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| Title: |
| Snake-like Robot |

| candidate(s): | | | | |
| --- | --- | --- | --- | --- |
| Håkon Bjerkgaard Waldum, Marcus Olai Grindvik, Ruben Svedal Jørundland | | | | |
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| --- |
| Supervisor(s): |
| Houxiang Zhang, Guoyuan Li |

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| Summary: |
| [The summary here will be identical to the SUMMARY section of the report] |

This report is submitted by students for evaluation at NTNU Ålesund.

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*Heading 1 Heading for level 1 (hotkey Alt-1)*

*Heading 2 Heading for level 2 (hotkey Alt-2)   
Heading 3 Heading at level 3 (hotkey Alt-3)   
Body Standard text in a paragraph. Use this for all "normal" text (Shortcut Alt-A)   
Definition used mainly in the section entitled "TERMINOLOGY"   
References used in the Reference section.   
AppendixList used in APPENDIX section.   
Comment in blue text. Remove all the text of this type of report.]*

*[NB! This template provides a suggested structure of the main report. The main structure shall be followed.. However, the report must be structured by creating sub-chapters under main shapters. To some extent uou are free to decide how many sub-chaøpters and levels you want. Try anyway to avoid too many levels – normally 3 levels are enough. The level is meant the number of under-the chapter, for example, chapter 4.3.4 is on level 3, while section 3.2 is on level 2]*

summary

*This report is the final project report of Best Practice Course – System engineering. The project of our team is about*

# terminology

RRT – Rapidly Exploring Random Tree

RRT\* - A Variant of the RRT-method

GUI – Graphical User Interface

ESP32 – A type of Microcontroller

TCP – Transmission Control Protocol

UDP – User Datagram Protocol

BLE – Bluetooth Low Energy

# introduction

*[This is the first chapter in the scientific report. It should treat the background for the project, the contractor, the problem / problem history and / or task to be solved. Here you should also say something about the scope or boundaries of the project.*

*Finally, you should briefly describe what the report further includes, amongst other things, what can the reader expect to find in the report.*

*Comment: This is where you will provide an introduction or a kind of presentation of the whole assignment. And it is also where you are going to present the issue to be resolved and any refinements made.*

*If the task has been dealt a specification of requirements, the main features from the requirements should be outlined here, with reference to the full requirements.]*

The project is based on modular robots. The task is to craft a modular snake-like robot that can find an object in a maze with the help of a overhead-camera as well as a front-mounted camera.

This is a task given to us by Houxian Zhang in the course “Introduksjon til Mekatronikk” as a final project for the course.

The goal is that the snake-like robot will be able to find its way around a maze to find an object, by having pre-existing knowledge of the maze by getting a feed from the overhead camera. During a new search after successfully finding the object, it should still be able to find its way around the maze if the maze has been changed, and the position of the object is changed.

There is also a goal of remote monitoring/control GUI. We want to be able to remotely control it via WiFi, and remote monitor what happens with the robot.

In this report we will go through our entire process for the task, from the beginning with building a theory for how this all should be achieved, till the final steps of testing and seeing it through to the end.

## Goals of the project

The specific goals of the project are as follows;

* Make a modular maze
* Use overhead camera to take picture of the maze
* Feed maze through pathfinding algorithm
* Send this path to the snake so it can efficiently search through it
* Search for object in maze using front-facing camera on snake
* Find the wanted object

The goal is that one can build the modular maze however one wants and the snake should be able to find the object in the most efficient way possible.

## Project Planning

The project planning consisted of separating the project into its base parts; hardware and software. From there subcategories were created for each of the categories.

Hardware was separated into;

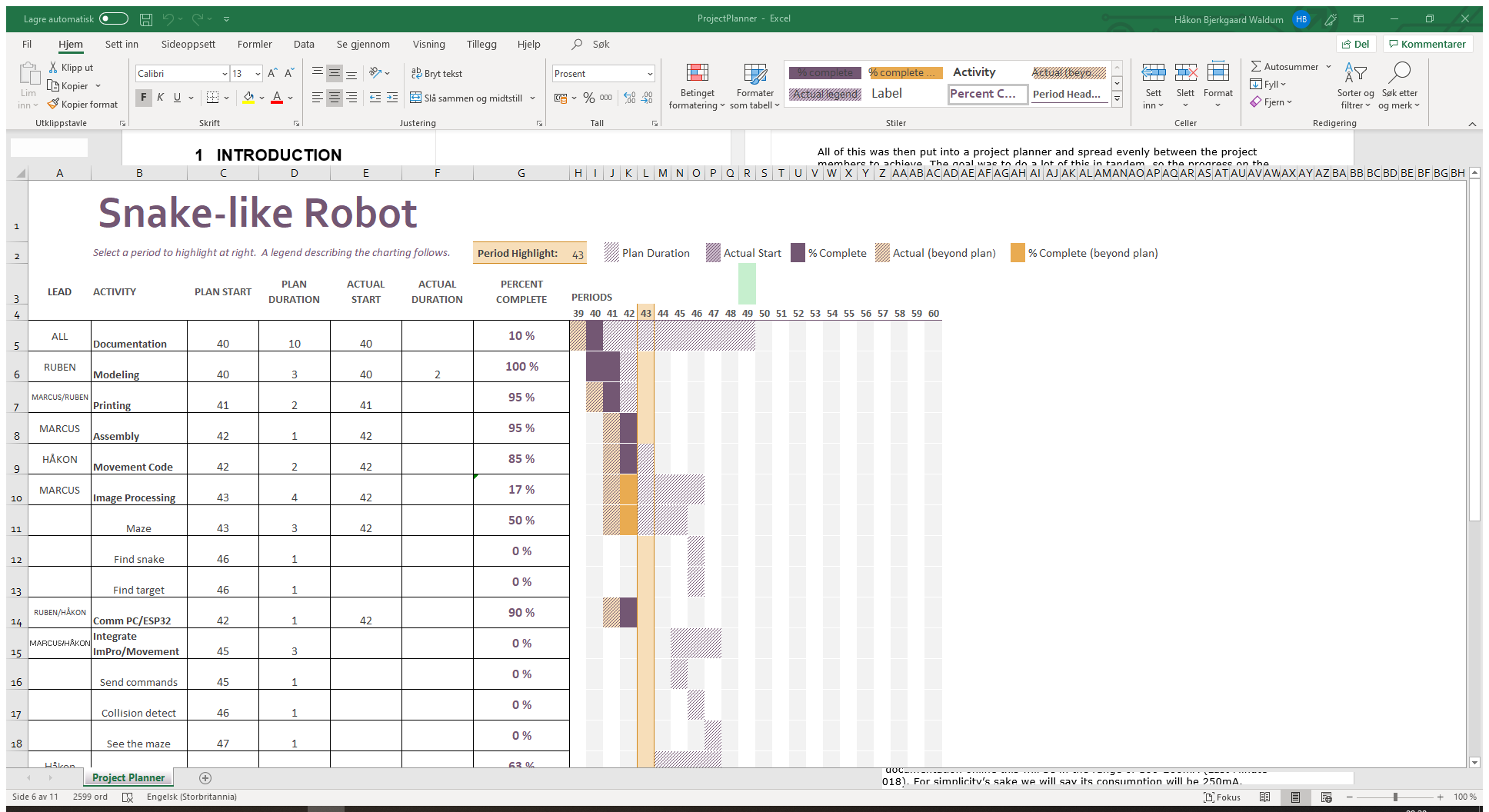
* Modelling
* Printing
* Circuitry
* Assembly
* Mazebuilding

Software was separated into:

* Image processing
  + Maze
  + Find snake
  + Find Target
* Communication ESP32/PC
* Pathfinding
* Remote GUI/Monitoring
* Giving commands to the snake

All of this was then put into a project planner and spread evenly between the project members to achieve. The goal was to do a lot of this in tandem, so the progress on the project would be efficient and swift.

### Project timetable



Timetable for project

The timetable (found in the appendices) was created and the tasks spread evenly between the project members. Here there are goals with corresponding predicted times for starting and finishing each task. There is also information here about how long the tasks actually took, which is shown compared to what was predicted.

During the project this was regularly updated so each member could see how the others were doing with their task if the work was done separately instead of together at the university.

## Risks and Possible Challenges

During this project there are a lot of risks and possible challenges that will be faced. This will be detailed and reflected upon during this report.

### Parts and Movement

During the movement of the snake-like robot there is always an inherent risk in parts being damaged by the movement or unintended collisions. This is something that has been thought of, and all parts are fastened tight during assembly to ensure that movement of parts during the snakes movements will be minimal.

There is also an inherent risk in the cabling of the electronics, that these will get worn by all the movement in the modules during a run. To mitigate this the modules have gotten guide rails for the cables to run via, so the wear will be reduced. The length of the cables have also been extended by a bit, so there is no risk of them being ripped apart during a movement.

### Pictures and lighting

As this will be done in different environments and at different times of day, there has to be some failsafe in that the pictures and video streams will not necessarily have the same lighting every time the program is run.

# Background and theoretical basis

## Reasoning for project

The reason that this is the project that was chosen was the challenges that would arise during the building and programming. Making the snake solve a maze is in itself not that big of a challenge, but incorporating a over-head camera to give the snake directions and finding the most efficient search-path is quite a challenge.

The combination of using the over-head camera with a front-facing camera presents quite the interesting problem; how does one synch the information from one camera with the other, and when the object in the maze is found, can we make the over-head camera be able to present this on just from the picture and position of the snake?

## Usage in the real world

This project has a lot of possible uses outside in the real world. Here some of them will be presented;

### Search-and-rescue

In a potential case of an earthquake hitting a city, one could have a drone fly over a location with a lot of rubble, to give a search-robot a general layout of the area, and guide it through the most efficient way of searching the area. Then by synching the robot and overhead drone, it could be possible to show on a video stream from the flying drone where there are possible locations for what the search-robot thinks are humans.

### USAGE 2

Fill text

## Power Consumption

When choosing the amount of batteries and their size, there are several things to take into account. The power consumption of the ESP32, as well as the 5 servos, the boost converter and the front facing camera will all factor into how long the battery time of this snake-like robot will be.

The ESP32 has several different modes it can run in to save on power consumption. For our purpose where we want access to its WiFi-capabilities we have to run it in what’s called “Active Mode”, which is the mode where its power consumption is biggest. According to documentation online this will be in the range of 160-260mA (Last Minute Engineers, 2018). For simplicity’s sake we will say its consumption will be 250mA.

The servos power consumption will all depend on how much torque it will need to apply to change its position. The producer of the servo has documented that the idle power consumption is 170mA, and at stall it will consume 1200mA (Tower Pro, 2019). From our experience we can see that it generally pulls around 200-300mA.

When it comes to what camera is used, it ended up being an ESP32-CAM, which has a OV2640 camera installed onto an ESP32. From what documentation is found about this unit, it seems that the maximum draw from it will be around 310mA (AI-Thinker, 2019). This is with flash on, as well as brightness set to maximum. So realistically it will draw less, but it’s better to calculate with the worst case scenario.

The boost converter has an efficiency of 90% according to the manufacturer (Texas Instruments, 2019).

We can therefore summarize the power consumption;

|  |  |  |  |
| --- | --- | --- | --- |
| **PART** | **POWER CONS.** | **AMOUNT** | **TOTAL CONS.** |
| ESP32 | 250mA | 1 | 250mA |
| ESP32-CAM OV2640 | 310mA | 1 | 310mA |
| MG995 | 300mA | 5 | 1500mA |
|  |  |  |  |
|  |  | TOTAL: | 2060mA |

The total draw at constant power consumption will be around 2060mA. When accounting for the boost converter we have to calculate this over to Watts, and see how much watt the boost converter will have to produce to reach this amount.

This is the general formula for calculating power. The voltage this all will run on is 5V.

With an efficiency of 0.9, the boost converter will have to produce;

Which then brings us back to;

So our current draw will be 2289mA.

Our snake-like robot has mounted four 2000mAh batteries. This means that our snake-like robot will in ideal situations run for just about 3.5 hours before running dry.

## Algorithm for Searching

After getting a picture of the maze, the picture is run through several filters before being used in a RRT\*-algorithm, which will find a path through the maze.

The RRT\* method is a continuation of the regular RRT-method. It is based on random node-placement and checking for collision before expanding onwards and doing this on repeat until it has run all its iterations.

The big difference between RRT and RRT\* is that RRT\* will look at old nodes when continuing its path to check if it can rewire the path to be more efficient. It does this by giving each node a “cost”, which is based on its distance to its parent node. It therefore compares the cost to its current parent, to another node that is close to check if the cost can be reduced.

This all results in a more linear path to the goal, instead of the path which would come from the regular RRT-method, which almost always will be very full of twists and turns and will not be as efficient.

# methods and materials

## Parts and Assembly

### Parts Included

The snake-like robot has a lot of parts included in it to work properly. It consists of a total of 5 modules that are connected to make it able to move as we want. The modules are basically all the same, but some of them have some unique flavor for all the parts to be able to fit properly. The front and the back are also unique in that the front has to be able to fit the front-facing camera, and the back has to have a end-plate so the batteries do not fall out.

|  |  |  |
| --- | --- | --- |
| **PART** | **AMOUNT** | **FUNCTION** |
| ESP32 | 1 | Controlling the movement of the snake-like robot, as well as communicating with the PC which does all the image processing, pathfinding etc. |
| Boost Converter | 2 | Converts the nominal voltage from the batteries to 5V for the servos and the ESP32. |
| ESP32-CAM | 1 | ESP32 with a camera mounted on it, mounted in the front of the snake-like robot, used for finding the object in the maze. |
| Battery 2000mAh | 4 | Used to supply the robot with the power required. |
| TP4056 LiPo Battery Charger | 1 | Used to slowly recharge the batteries between usage when connected through a USB. |

#### Servos

The servos used are a type which are called TowerPro MG995. These are quite small, and have can turn from 0° to 180°, and run on 4.8V to 6.6V. These make them ideal for this project, as we do not need more than 180° turning for the movement of the robot.

The power consumption of them also make them ideal, they use quite a bit as discussed earlier in the report, but they do not consume so much that it is a problem for the life time of the robot.

Their update time also make them quite good for this, as they only use 0.2s to turn 60° at ~4.8V (Tower Pro, 2019). This make them quite fast, which in return makes the robot able to move quite fast if need be.

#### ESP32

The microcontroller used in this project is a SparkFun-microcontroller with the ESPRESSIF ESP32 chip. When you compare this to an Arduino, the Arduino falls quite short when it comes to computing power and speed.

It has a dual-core processor with up to 240MHz clock frequency, as well as integrated WiFi-transceiver and dual-mode Bluetooth (both classic and BLE) (SparkFun, 2019).

This all makes the controller quite fast, and ideal for a situation like this where a lot of information has to go back and forth while doing tasks.

The ESP32 mounted in the front with a integrated OV2640 camera has the same specs as the SparkFun-module, the only difference being the OV2640 camera that is mounted on the board.

The camera mounted is capable of giving pictures and streams in a resolution up to 1600x1200px (ArduCam, 2019). At full resolution it can do up to 15fps. This is not very relevant for the project, as there will mostly be still pictures returned from the front-facing camera.

#### Batteries

The batteries used are relatively standard Lithium-Polymer rechargeable batteries. They have a nominal capacity of 2000mAh, and a nominal voltage of 3.7V (RS Pro, 2019).

The reason for using these exact batteries are their size and capacity. The size is 62x43.3x7mm, which make them ideal for fitting inside the modules for the robot, which have a dimension of 64x64mm.

The capacity makes us able to run the robot for a long time, without having to recharge the batteries. This is discussed further up in the report, under power consumption.

#### Boost Converter

The boost converters used for this project are converters that can do 2V-24V to 5V-28V, with an output of 2A (BangGood, 2019).

With the total consumption of this robot being around 2000mA, there was a need for boost converters that could handle around that output. So with two of them installed, there was no fear of getting brownout-errors from the ESP32 (Brownout-error is an error given when there was not enough power available).

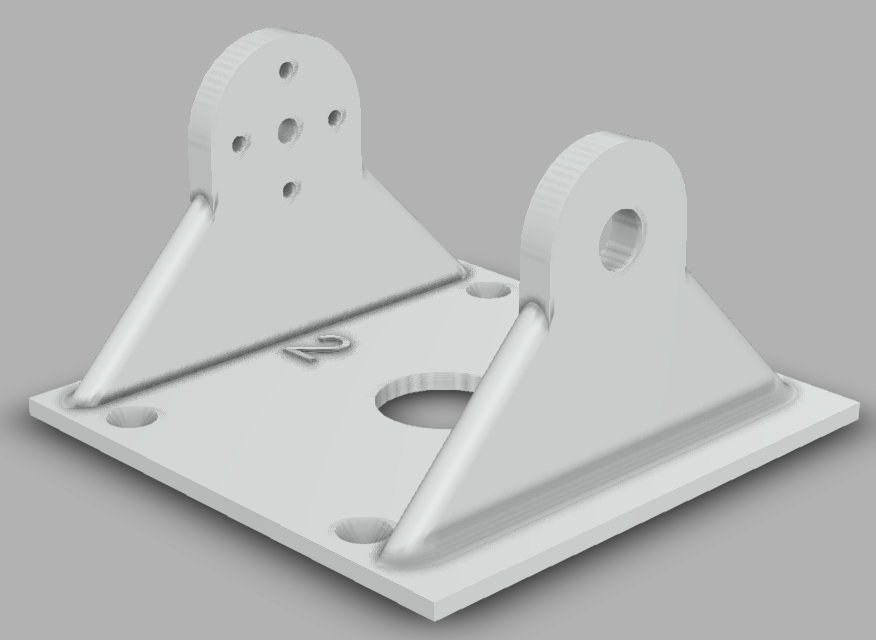
#### USB Battery Charger

For the charging of a battery, a TP4056 LiPo Battery Charger with USB connection was used. This has a charging current of 1A and a full charge voltage of 4.2V (BangGood, 2019).

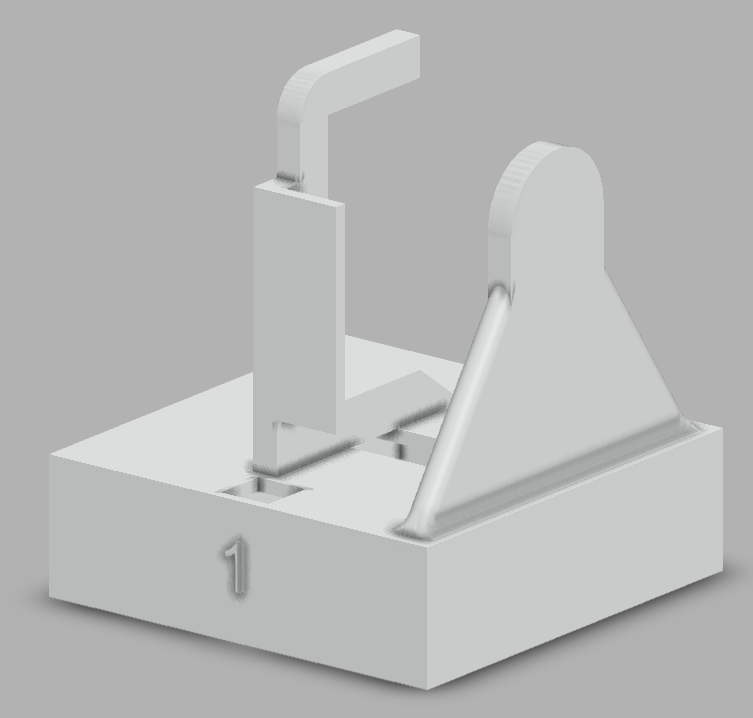
This makes the charging not the fastest, but at least gives a consistent way to charge the batteries easily by using a micro USB-cable.

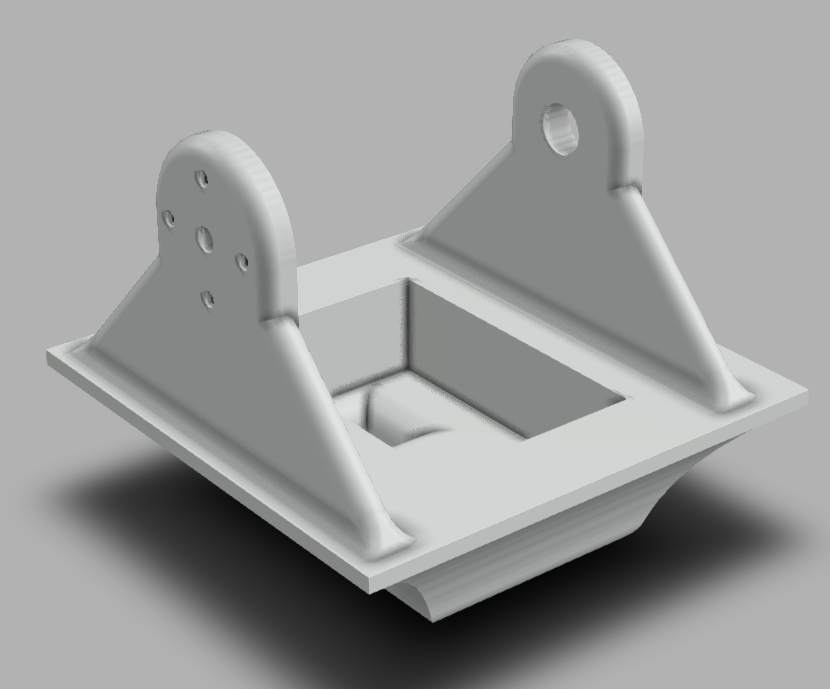
### 3D Models

All mechanical parts for the snake-like robot are modelled using Fusion 360, and are made so it can be expanded with relative ease. Under are shown the basic parts, with also some unique parts, and the complete assembly.

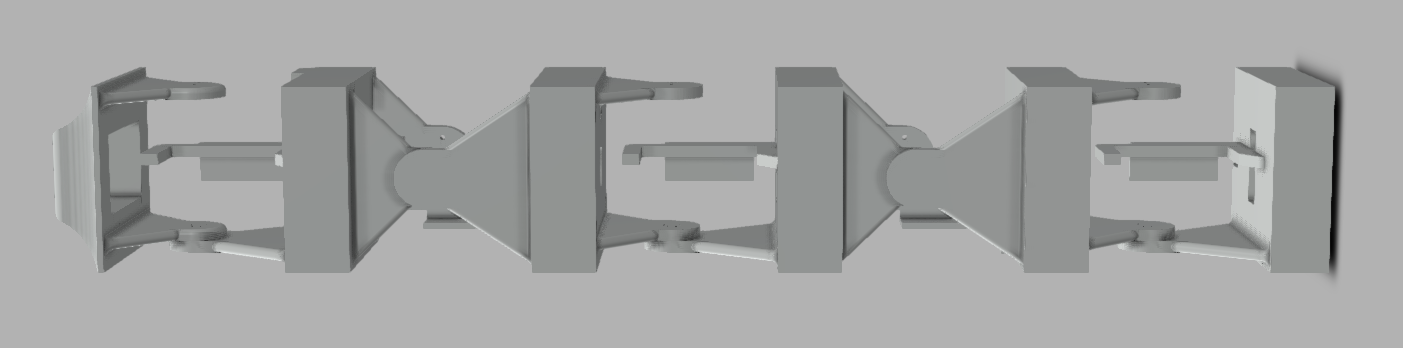


Over one of the parts are shown, this is a basic part that is connected to the other piece which will have the servo mounted on it.

This part is connected to the first part shown. This is the one that has the servo mounted on it, it also has a thick base which has room for batteries, boost-converters or similar parts.

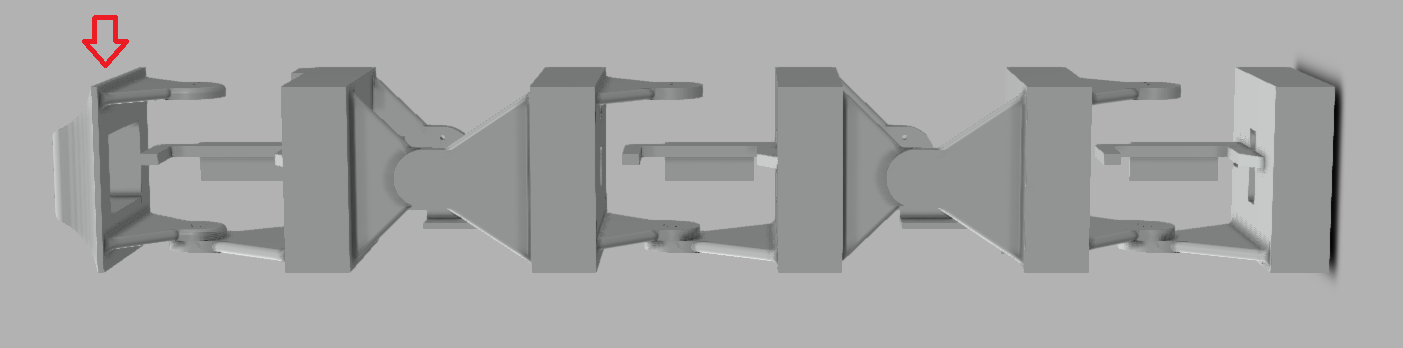


This is the front of the snake-like robot. This has space in it for the front-facing camera. This part will be painted in a distinct color, which makes it possible to find the front of the snake-like robot with ease.

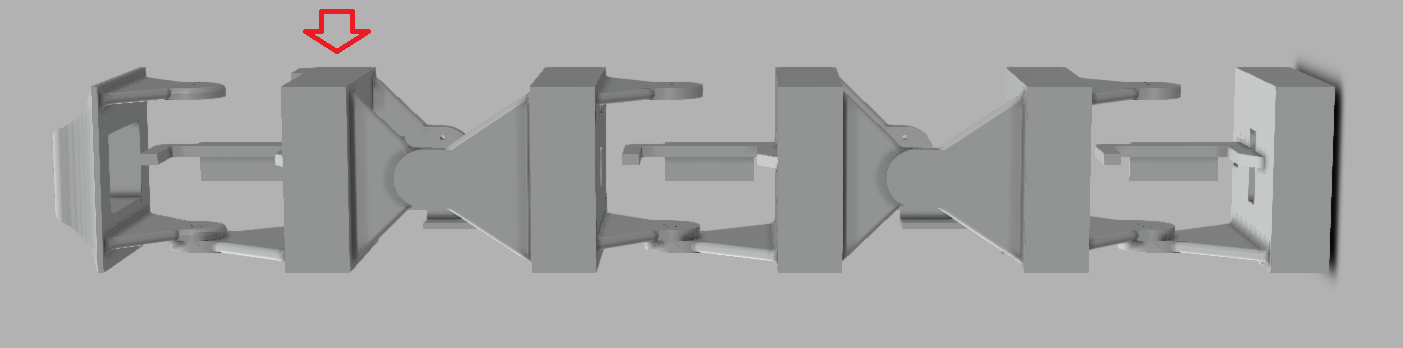


The snake-like robot assembled completely is shown above. As mentioned earlier, it consists of 5 modules, with a designated front, and a designated back. All the parts in the middle between the two modules mounted together are made for storing the electronic parts needed for the project.

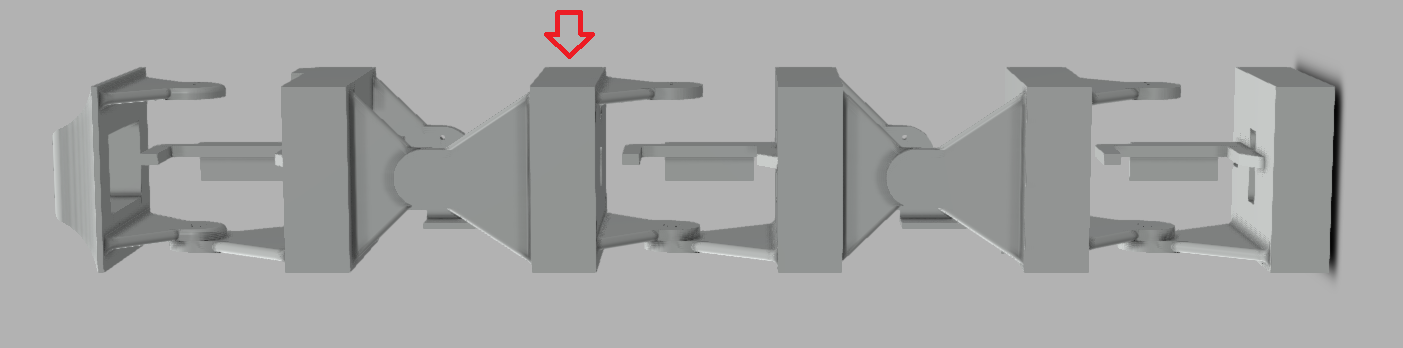
### Assembly



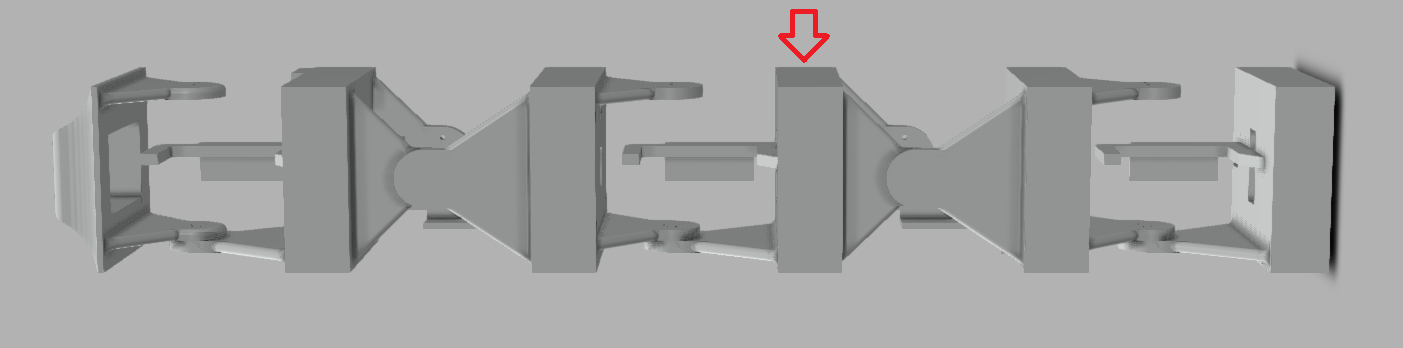
In the first piece there is only the ESP32-CAM which is mounted. This part is only connected to power, and sets up a Web Server on its own IP-address, port 80. Which is accessed by Python to retrieve a video stream or a picture.



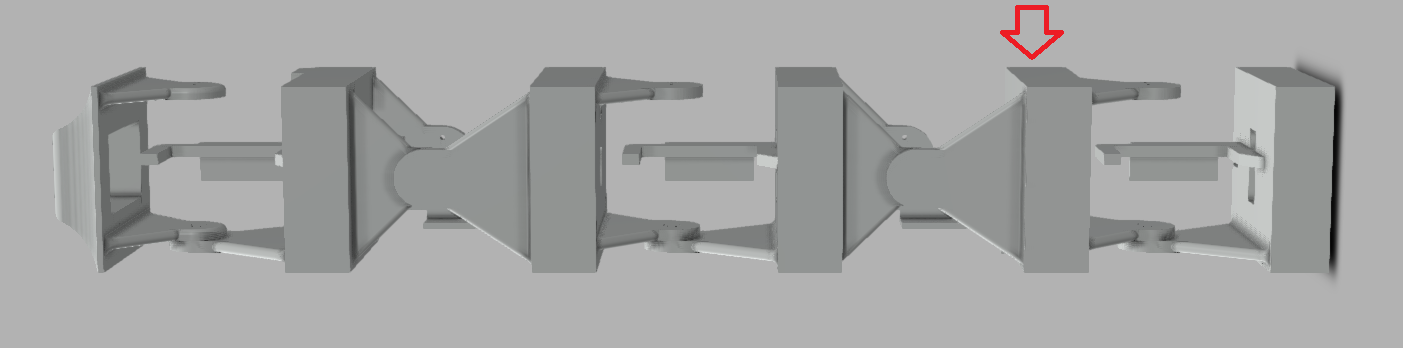
In the second piece there is mostly just circuitry, a connection point for ground and +5V. This is just a junction for the cables basically.



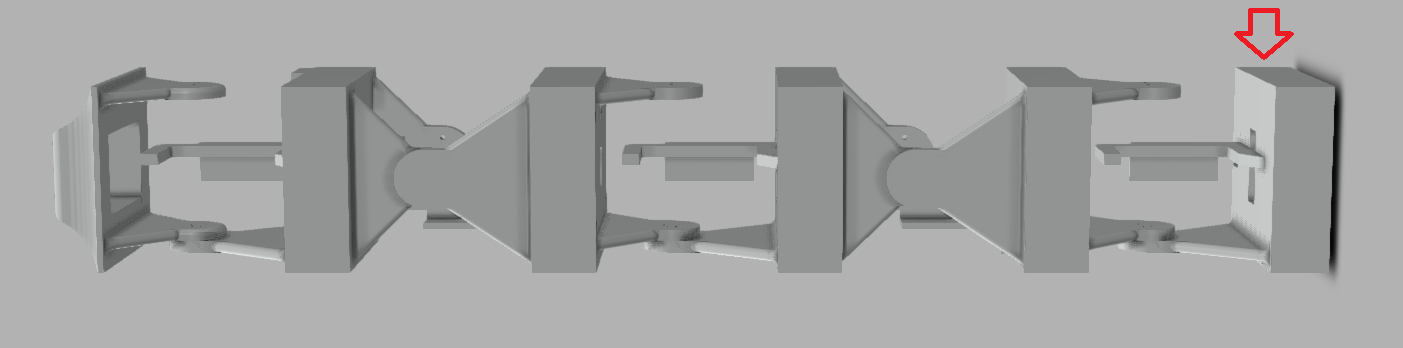
In this part the ESP32 is mounted, as well as a button which is mounted to be able to reprogram the ESP32.



‘In this part the whole power circuit is mounted, which consists of the two boost converters, external power port as well as a power button to be able to remove power from the servos and the ESP32.



This part consists of two batteries connected in parallel. These just supply the rest of the robot.



This part consists of two batteries, as well as the USB recharging board, which makes it possible to recharge the batteries slowly.

## Software

The software for the robot is done with two programming languages;

* Arduino
* Python

The ESP32 and ESP32-Cam both run on Arduino, and the rest of the programming (image analysis, pathfinding etc.) run on Python.

### Movement

The movement is done in the ESP32, and is done with Arduino. The movement is based on a phase difference between the different modules to actually make it move efficiently.

This is all based on the lectures from Houxiang Zhang, where he details what his own experiments when working with these kind of modular robots resulted in.

For the forward and backward movement, the formula used is;

This is then sent to the vertical modules of the robot. The phase shift between the modules for forward movement is 120°.

When it comes to turning, this is done by just adjusting the angle of the two horizontal modules of the robot by giving them an offset adjustment. This is done by giving them a direction (left or right), then giving them an angle to turn by.

### Commands

The commands given to the ESP32 is done via UDP, this is detailed further into the report under Communication. The PC sends single letter commands to the ESP32, some examples are “f” for forward, “b” for backwards etc.

This makes the snake go forwards or backwards respectively. The snake then sends information back to the PC by just sending an “a” every 0.5s to say that it is alive, this is done so there is knowledge about whether the snake is able to communicate back and forth since UDP just sends and forgets, and gives no feedback to the sender if the message arrived.

### Image Analysis

The image analysis for this project is done in Python, by using the OpenCV library. This supplies a wide array of tools to do almost anything with incoming streams or pictures.

#### Overhead Camera for Maze

For the overhead camera the basic gist of the operations are;

* Take picture
* Blur picture to smooth out uneven colours
* Use Canny Edge detect to find the maze
* Use Hough Transform to find lines
* Return these lines to the RRT\* method

When blurring the picture the Gaussian Blur-method is used. What this does is that it is smoothing out the uneven colours, as it is a low pass filter. What it basically does is use a 7x7 mask, and convolves this over the picture. It was decided to use the Gaussian Blur because this is one of the most efficient ways of blurring a picture, as well as because the Canny Edge Detect works best if a Gaussian Blur is applied before running it.

The Canny Edge detect works by detecting the intensity of the gradients in X- and Y-directions, before it finds the edge gradient by using this formula:

Thus finding the edges of the picture.

By then applying a Hough Transform to find the lines. This works by it detecting possible lines and voting over what it will determine as lines. This makes it possible to narrow in what it actually detects.

It then gives out a x-coordinate, y-coordinate and its angle relative to the X-plane. The function used in this project is a Hough Transform which is based on probability. This returns the (x1,y1) and (x2,y2) of the lines it finds. This makes it easy to use in the later functions for producing the maze in a coordinate system for the RRT\* to work with.

#### Overhead Camera for the Snake

Skriv om hva man gjør for overhead-camera for å finne slangen

#### Front-facing Camera

Skriv om hva man gjør for front-facing camera

### Graphical User Interface

Snakk om hva som skjer med GUI’en

### Pathfinding

The pathfinding for the project is done with the RRT\*-method. This method takes in the coordinates for all the lines found from the image analysis of the maze, thus creating a maze in a coordinate system.

It then gets the information about the start point for the maze (the snakes position), as well as all the “goals” in the maze, which will be the different dead ends.

It then iterates over these goals, to try every possible way to each goal, and then to the separate goals after. After it has computed all this, it compares the different paths to find which path will be the most efficient path to take for the snake to search the whole maze.

When the final path is chosen, it will send this path to the GUI to show to the end-user, and then send all information to the algorithm that sends the commands to the snake and monitors its position.

### Logging

The logger runs in the background at all times, and creates a document with everything that happens during the programs run. It details all commands sent to the snake, how many iterations the pathfinding-algorithm ran for, as well as all other communication between parts of the program and between the PC and the ESP32.

This makes it possible to recreate a run for the snake, by having all information available about what happened, what it did and what commands were sent during a run.

## Test Setup and Plan

## Computer Analysis Programs

## Communication

### Communication between ESP32 and PC

Our initial plan for communication between the ESP32 and the computer was to use WiFi and send information via TCP. This is because TCP sends a message back when receiving packets to give notice if the package does not arrive or there is any other problem (receiver not connected to the internet etc.). But during the testing phase we saw that sending just a 100x200 array could take up to 9s one way. This would take way too much time to be able to actively send pictures and get information back to the snake to tell it if it has found the object.

It was quickly decided to try out UDP to check the time for sending information via this protocol instead. The downside to using UDP is of course that it is “fire-and-forget”. It does not care if the receiver is not online, it send the packet and is quite happy with the result regardless of what happens with the packet.

During testing here it was found that sending the same array as earlier took less than 1ms. This is a drastic improvement and it was quickly decided that this is the protocol to use. We do not see it as a huge risk, as the PC and the snake will not be far from each other, and we will also make a checksum-kind of check to see that the package is received as it is expected.

As for how to send the pictures from the front-facing camera to the PC, after testing the first camera that was supplied (a VC0706 UART Camera) it was found that it did not want to communicate with anything. Therefore it was changed with a ESP32 with integrated camera. This camera creates a webserver which it “streams” its content to. This makes it quite easy to use Python to send requests to the server, which makes the camera take a snapshot.

# results

## Theoretical Analysis

## Experimental Results

## Design Alternatives

### Alternative 1

### Alternative 2

### Alternative 3

## Challenges and Problems

### Communication challenges

During the programming of the Arduino the program was sliced into separate modules to easily be able to test each module to see that everything worked as expected. During the merging of the programs there came some challenges that were not expected.

Specifically during the merging of the movement and the communication modules. When initializing the Arduino program during the testing here, everything went as expected. The module initialized and attached the servos to the right pins, and then connected to the WiFi and sent the test-package to a given IP and Port. But during the parsing of an incoming packet the ESP32 raised a Guru Meditation Error (the ESP32’s variation of a BSOD), saying “LoadProhibited” and gave a dump of information.

From what we could deduce from documentation found online this was because the application attempted to access a member of a structure, but the pointer to the structure was NULL (ESPRESSIF, 2019). After a lot of testing and debugging we found that if we changed the pins the servo attached to, everything went fine. After this worked, we realized that one of the pins we attached the servo to was pin 16, which is an RX-pin, which probably is what caused our problem.

# Discussion

# Conclusion

*[Here you should present the main results of the work together with the experience you've gained in the process. Here you will summarize the most important chapter discussions, and arrive at a conclusion. Did you solve the problem as required or expected with the chosen methods? Was the result according to the mission stated bye the employer? What did we learn from this project, both scientifically, and not least in relation to the work process of a project? ]*

# ReferENCES

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*[Authors, title of book or article, name of journal or publisher / publisher, or no date for the journal, year, place as referred to in the report. Course lectures can also be referred to, as with the title on the subject and the name of the presenter. Internet pages must also be included. Even oral discussion partners can be included in the reference list, when this is a source of important or detailed information used in the report*

*see example below]*

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Appendix

*[Material and data prepared or collected in connection with the project, but not natural to include in the main part of the report. The reason cam be the level of details, volume or format.*

*Typical examples are: detailed calculations or analysis, set of design drawings, supporting information, computer code etc…. ]*

Appendix A Test data from engine testbed

Appendix B FEM analysis of cylinder liner

Appendix C Design drawings

Appendix D Material properties

Appendix E etc….etc…..