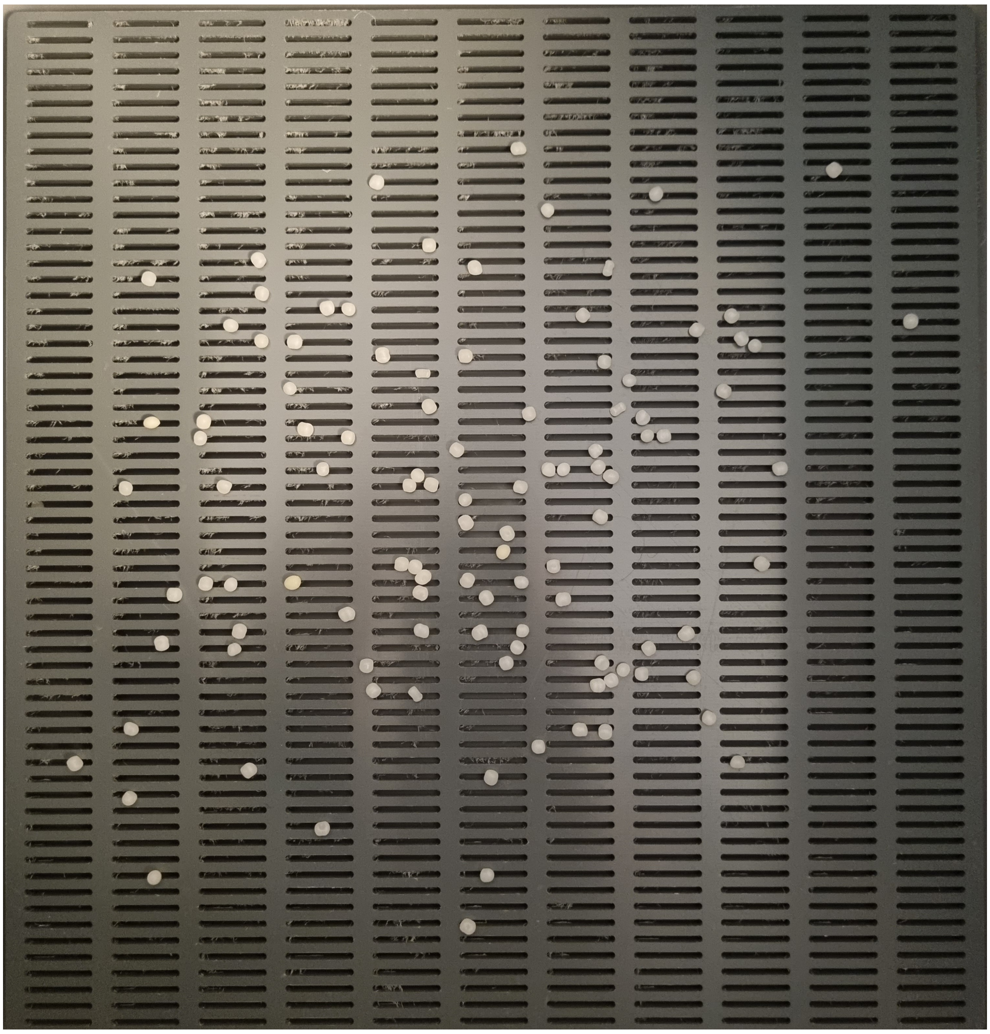

Figure 5.21: Picture of plastic pellets in artificial environment

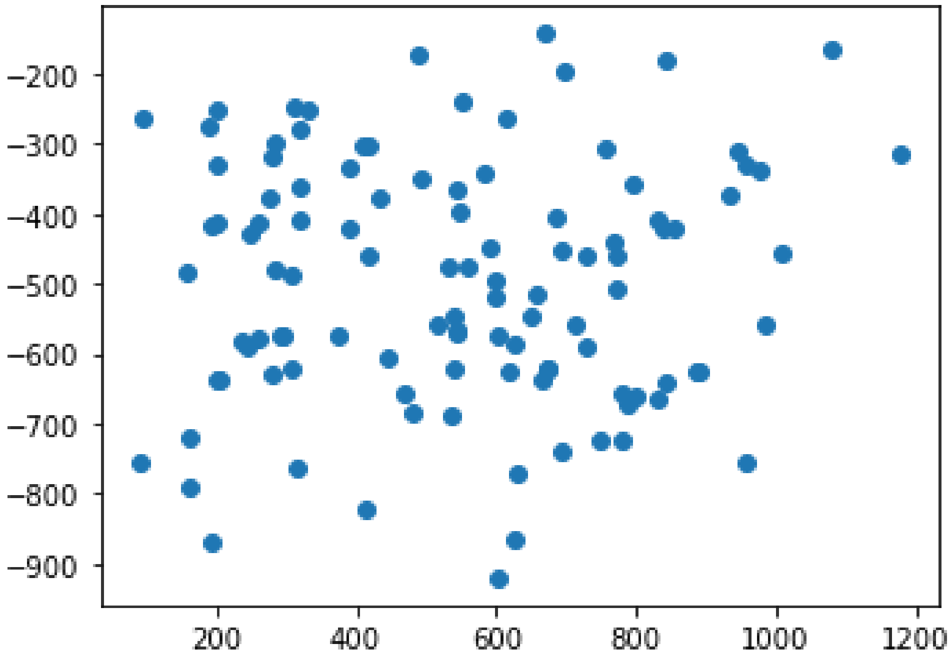

Figure 5.22: Detections made on the artificial environment

When taking a picture of the roe bed and running it through the model, the positions of detections can be seen in 5.22 while the input image can be seen in 5.21. It does not detect every single pellet, but it is very close.

Chapter 6

Discussion

As can be observed, there are problems in how the actuator lengths are calculated. Several attempts at implementing something functional were made by the author and others, but ultimately none gave the desired results of making the robot project a square pattern on the floor. The optimization approach gave the closest result, which ended up being similar to a trapezoid. Exactly why this resulted in a trapezoid is not entirely known, but there might be several reasons. For example, there may be an angular offset somewhere in the code that could skew the image. There could also perhaps be some hardware settings that could have caused the issue. Either way, this approach seems to have been the most functional one and it is recommended that it be investigated further.

The start and stopping point of the robot were always the same during these tests, and it was observed that the robot always pointed to the exact same point withing a margin of $\pm$1-2 mm when finishing the test runs. Since the desired square pattern was never fully achieved, proper repeatability testing was not performed, but based on these observations, one can say that the repeatability is at a satisfying level.

As can be seen in the plots in the results, different settings of accuracy were attempted. The ones with line-structures in them had a lower accuracy setting on the LAC-boards, meaning they had a higher threshold for initiating a movement, meaning that the smallest adjustments would be ignored. Alternatively, the other ones were done with a high accuracy setting and gave no such artifact-lines. However, the high accuracy setting gave small oscillations around the desired points of about $\pm$1 mm, while the lower accuracy setting gave no such oscillations. There is likely to be a optimal point of tuning these settings, maybe also by adjusting the speed of the actuators, it could be possible to achieve something very accurate that does not oscillate.

The CV-model made by Marius Tjore performs very well with the test setup with plastic pellets. It does not perfectly tag every pellet, but nearly all of them and that is good enough for testing. The input image had to be adjusted so that each pellet was around the size of 10x10 pixels, which was the size the model was trained on. This might give an indication that it won't perform well if the stereo cameras are angled downward towards the roe field so that the roe will have different sizes as they're closer or further away from the camera. There may therefore be necessary to train a new model that can detect different sizes of roe.

During the course of testing the robot, many different solutions for actuator lenght calculations were made, and these were easy to implement with the rest of the code. The program has proved to be easy to modify and modular by design. Hopefully, this will be of help for anyone wanting to continue this work. All source code can be found on the GitHub-page for this masters assignment [20].

Chapter 7

Further Work

7.1 Software

7.1.1 Implementation of stereo Vision

The biggest setback of this project was the late delivery of the Luxonis stereo camera. As Marius Tjore concluded with in his masters thesis, a good method for depth estimation of dead roe would be very important for making a viable solution for localization of the dead roe. A stereo vision camera placed below water surface would be an easy and cheap way to achieve high precision positioning. What remains to be determined is if the model Marius Tjore made is viable for use with the stereo vision camera placed far closer to the roe than what was done earlier, and also if the individual cameras being placed at an angle will affect the performance. When placed at an angle towards the centre between them, some roe will be close and large in the image and some further away and therefore smaller. The model is trained on images of dead roe at 10x10 pixels and as was observed in the results, the pixel size of the dead roe in the input image is crucial.

7.1.2 Investigate different CV approaches

Depending on how well the current CV-model performs with the stereo vision camera, it may be beneficial to look at different approaches to how this is performed. Since the eccentricity of the circle shapes of roe is quite high it might be possible to make a simpler blob detector with some sort of midpoint estimator based on looking at the curvature of the edge of the roe. Alternatively, it might be necessary to train a whole new model using angled pictures of an area with roe.

7.1.3 Route optimization

Once the stereo vision detection and localization has been fully integrated with the robot, it would be beneficial to implement a method for sorting the position list of dead roe in a way that corresponds to the shortest path to reach all, in order to optimize the run time of the robot. There are probably several different methods in doing this, depending on how many dead roe are in the field. If there are few (10) it might be reasonable to device an exact algorithm [1], but if there are in the order of magnitude of a hundred, the problem will most likely require a heuristic algorithm such as Nearest Neighbour to be able to construct a route in reasonable time. It might be a good idea to analyze the general distribution of roe, this might give reason to follow certain approaches.

7.1.4 Different approaches to angular control

As have been shown in this project, it is not necessarily easy to describe the kinematics of such a robot accurately enough for using it as a basis for a control algorithm. One also have to be careful in what assumptions are made and used as this could affect accuracy more than expected.

Control algorithm based on numerical optimization

As was seen in the results, going away from the hard-coded geometry and using an approach based on numerical optimization to find the correct rotational matrices and actuator lengths yielded a far better result. The resulting 'square' was quite skewed, but overall it most likely possible to make some adjustments to be able to make it quite accurate.

Using different approaches to kinematic calculations

There were also some ideas as to how one could define the kinematics in a different way to make a working solution. The main idea posed by Mads Erlend Bøe Lysøe was to instead of using roll, pitch and yaw (X, Y and Z) to define the rotational matrices, one could use the two vectors between the mounting points of actuator 1-2 and 1-3 as basis for two rotational matrices. These two vectors are a basis for the plane, and one could then use this in an algorithm that would find the actuator lengths that would make it so that the vector from the plane to the position of the dead roe was along the orthogonal axis to the plane in the centre of the platform. Essentially, finding the set of actuator lengths that would define a plane that is orthogonal to the vector between platform centre and roe position.

Hardware feedback

I would also like to pose the idea of ignoring the kinematics to some degree and instead use sensors such as a gyro, accelerometer or maybe even an IMU mounted on the plate and a PID-controller to control the robot. This could provide a far easier method to check the correctness of the movements and to double check that the actual angles are corresponding to what is intended.

[1] Simply try all different ways of doing it and check the total distance

7.2 Mechanics

7.2.1 Mounting parallel manipulator on cylinder robot

Once the parallel manipulator robot is in a functional state, it would then have to be combined with the cylinder robot made by Edda Solem. Since the robot adds a fair bit of height, it is advised to move the swing bar further up along the central axis rod to accommodate it. The control unit for this robot is an arduino DUE so it should be relatively easy to make a combined motor control for both using one of the arduinos.

7.2.2 Determine Placement of Stereo Camera

Placing the stereo camera might be challenging. It should be below the waterline, but also so far up it can capture a wide enough area, but not so high up it interferes with the platform or extraction actuator. It might also be possible to solve both the issue of control and camera placement, by mounting the cameras at set points on the platform so that they move with it. This could allow for implementing camera odometry to navigate the endpoint of the actuator to dead roe.

Chapter 8

Conclusion

The parallel manipulator robot which has been built and programmed as a part of this masters project is functional, however it does not yet have a satisfactory way of mapping actuator lengths to achieve the correct positioning to reach dead roe. It does have a high accuracy and high repeatability, so if a way to accurately calculate the right actuator lengths can be found, the robot may be a viable solution for further implementation with stereo vision localization and a cylinder robot to reach each sector of the roe inlay. The code for data processing, kinematic calculations and drivers for communication and control of motor controllers, made during the course of this masters project, provides a modular environment for further implementations in terms of kinematics or optimization algorithms that can perform better than what the current implementations does. The test environment with plastic pellets and roe inlay plate will simplify further testing when the time comes to incorporate stereo vision localization.

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Appendix A

Additional Material

Masteravtale/hovedoppgaveavtale

Sist oppdatert 11. november 2020

Fakultet	**Fakultet for informasjonsteknologi og elektroteknikk**
Institutt	**Institutt for teknisk kybernetikk**
Studieprogram	**MTTK**
Emnekode	**TTK4900**

Studenten

Etternavn, fornavn	**Reinsborg, Ingebrigt Stamnes**
Fødselsdato	**12.02.1998**
E-postadresse ved NTNU	**ingebrigt.s.reinsborg@ntnu.no**

Tilknyttede ressurser

Veileder	**Morten Omholt Alver**
Eventuelle medveiledere	
Eventuelle medstudenter	

Oppgaven

Oppstartsdato	**24.01.2022**
Leveringsfrist	**20.06.2022**
Oppgavens arbeidstittel	**Improving design of robot for extracting dead fish roe**
Problembeskrivelse	**The assignment consists of making improvements to an existing robot made by previous students, so that the robot may become a viable automatic solution for removing dead fish roe in hatcheries in the aquacultural industry.**

Risikovurdering og datahåndtering

Skal det gjennomføres risikovurdering? **Dersom «ja», har det blitt gjennomført?**	**Nei** **Nei**
Skal det søkes om godkjenninger? (REK*, NSD)**	**Nei**
Skal det skrives en konfidensialitetsavtale i forbindelse med oppgaven? **Hvis «ja», har det blitt gjort?**	**Nei** **Nei**

*   Regionale komiteer for medisinsk og helsefaglig forskningsetikk (https://rekportalen.no)
** Norsk senter for forskningsdata (https://nsd.no/)

Eventuelle emner som skal inngå i mastergraden

Retningslinjer - rettigheter og plikter

Formål

Avtale om veiledning av masteroppgaven/hovedoppgaven er en samarbeidsavtale mellom student, veileder og institutt. Avtalen regulerer veiledningsforholdet, omfang, art og ansvarsfordeling.

Studieprogrammet og arbeidet med oppgaven er regulert av Universitets- og høgskoleloven, NTNUs studieforskrift og gjeldende studieplan. Informasjon om emnet, som oppgaven inngår i, finner du i emnebeskrivelsen.

Veiledning

Studenten har ansvar for å

- Avtale veiledningstimer med veileder innenfor rammene master-/hovedoppgaveavtalen gir.
- Utarbeide framdriftsplan for arbeidet i samråd med veileder, inkludert veiledningsplan.
- Holde oversikt over antall brukte veiledningstimer sammen med veileder.
- Gi veileder nødvendig skriftlig materiale i rimelig tid før veiledning.
- Holde instituttet og veileder orientert om eventuelle forsinkelser.
- Inkludere eventuell(e) medstudent(er) i avtalen.

Veileder har ansvar for å

- Avklare forventninger om veiledningsforholdet.
- Sørge for at det søkes om eventuelle nødvendige godkjenninger (etikk, personvernhensyn).
- Gi råd om formulering og avgrensning av tema og problemstilling, slik at arbeidet er gjennomførbart innenfor normert eller avtalt studietid.
- Drøfte og vurdere hypoteser og metoder.
- Gi råd vedrørende faglitteratur, kildemateriale, datagrunnlag, dokumentasjon og eventuelt ressursbehov.
- Drøfte framstillingsform (eksempelvis disposisjon og språklig form).
- Drøfte resultater og tolkninger.
- Holde seg orientert om progresjonen i studentens arbeid i henhold til avtalt tids- og arbeidsplan, og følge opp studenten ved behov.
- Sammen med studenten holde oversikt over antall brukte veiledningstimer.

Instituttet har ansvar for å

- Sørge for at avtalen blir inngått.
- Finne og oppnevne veileder(e).
- Inngå avtale med annet institutt/ fakultet/institusjon dersom det er oppnevnt ekstern medveileder.
- I samarbeid med veileder holde oversikt over studentens framdrift, antall brukte veiledningstimer, og følge opp dersom studenten er forsinket i henhold til avtalen.
- Oppnevne ny veileder og sørge for inngåelse av ny avtale dersom:
    - Veileder blir fraværende på grunn av eksempelvis forskningstermin, sykdom, eller reiser.
    - Student eller veileder ber om å få avslutte avtalen fordi en av partene ikke følger den.
    - Andre forhold gjør at partene finner det hensiktsmessig med ny veileder.
- Gi studenten beskjed når veiledningsforholdet opphører.
- Informere veileder(e) om ansvaret for å ivareta forskningsetiske forhold, personvernhensyn og veiledningsetiske forhold.
- Ønsker student, eller veileder, å bli løst fra avtalen må det søkes til instituttet. Instituttet må i et slikt tilfelle oppnevne ny veileder.

Avtaleskjemaet skal godkjennes når retningslinjene er gjennomgått.

Godkjent av

Ingebrigt Stamnes Reinsborg
Student

06.12.2021
Digitalt godkjent

Morten Omholt Alver
Veileder

07.12.2021
Digitalt godkjent

Lill Hege Pedersen
Institutt

07.12.2021
Digitalt godkjent

Fastsatt av Rektor 20.01.2012

STANDARDAVTALE

om utføring av masteroppgave/prosjektoppgave (oppgave) i samarbeid med bedrift/ekstern virksomhet (bedrift).

Avtalen er ufravikelig for studentoppgaver ved NTNU som utføres i samarbeid med bedrift.

Partene har ansvar for å klarere eventuelle immaterielle rettigheter som tredjeperson (som ikke er part i avtalen) kan ha til prosjektbakgrunn før bruk i forbindelse med utførelse av oppgaven.

Avtale mellom

Student: **Reinsborg, Ingebrigt Stamnes**	født: **12.02.1998**

Veileder ved NTNU: **Morten Omholt Alver**

Bedrift/ekstern virksomhet: **Norwegian Fish Farms Tydal AS**

og

Norges teknisk-naturvitenskapelige universitet (NTNU) v/instituttleder

om bruk og utnyttelse av resultater fra masteroppgave/prosjektoppgave.

1. Utførelse av oppgave

Studenten skal utføre masteroppgave i samarbeid med

Norwegian Fish Farms Tydal AS

bedrift/ekstern virksomhet

24.01.2022- 20.06.2022

startdato – sluttdato

Oppgavens tittel er:

Improving design of robot for extracting dead fish roe

Ansvarlig veileder ved NTNU har det overordnede faglige ansvaret for utforming og godkjenning av prosjektbeskrivelse og studentens læring.

2. Bedriftens plikter

Bedriften skal stille med en kontaktperson som har nødvendig veiledningskompetanse og gi studenten tilstrekkelig veiledning i samarbeid med veileder ved NTNU. Bedriftens kontaktperson er:

Stian Aspaas

Formålet med oppgaven er studentarbeid. Oppgaven utføres som ledd i studiet, og studenten skal ikke motta lønn eller lignende godtgjørelse fra bedriften. Bedriften skal dekke følgende utgifter knyttet til utførelse av oppgaven:

Unknown

3. Partenes rettigheter

a) Studenten

Studenten har opphavsrett til oppgaven. Alle immaterielle rettigheter til resultater av oppgaven skapt av studenten alene gjennom oppgavearbeidet, eies av studenten med de reservasjoner som følger av punktene b) og c) nedenfor.

Studenten har rett til å inngå egen avtale med NTNU om publisering av sin oppgave i NTNUs institusjonelle arkiv på internett. Studenten har også rett til å publisere oppgaven eller deler av den i andre sammenhenger dersom det ikke i denne avtalen er avtalt begrensninger i adgangen til å publisere, jf punkt 4.

b) Bedriften

Der oppgaven bygger på, eller videreutvikler materiale og/eller metoder (prosjektbakgrunn) som eies av bedriften, eies prosjektbakgrunnen fortsatt av bedriften. Eventuell utnyttelse av videreutviklingen, som inkluderer prosjektbakgrunnen, forutsetter at det inngås egen avtale om dette mellom student og bedrift.

Bedriften skal ha rett til å benytte resultatene av oppgaven i egen virksomhet dersom utnyttelsen faller innenfor bedriftens virksomhetsområde. Dette skal fortolkes i samsvar med begrepets innhold i Arbeidstakeroppfinnelsesloven[1] § 4. Retten er ikke-eksklusiv.

[1] Lov av 17. april 1970 om retten til oppfinnelser som er gjort av arbeidstakere

Bruk av resultatet av oppgaven utenfor bedriften sitt virksomhetsområde, jf avsnittet ovenfor, forutsetter at det inngås egen avtale mellom studenten og bedriften. Avtale mellom bedrift og student om rettigheter til oppgaveresultater som er skapt av studenten, skal inngås skriftlig og er ikke gyldig inngått før NTNU har mottatt skriftlig gjenpart av avtalen.

Dersom verdien av bruken av resultatene av oppgaven er betydelig, dvs overstiger NOK 100.000 (kommentert i veiledningen[2] til avtalen), er studenten berettiget til et rimelig vederlag. Arbeidstakeroppfinnelsesloven § 7 gis anvendelse på vederlagsberegningen. Denne vederlagsretten gjelder også for ikke-patenterbare resultater. Fristbestemmelsene i § 7 gis tilsvarende anvendelse.

c) NTNU

De innleverte eksemplarer/filer av oppgaven med vedlegg, som er nødvendig for sensur og arkivering ved NTNU, tilhører NTNU. NTNU får en vederlagsfri bruksrett til resultatene av oppgaven, inkludert vedlegg til denne, og kan benytte dette til undervisnings- og forskningsformål med de eventuelle begrensninger som fremgår i punkt 4.

4. Utsatt offentliggjøring

Hovedregelen er at studentoppgaver skal være offentlige. I særlige tilfeller kan partene bli enig om at hele eller deler av oppgaven skal være undergitt utsatt offentliggjøring i maksimalt 3 år, dvs. ikke tilgjengelig for andre enn student og bedrift i denne perioden.

Oppgaven skal være undergitt utsatt offentliggjøring i

Ikke aktuelt

Behovet for utsatt offentliggjøring er begrunnet ut fra følgende:

De delene av oppgaven som ikke er undergitt utsatt offentliggjøring, kan publiseres i NTNUs institusjonelle arkiv, jf punkt 3 a), andre avsnitt.

http://www.lovdata.no/all/hl-19700417-021.html

[2] Veiledning til NTNUs standardavtale om masteroppgave/prosjektoppgave i samarbeid med bedrift http://www.ntnu.no/studier/standardavtaler

Selv om oppgaven er undergitt utsatt offentliggjøring, skal bedriften legge til rette for at studenten kan benytte hele eller deler av oppgaven i forbindelse med jobbsøknader samt videreføring i et doktorgradsarbeid.

5. Generelt

Denne avtalen skal ha gyldighet foran andre avtaler som er eller blir opprettet mellom to av partene som er nevnt ovenfor. Dersom student og bedrift skal inngå avtale om konfidensialitet om det som studenten får kjennskap til i bedriften, skal NTNUs standardmal for konfidensialitetsavtale benyttes. Eventuell avtale om dette skal vedlegges denne avtalen.

Eventuell uenighet som følge av denne avtalen skal søkes løst ved forhandlinger. Hvis dette ikke fører frem, er partene enige om at tvisten avgjøres ved voldgift i henhold til norsk lov. Tvisten avgjøres av sorenskriveren ved Sør-Trøndelag tingrett eller den han/hun oppnevner.

Denne avtale er underskrevet i 4 - fire - eksemplarer hvor partene skal ha hvert sitt eksemplar. Avtalen er gyldig når den er godkjent og underskrevet av NTNU v/instituttleder.

06.12.2021	Ingebrigt Stamnes Reinsborg

Elektronisk godkjent, dato student

07.12.2021	Morten Omholt Alver

Elektronisk godkjent, dato veileder ved NTNU

07.12.2021	Lill Hege Pedersen

Elektronisk godkjent, dato instituttleder, NTNU institutt

Elektronisk godkjent, dato for bedriften/institusjonen stempel og signatur

Master`s Agreement / Main Thesis Agreement

Faculty	**Faculty of Information Technology and Electrical Engineering**
Institute	**Department of Engineering Cybernetics**
Programme Code	**MTTK**
Course Code	**TTK4900**

Personal Information

Surname, First Name	**Reinsborg, Ingebrigt Stamnes**
Date of Birth	**12.02.1998**
Email	**ingebrigt.s.reinsborg@ntnu.no**

Supervision and Co-authors

Supervisor	**Morten Omholt Alver**
Co-supervisors (if applicable)	
Co-authors (if applicable)	

The Master`s thesis

Starting Date	**24.01.2022**
Submission Deadline	**20.06.2022**
Thesis Working Title	**Improving design of robot for extracting dead fish roe**
Problem Description	**The assignment consists of making improvements to an existing robot made by previous students, so that the robot may become a viable automatic solution for removing dead fish roe in hatcheries in the aquacultural industry.**

Risk Assessment and Data Management

Will you conduct a Risk Assessment? **If "Yes", Is the Risk Assessment Conducted?**	**No** **No**
Will you Apply for Data Management? **(REK*, NSD**)**	**No**
Will You Write a Confidentiality Agreement? **If "Yes", Is the Confidentiality Agreement Conducted?**	**No** **No**

* REK -- https://rekportalen.no/

** Norwegian Centre for Research Data (https://nsd.no/nsd/english/index.html)

Topics to be included in the Master`s Degree (if applicable)

Guidelines – Rights and Obligations

Purpose

The Master's Agreement/ Main Thesis Agreement is an agreement between the student, supervisor, and department. The agreement regulates supervision conditions, scope, nature, and responsibilities concerning the thesis.

The study programme and the thesis are regulated by the Universities and University Colleges Act, NTNU's study regulations, and the current curriculum for the study programme.

Supervision

The student is responsible for

- Arranging the supervision within the framework provided by the agreement.
- Preparing a plan of progress in cooperation with the supervisor, including a supervision schedule.
- Keeping track of the counselling hours.
- Providing the supervisor with the necessary written material in a timely manner before the supervision.
- Keeping the institute and supervisor informed of any delays.
- Adding fellow student(s) to the agreement, if the thesis has more than one author.

The supervisor is responsible for

- Clarifying expectations and how the supervision should take place.
- Ensuring that any necessary approvals are acquired (REC, ethics, privacy).
- Advising on the demarcation of the topic and the thesis statement to ensure that the work is feasible within agreed upon time frame.
- Discussing and evaluating hypotheses and methods.
- Advising on literature, source material, data, documentation, and resource requirements.
- Discussing the layout of the thesis with the student (disposition, linguistic form, etcetera).
- Discussing the results and the interpretation of them.
- Staying informed about the work progress and assist the student if necessary.
- Together with the student, keeping track of supervision hours spent.

The institute is responsible for

- Ensuring that the agreement is entered into.
- Find and appoint supervisor(s).
- Enter into an agreement with another department / faculty / institution if there is an external co-supervisor.
- In cooperation with the supervisor, keep an overview of the student's progress, the number of supervision hours. spent, and assist if the student is delayed by appointment.
- Appoint a new supervisor and arrange for a new agreement if:
  - The supervisor will be absent due to research term, illness, travel, etcetera.
  - The student or supervisor requests to terminate the agreement due to lack of adherence from either party.
  - Other circumstances where it is appropriate with a new supervisor.
- Notify the student when the agreement terminates.
- Inform supervisors about the responsibility for safeguarding ethical issues, privacy and guidance ethics
- Should the cooperation between student and supervisor become problematic, either party may apply to the department to be freed from the agreement. In such occurrence, the department must appoint a new supervisor

This Master`s agreement must be signed when the guidelines have been reviewed.

Signatures

Ingebrigt Stamnes Reinsborg
Student

06.12.2021
Digitally approved

Morten Omholt Alver
Supervisor

07.12.2021
Digitally approved

Lill Hege Pedersen
Department

07.12.2021
Digitally approved

By order of Rector: 20 January 2012

STANDARD AGREEMENT

concerning work on a master's thesis/project assignment (academic work) done in cooperation with a company/external organization (organization).

This is the authoritative agreement that governs academic work by students at the Norwegian University of Science and Technology (NTNU) that is carried out in cooperation with an organization.

The involved parties have the responsibility to clarify whether or not a third party (that is not a party to this agreement) may have intellectual property rights to the project background before the latter is used in connection with the academic work.

Agreement between

Student: **Reinsborg, Ingebrigt Stamnes**	Date of birth: **12.02.1998**

Supervisor at NTNU: **Morten Omholt Alver**

Company/external organization: **Norwegian Fish Farms Tydal AS**

and

Norwegian University of Science and Technology (NTNU), represented by the Head of Department

concerning the use and exploitation of the results from a master's thesis/project assignment.

1. Description of the academic work

The student is to carry out Master`s thesis in cooperation with

Norwegian Fish Farms Tydal AS

company/external organization

24.01.2022– 20.06.2022

starting date – completion date

Title of the academic work:

Improving design of robot for extracting dead fish roe

The responsible supervisor at NTNU has overall academic responsibility for structuring and approving the description of the academic work and the student's learning.

2. Responsibilities of the organization

The organization is to appoint a contact person who has the necessary experience in supervision and will give the student adequate supervision in cooperation with the supervisor at NTNU. The contact person at the organization is:

Stian Aspaas

The purpose of completing the academic work is academic training for the student. The academic work is part of a student's course of study and the student is not to receive wages or similar compensation from the organization. The organization agrees to cover the following expenses that are associated with carrying out the academic work:

Unknown

3. Rights of the parties

a) The student

The student holds the copyright to his/her academic work. All intellectual property rights to the results of the academic work done by the student alone during the academic work are held by the student with the reservations stated in points b) and c) below.

The student has the right to enter into an agreement with NTNU concerning the publication of his/her academic work in NTNU's institutional archive on the Internet. The student has also the right to publish his/her academic work or parts of it in other media providing the present agreement has not imposed restriction concerning publication, cf. Clause 4.

b) the organization

If the academic work is based on or develops materials and/or methods (project background) that are owned by the organization, the project background is owned by the organization. If the development work that includes the project background can be commercially exploited, it is assumed that a separate agreement will be drawn up concerning this between the student and the organization.

The organization is to have the right to use the results of the academic work in its own activities providing the commercial exploitation falls within the activities of the organization. This is to be interpreted in accordance with the terminology used in Section 4 of the Act Respecting the Right to Employees' Inventions (Arbeidstakeroppfinnelsesloven). This right is non-exclusive.

The use of the results of the academic work outside of the activities of the organization, cf. the last paragraph above, assumes that a separate agreement will be drawn up between the student and the organization. The agreement between the student and the organization concerning the rights to the results of the academic work produced by the student is to be in writing and the agreement is invalid until NTNU has received a copy of the agreement in writing.

If the value of the results of the academic work is considerable, i.e. it is more than NOK 100 000, the student is entitled to receive reasonable compensation. Section 7 of the Act Respecting the Right to Employees' Inventions states how the amount of compensation is to be calculated. This right to compensation also applies to non-patentable results. Section 7 of the Act also states the applicable deadlines.

c) NTNU

All copies of the submitted academic work/files containing the academic work and any appendices that are necessary for determining a grade and for the records at NTNU, are the property of NTNU. The academic work and any appendices to it can be used by NTNU for educational and scientific purposes free of charge, except when the restrictions specified in Clause 4 are applicable.

4. Delayed publication

The general rule is that academic work by students is to be available in the public domain. If there are specific circumstances, the parties can agree to delay the publication of all or part of the academic work for a maximum of 3 years, i.e. the work is not available for other students or organizations during this period.

The academic work is subject to delayed publication for:

Not applicable

The grounds for delayed publication are as follows:

The parts of the academic work that are not subject to delayed publication can be published in NTNU's institutional archive, cf. Clause 3 a) second paragraph.

Even if the academic work is subject to delayed publication, the organization is to make it possible for the student to use all or part of his/her academic work in connection with a job application or follow-up work in connection with doctoral study.

5. General

This agreement takes precedence over any other agreements that are or will be entered into by two of the parties mentioned above. In case the student and the organization are to enter into a confidentiality agreement concerning information the student obtains while he/she is at the organization, NTNU's template for a confidentiality agreement is to be used for this purpose. If there is such an agreement, it is to be appended to the present agreement.

Should there be any dispute relating to this agreement, it should be resolved by negotiation. If this does not lead to a solution, the parties agree to the matter being resolved by arbitration in accordance with Norwegian law. Any such dispute is to be decided by Sør-Trøndelag District Court or a body appointed by this court.

This agreement is signed in 4 - four - copies, where each party to this agreement is to keep one copy. The agreement comes into effect when it has been approved and signed by NTNU represented by the Head of Department.

Note that the Norwegian version of this standard agreement is the authoritative version.

06.12.2021	Ingebrigt Stamnes Reinsborg

Digitally approved, date (dd.mm.yy) student

07.12.2021	Morten Omholt Alver

Digitally approved, date (dd.mm.yy) supervisor at NTNU

07.12.2021	Lill Hege Pedersen

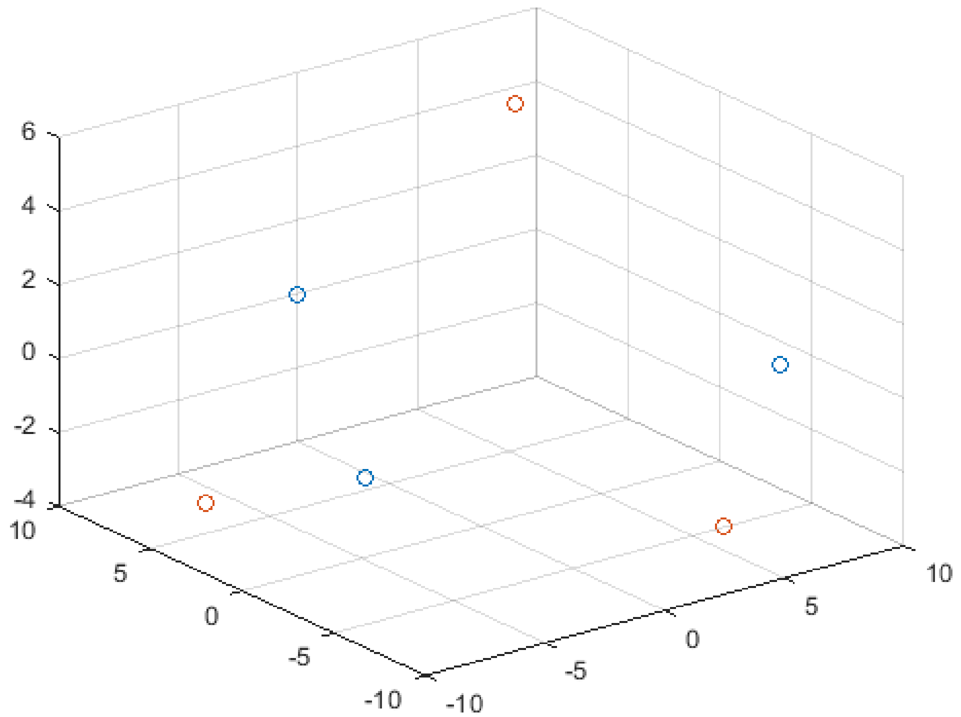
Digitally approved, date (dd.mm.yy) Head of Department, NTNU

place, date (dd.mm.yy) for company/organization
signed and stamped

Appendix B

Additional Code

```
h=10;                          %avstand fra plate ned til rogn
x=4;                           %rognets posisjon i x
y=4;                           %rognets posisjon i y
rogn=x+y*1i;                   %kompleks bare for Ã¥ bruke
 matlabfunksjonalitet
rognradius=abs(rogn);          %avstand fra sentrum i rognemÃ¦ren
pitch=atan(rognradius/h);      %rotasjon om x-akse
yaw=angle(rogn)-pi/2;          %rotasjon om z-akse

actuator_init=10*[0 1 0;-sqrt(3)/2 -1/2 0;sqrt(3)/2 -1/2
 0]'; %aktuatorenens utgangsposisjon

P=[1 0 0; 0 cos(pitch) -sin(pitch);0 sin(pitch) cos(pitch)];
  %rotasjonsmatrise for pitch

Y=[cos(yaw) -sin(yaw) 0;sin(yaw) cos(yaw) 0;0 0 1];
  %rotasjonsmatrise for yaw

actuator=Y*P*actuator_init; %aktuatorenens sluttsposisjon, pitche
 fÃ¸rst for riktig rognradius, sÃ¥ yawe til korrekt rognvinkel


scatter3(actuator_init(1,:),actuator_init(2,:),actuator_init(3,:));
hold on
scatter3(actuator(1,:),actuator(2,:),actuator(3,:));
```



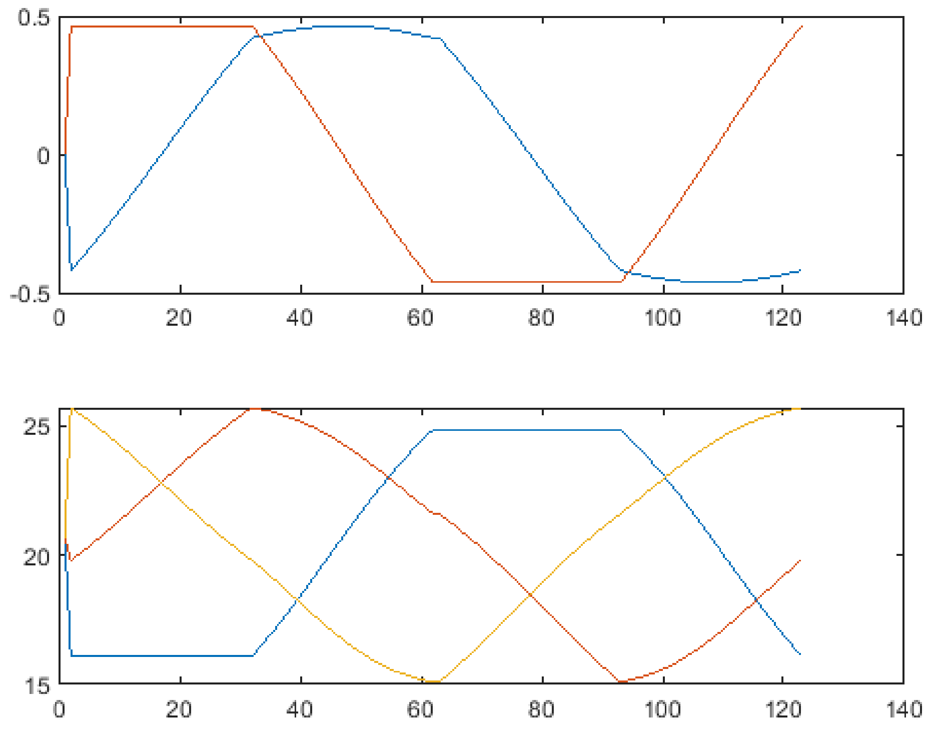
Published with MATLAB® R2021a

```
%
thetas = [0 2*pi/3 4*pi/3]';
rad0 = 4.75;
rad1 = 10;
pos0 = [rad0*cos(thetas) rad0*sin(thetas) zeros(3,1)]' % Upper
 platform
pos1 = [rad1*cos(thetas) rad1*sin(thetas) zeros(3,1)]' % Lower
 platform


platformDist = 20; % Distance between platform centers
% Positions to point at:
x = [0; 7.5*ones(30,1); (7.5:-0.5:-7.5)'; -7.5*ones(30,1);
 (-7.5:0.5:7.5)'];
y = [0; (7.5:-0.5:-7.5)'; -7.5*ones(30,1); (-7.5:0.5:7.5)';
 7.5*ones(30,1)];
z = 15;
%figure, nexttile,plot(x,y, '* -')

global targetVec

theta = [0;0;15];

results = zeros(length(x),3);
resultsLL = zeros(length(x),3);
for i=1:length(x)
    targetVec = [x(i); y(i); z];
    theta = fminsearch(@objFun, theta);
    results(i,:) = theta';

    % Find leg lengths:
    % First transform all lower platform points:
    roll = theta(1)
    pitch = theta(2)
    R = calcR(roll, pitch);
    skewPoints = R*pos1;
    skewPoints(3,:) = skewPoints(3,:) + platformDist;
    % Leg length:
    sqPosdiff = (skewPoints - pos0).^2; % Squared distances
    lDists = sqrt(sum(sqPosdiff,1));
    resultsLL(i,:) = lDists;
end

figure,
nexttile, plot(results(:,1:2))
nexttile, plot(resultsLL)

dlmwrite('roll_pitch_dist.csv',results)
dlmwrite('leg_lengths.csv',resultsLL)

function R = calcR(roll, pitch)
    % 3D rotation matrix (alpha = roll, beta = pitch, gamma = yaw
```

```
    alpha = roll; beta = pitch; gamma = 0;
    R_z = [cos(gamma) -sin(gamma) 0; sin(gamma) cos(gamma) 0; 0 0 1];
    R_y = [cos(beta) 0 sin(beta); 0 1 0; -sin(beta) 0 cos(beta)];
    R_x = [1 0 0; 0 cos(alpha) -sin(alpha); 0 sin(alpha) cos(alpha)];
    R = R_z*R_y*R_x;
end

function value = objFun(theta)
    global targetVec
    roll = theta(1);
    pitch = theta(2);
    translate = theta(3);

    R = calcR(roll, pitch);

    finalVec = (R*[0;0;translate]);
    deviation = targetVec-finalVec;
    value = deviation'*deviation;

end
```

```
pos0 =

    4.7500   -2.3750   -2.3750
         0    4.1136   -4.1136
         0         0         0


pos1 =

   10.0000   -5.0000   -5.0000
         0    8.6603   -8.6603
         0         0         0


roll =

     0


pitch =

     0


roll =

   -0.4205


pitch =

    0.4636
```

```
    0.4089


roll =

   -0.4254


pitch =

    0.4366


roll =

   -0.4205


pitch =

    0.4636
```



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