Intrinsic force-torque sensor system for a next-generation snake robot (HOAL)

May 16, 2021

Bachelor thesis

Preliminary project report

Authors

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Supervisor: Pål Mathisen

Client: Jostein Løwer

NTNU
Norwegian University of
Science and Technology

Introduction

Intent of report

The *Preliminary Project Report* intends to iterate and identify some of the challenges of the project, as well as elaborate on the scope of the main bachelor thesis report. It iterates on the technical aspect of the project, moreover it describes the projects preliminary approach to the upcoming challenges. Furthermore, it defines the groups goals for the Bachelor thesis.

It also presents the management part of the project, regarding organization, cost plan, risk evaluation and quality assurance.

Background

Mamba, the current snake robot at the Department of Engineering Cybernetics at NTNU, is outdated and due for an upgrade within the next years. One of the planned upgrades is a new torque sensor, developed by Pål Liljebäck in 2011. Due to the then current market there were no viable commercial sensors available and Liljebäck developed his own, which has several flaws, making it unsuitable regarding the importance of accurate and reliable torque-measurement upon proving *Hybrid Obstacle Aided Locomotion* as concept. The target of this project is therefore to find a more suitable solution for torque measurement. Technology, and the market for technology, makes rapid advancements over a 10 year period (since the original iteration of Liljebäck's snake robot) so its desired that the solution works upon commercially available sensor technology. Discovery of a suitable commercial sensor, would make the upgrade process of the current robot streamlined and any repairs to said component would be simplified.

The thesis assignment

<table>
<tr><td colspan="2">Navn bedrift:
NTNU ITK</td><td colspan="3">Kontaktperson: Øyvind Stavdahl
Epost: oivind.stavdahl@ntnu.no</td></tr>
<tr><td colspan="5">Tittel på oppgave:
Intrinsic force-torque sensor system for a next-generation snake robot</td></tr>
<tr><td>Hvilken studieretning passer oppgaven for? (kryss av for alle aktuelle retninger):</td><td>Automatisering
X</td><td>Elektronikk</td><td>Elkraftteknikk</td><td>Instrumentering
X</td></tr>
<tr><td colspan="5">Short description:
The assignment revolves around the subject of snake robots. Snake robots are hyper-redundant robots intended to mimic biological snakes. The HOAL project (where HOAL means Hybrid Obstacle Aided Locomotion) aims to make snake robots autonomously navigate in rugged and cluttered terrain. In the HOAL project the robot seeks to use the fixed obstacles that it encounters in its path to aid propulsion. To achieve this goal, though, there is the need for an advanced sensor system that lets the snake robot gather sufficient information about its environment, information that will then be used to decide how to move. The core part of this sensor system is then the ability to continuously and precisely sense the forces and torques that are acting on each joint. This assignment focuses then on the development of an improved force-torque measurement system to be implemented in the next generation of snake robots.

Expected key tasks (all of them in collaboration with the HOAL-team):
Get acquainted with the Mamba robot, and with the previous research on snake robots from the Department of Engineering Cybernetics.
Develop a specification for a force/torque measurement system for a novel snake robot.
Investigate the market for commercially available force-torque sensors and identify which ones are suitable for a novelsnake robot.
Build a test model for the force/torque sensor system, test it in real life conditions, and assess its performance</td></tr>
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As presented in the course document *"Bacheloroppgaver 2021"*

Contents

List of Figures

Nomenclature

ITK	Department of Engineering Cybernetics
HOAL	Hybrid Obstacle Aided Locomotion
Torque	Torque is the force that causes an object to acquire angular acceleration.
Force	An interaction that, when unopposed, will change the motion of an object.
m	Mass
a	Acceleration
τ_n	Symbol for torque applied on the n'th joint
h_n	Symbol for the constraint force vector applied on the n'th joint
f_{ext}	Symbol for external forces vector
F_R	Symbol for friction force vector

1 Theory

1.1 Torque

Torque is a measurement of the rotational force causing an object to acquire angular momentum. Torque is measured in either Newton-meters or foot-pounds and is most commonly referenced in the automotive industry where it describes the available twisting force an engine can generate when it exerts itself.

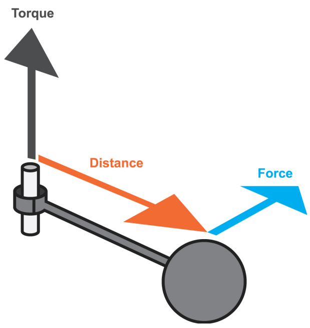


Figure 1: Relation between force and torque

$$\tau = r \times F \tag{1}$$

$$\tau = ||r||\,||F||\sin\theta \tag{2}$$

where τ is the torque vector
r is the position vector.
F is the force vector.
θ is the angle between the force vector and the lever arm vector.

Wikipedia Torque [1]

1.2 Torque and HOAL

The main appeal of building an artificial snake is the real-life counterpart's ability to exploit rough terrain. Snakes move by friction, the scales and schutes on the belly are asymmetrically shaped to only provide friction in a single direction. If this single direction friction where to be made to omnidirectional as seen in [2] or removed all together the snake would be unable to propel itself. Snakes therefore heavily exploit the roughness in the terrain to locomote. This is called *Obstacle Aided Locomotion* and revolves around using the body to put pressure on irregularities in the terrain to push itself in its desired direction [3]. As this type of locomotion can be achieved entirely without relying on friction it is the most efficient way a serpent can move.
This ability to move better in terrain than on smooth ground is the main appeal of snake

robots and why the snake-group chose to create a HOAL.
As the snake robot is autonomous the knowledge of position is crucial to the snakes movement, traditionally this has been done by utilizing pressure sensors to accurately measure the force exerted on each joint by the terrain. Although this type of system is fully functional the snake-group's current iteration, Kulko has implemented the more experimental *torque* model. This model revolves around the physical torque felt by the individual joints of the HOAL and has the benefit of only requiring a single sensor per joint thus simplifying a already tremendously complex system. One thing to note is how reliant a torque system is on accurate measurements, as explained by Christian Holden and Øyvind Stavdahl [4] *"Given a set of external contact points and a desired total propulsive force, we show which motor torques are necessary to achieve this. The problem typically presents an infinite number of solutions, and is therefore solved by minimizing the consumed energy (using motor torque as a proxy)."*

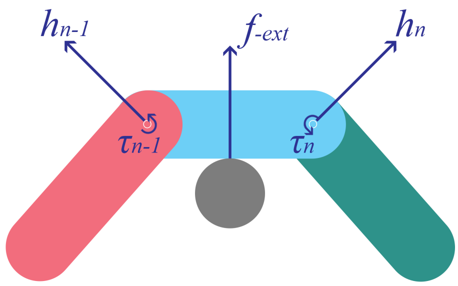


Figure 2: Forces applied on the snake joints when pushing up against a stationary object

The challenge and aim of the thesis is through measurement of torque and constraint forces on each axes, provide the necessary values to assume or approximate external forces applied on each joint. The equation is derived by Newton's second law, as described in equation (4). It relies on the assumptions that mass is known, accelerations is measured through an accelerometer and there is little to no friction force applied on the joints.

$$F_R \approx 0$$

$$\Sigma F = ma \tag{3}$$

$$f_{ext} = ma - h_n - h_{n-1} \tag{4}$$

1.3 Measuring torque

Torque can be divided into two types, static- and dynamic torque. Static torque is the torque applied when it is in equilibrium with countering external torque/forces, and therefore is virtually stationary in terms of rotation. Dynamic torque is the torque applied to the object when the force applied is larger than the countering torque/forces, and therefore is accelerating and has an angular momentum that could be measured. Static- and dynamic torque, in terms of the measurement technique, is drastically different, and both can't usually be measured with the same sensor.

Different types of torque sensors: [5]

Absorption type:
Introduces a countering force/torque to a rotating shaft, measures it and thereby is able calculate the torque. Examples are frictional absorption, hydraulic absorption, electro-magnetic absorption and prony break. These sensors usually measures dynamic torque.

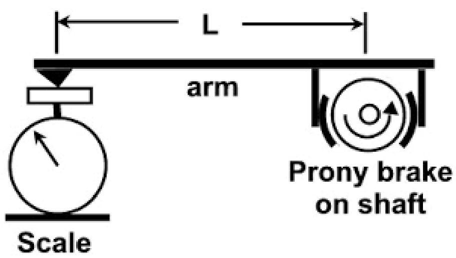


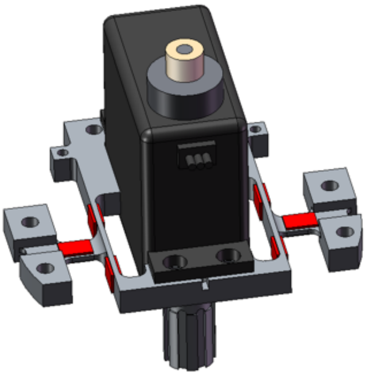
Figure 3: Illustration of the functionality of a prony break sensor

Transmission type dynamometer:
Measures the shear stress a shaft applies to a surface, and thereby measures static torque. The relation between torque and the parameters of a solid cylindrical shaft under shear stress is given by (5).

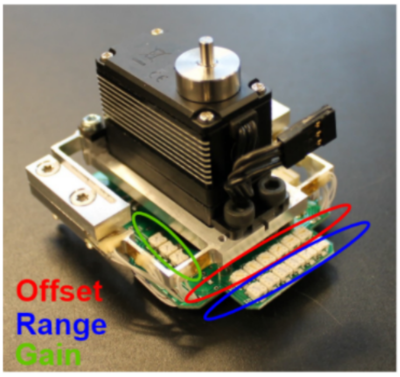
$$\tau = \frac{G\pi r^4\phi}{2l} \tag{5}$$

where G is the modulus rigity of the shaft material.
r is the radius of the shaft.
ϕ is the angle of deflection.
l is the length of the shaft.

The torque is measured by either measuring the deflection angle ϕ caused by a twisting force, or by detecting the effect of this deflection on transducers like strain gauges. The Mamba robot uses a strain gauge measurement system shown in Figure 4.



(a) 3D model of the strain gauge system



(b) The calibration system

Figure 4: The force-torque sensor system the Mamba snake-robot

1.3.1 Model examples

Below there is listed several different types of commercially available force-torque sensor systems.

- Prony brake sensor i.e. Slip Ring Torque Sensor T4A by HBM. *Dynamic* [6]
- TRS600 rotary torque sensor by Futek *Dynamic rotary* [7]
- The Kulko measurment system. *3-axis static* [8]
- K3R70 3-axis torque sensor by Me-Meßsysteme. *3-axis static* [9]
- K6D40 6-axis torque sensor by Me-Meßsysteme. *6-axis static* [10]

2 Technical part

2.1 Problem description

As mentioned in *Background* the force-torque measurement system in the most current snake robot on ITK *Mamba*, is flawed, old and inaccurate. The aim of this project is to investigate the market for commercially available force-torque sensors and develop a platform for force-torque measurement on future snake-robots. There are three quite substantial flaws with the current system; linearity, bend-ability and calibration. Linearity is heavily linked to calibration as well as heat. The system will output exponentially different values in correlation with rising or sinking temperatures. Traditionally this has been combated by utilizing a calibration system to fine tune the output to preform well within a certain range but due to the systems rapid temperature flux this range is far to small. This lack of heat dissipation is caused by the original intent of the system to be waterproof.
Another issue at hand is the calibration of the sensor system itself. To successfully measure torque in 3 axis you will need a total of six strain gauges per joint, each of these further require a Wheatstone bridge consisting of 2 potentiometers needed for manipulation of the bridge balance. This results in a total of 12 potentiometers per joint that needs to be manually adjusted and calibrated.

A picture of the current solution can be seen in 4.

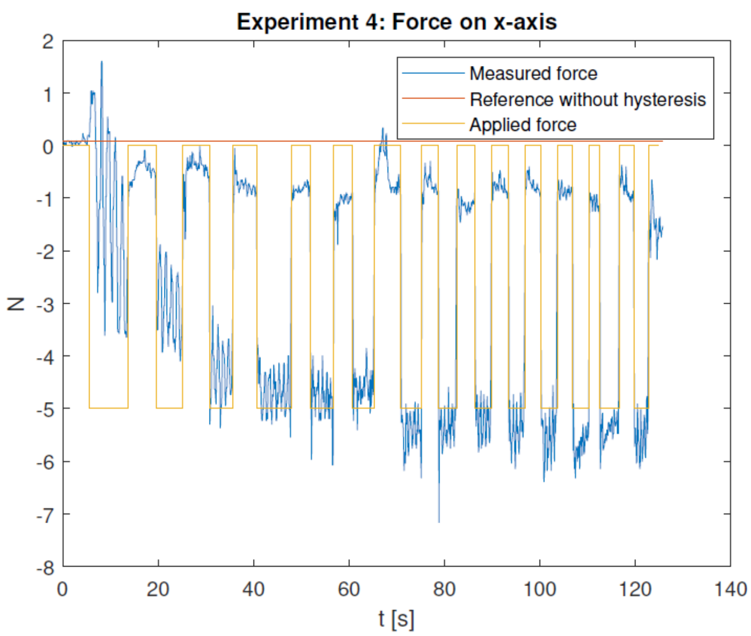


Figure 5: A graph from Veslum's experiment on the Mamba sensor system, showcasing the inaccuracy and hysteresis, in this case, force measurement along the x-axis. [11]

2.2 Project intent

This subsection describes the intent of the project as stated in *the thesis assignment* and in project meetings and seminars with the client and supervisor.

2.2.1 Investigate the market

Based on specifications defined in the project in collaboration with the client, the project aims to locate an appropriate force-torque sensor on the market, with the intent to deliver a redundant and accurate force-torque measurement system for the next-generation snake robot. A specialized measurement system that shall aid future research projects upon achieving HOAL.

2.2.2 Research

The group's participants shall get acquainted with the Mamba robot, and with the previous research on snake robots from the Department of Engineering of Cybernetics. These documents are provided by the client, moreover the group will be given access to the HOAL-team's research file sharing-drive. Furthermore, relevant research and documents for other places may used. The preliminary research phase and some relevant findings is stated in this report, more relevant findings from previous research will be cited and discussed in the bachelor thesis.

2.2.3 Develop specifications

Based on previous research, discussions with the client, and the project's findings, the bachelor thesis aims to develop specifications for a force-torque sensor system for a novel snake robot. These shall first be developed before ordering the necessary components, and may be amended or changed in the testing and assessment of the sensor system. The intent of these specifications is for future research to have material upon choosing or developing future force-torque sensor systems for novel snake robot.

2.2.4 Implementation, testing and assessment

When the necessary components are received, the sensor system needs to be built and implemented on a test model. The model shall be put through rigorous tests, and it's performance shall be assessed.

As stated by the client, the next generation of snake robot does not intend to achieve everything regarding the robotic imitation of a snake, but to prove *Hybrid Obstacle Aided Locomotion* as a concept. Thereby, this project's intention is not to solve all the problems regarding force-torque measurement, but to find an improved commercial solution that solves as many problems as possible, and hopefully lay the foundation for torque-measurment in future research. Accurate and reliable measurement being the highest priority.

2.3 Process goals

Process goals describes the projects goals in terms of the process, and the expected individual gain.

The project aims to be an important experience for it's participants regarding group work, cooperation, and writing reports. Morover, that it's participants gets acquainted with force-torque measurement technology and learn more about snake robots.

2.4 Effect goals

The effect goals describes what the client wants to achieve with the project.

The goal is to aid the HOAL-team in the development of a new snake robot with regards to the force-torque measurement system. The project must identify the specifications for an intrinsic force-torque measurement system suitable for a snake robot. Moreover, to find a suitable sensor on the market, develop a test bench and assess it's performance with regards to the specifications and predetermined goals. The client also wants this project to lay the foundation for force-torque measurement in other future snake robots. The group must also get acquainted with previous research on snake robots, and use previous relevant findings to determine the specifications for a force-torque measurement system embedded in a snake robot.

To summarize, the overall goal is to resolve the existing issues with new solutions. Some of these problems are as follows; accuracy, redundancy, hysteresis, as well as complexity of construction. The issue of complexity revolves around the existing hand made torque sensors which are far from optimal and time consuming to produce. The current iteration has to be milled out of aluminium, manually glued with strain-gauge sensors, and assembled by hand, which is a tedious and inaccurate process. By developing a solution to interpret a commercially available sensor into the current system, the aim is to aid in speeding up construction by removing the "hand made"-aspect of production of each robotic joint.

There is also the issue of calibration, as mentioned earlier. The calibration of each sensor involves adjusting 12 separate dials (shown in figure 4b) and is a futile process. Furthermore, it has to be readjusted as new joints are mounted, which makes the process tedious. However, the calibration has little to no effect on accuracy as the other issues are making the sensor inherently inaccurate. Anyhow, having a less time consuming and tedious way of calibrating the sensor system is a goal.

In terms of hysteresis, there are many issues. The main one being that the robot is prone to high temperatures, as the motors has a high current draw, and there are nowhere for the heat to escape. The current system is not capable of performing at high temperatures, causing massive hysteresis in the measurement. The goal is then, obviously, to not have issues with hysteresis and inaccuracy at high temperatures.

These are some of the issues. By utilizing a mass manufactured sensor over a home-made one, the goal is to benefit from the precision that comes with serialised production hopefully reducing or removing the linearity as well as the calibration issues.

2.5 Outcome goals

Describes the project's final goals, and what shall have been accomplished upon completion by may 2021.

- Found a suitable sensor on the commercial market, that meets the specifications of a snake robot.
- Developed specifications for future development.
- Implemented the sensor-system on a single snake robot joint and built a test model.
- Designed and constructed a measurement system that fulfils the expectations and specifications set.
- Improved calibration system.
- Resolved issues as to measurement accuracy and hysteresis, proved in the assessment phase.
- The system can withstand high temperature variations.
- The system is implementable in a snake robot in terms of physical dimensions.
- The HOAL team is pleased with the result, the research's findings, and the sensor system will be relevant for future research on both HOAL and snake robots.

2.6 Project description

The project has been divided into smaller parts to make it easier to comprehend. These parts are shown as a hole in section A however a short summary is listed here.

- Read up on previous research to get up to speed with the project.
- Create a preliminary project containing necessary information to ensure a smooth workflow.
- Create specifications and system documentation that will aid the HOAL-team in future research and projects on snake-robots.

- Find a commercially available force-torque sensor. Moreover document type, specifications and supplier for future development, service and repair.
- Document and present the project's findings regarding the implementation of an embedded force-torque measurement system on a novel snake robot.
- Implement the sensor-system on a single snake robot joint, develop a test bench and assess it's performance based on set criteria and specifications.
- Designed a measurement system that fulfils the expectations and specifications set.

2.7 Objective specifications regarding the sensor system

- **Temperature:** Should be able to withstand a wide range of temperatures or at least be able to compensate for varying temperatures.
- **Physical design-limits:** There are no specified physical limitations as per date for the system but it should not be wider than around 20 cm in diameter and not weigh an unnecessary amount. Moreover, it needs to be slim, and not increase the distance between the joints by too much.
- **Measurements:** The system needs to be able to measure torque in three different axis (x,y,z) and should measure an appropriate amount of newton meters. Moreover, it would be preferable if it also could measure linear force in 3 axes, as well as measure dynamic torque.
- **Range:** The range is unspecified at this point, but will be added when further research has been done.
- **Budget:** The available budget is up to the group to determine but if possible it should be as cheap as possible
- **Calibration:** The system will require some fine tuning, but this should be a minimal amount.

The specifications shall be further determined in the bachelor thesis, in accordance with the given assignment.

2.8 Expected challenges

"A force sensing system for a snake robot is challenging since the robot is articulated. In particular, the force sensing capabilities of the robot should be maintained independently of how the joints are flexed which represents a significant design challenge"
[8] *Pål Liljebäck* 2011, page 236

Though not of great relevance for the project, Liljebäck's words regarding the development of a force-measurement system in a snake robot, gives the group an indicator that there are challenges to come.

Physical:
Finding a sensor that meets the necessary physical design limits could be challenging, and meeting all of the desired specifications may prove to be impossible. Therefore, if necessary the project must also assess and evaluate, along with the client, what aspects needs to prioritized and which short-comings could be tolerated.

Furthermore, the specifications, as described by the client, are fairly undefined with loose terms. The specifications shall be further clarified in this project, with regards to the main goal of creating a robust, accurate, and reliant measurement system.

Technological:
Although the market has changed in recent years there is still no guarantee that a suitable sensor has become commercially available. If available, the sensor may also have some redundant features that will lead to unnecessary weight or power drain.

Covid-19:
The ever looming presence of Covid-19 is also a deeming factor, if another lockdown occurs the shipping of components may cause delays. The virus will also have a substantial effect on our access to campus resources, and therefore indirectly affecting the construction of a proper test bench. If the components where to break during the tests the shipping time would force us to pause the tests prematurely and paired with the elongated Covid shipping times the results could be crippling.

Covid may also affect cooperation with the client, in terms of physical inspection and briefing on the *Mamba* robot. And other things that may be elongated or cancelled if the situation escalates, i.e. campus remains closed, lockdown, one or more of the projects participants gets infected, etc.

If the pandemic halts the physical aspect and -execution of the project, there shall at least be enough documentation to implement it physically when the global situation enables it

3 Project management

3.1 Project participants

Joel Mörlin

Age: 21 years old

Tlf: 48366000

E-Mail: joeltn@stud.ntnu.no

Experience:
Study specialization with a focus on electricity, Rud Upper Secondary school (2016 - 2018).
Currently studying electrical engineering with specialization in instrumentation at NTNU

Project experience:
Has previously worked on designing and manufacturing a complete EKG system in collaboration with another student

Goals:
I want to deepen my understanding of torque measurement systems whilst also learning the ins and outs of constructing a viable testing environment. Furthering My report writing abilities are also on the menu as i have little to no experience with this type of writing.

Victor Melhuus

Age: 22 years old

Tlf: (+47) 48208879

E-Mail: victorme@stud.ntnu.no

Experience:
Study specialization, Ullern Upper secondary school (2015 - 2017).
The Royal Norwegian Air Force, Force protection soldier at Ørland Main Airstation (2017-2018).
Currently studying electrical engineering with specialization in automation at NTNU (2018-2021)

Project experience:
A major automation project the spring of 2020, which amounted to a little less than a Bachelor Thesis.

Goals:
To use knowledge acquired through my education to solve relevant practical problems, to get better at team-work, to learn, and to get a decent grade. Always shoot for A.

Oscar Mørk

Age: 22 years

Tlf: 92093543

E-Mail: Oscar.mork@hotmail.com

Experience:
Study specialization, Oslo handelsgymnasium (2015-2017).
The Royal Norwegian Navy, Guard solider at Haakonsvern (2017-2018).
Student assistant, NTNU (2019-Now).
Currently studying electrical engineering with automation specialization at NTNU.

Project experience:
Previously worked on making a self regulating water tank system using PLC and other sensores in a group of 6.

Goals:
For this project my ultimate goal would be to apply my theoretical knowledge to a practical situation and in that way gain an overall better understanding of the field. This would help my further studies as well as enhance my ability to complete projects later. For the assignment i have set my personal goal at a B grade but will be working for achieve an A. This basically means that i will be striving towards an A but will be competent with a B, something i think is achievable as long as we put the work hours in.

3.2 Quality assurance

To assure that the project gets completed within the specified time frames and that the quality of the work is of a high standard a couple of systems have been put in place:

- Weekly meetings: There will be conducted weekly meetings where last weeks efforts will be reviewed and next weeks tasks will be discussed. This will assure that each party of the group at all times has knowledge about the state of the project as well as what needs to be completed next.
- Two week rapports: There will be written two week rapports in the weeks where there are no scheduled meetings with the supervisor and client to make sure both are up to date on the current progress of the project.
- Work packages: For the project there has been created work packages which contain information about what tasks need to be completed and when they need to be completed. This greatly enhances the groups ability to comprehend the assignment and therefore ensures that the right assignments are completed.
- Hour lists: During the workdays the amount of hours put in as well as the work completed in said hours will be recorded in an excel document. This will ensure that everyone puts in the same amount of effort and that everyone puts in enough effort.

3.3 Equipment and resources

Funding: The group has been granted a somewhat loose budget where funding will be granted as long as the group can convince the client that such funding is necessary.

Workshop: In the basement of *Gamle elektro D-blokk* the group has been granted access to the workshop that has been used for previous design and testing of the snake robots. Here it is possible to keep equipment as well as run tests on the new system.

3D-Printer: Along with the snake robot workshop the group has been given access to a 3D-printer to print necessary items to help with the project. It is stationed in the snake workshop.

Previous research and current snake robot: The group has been given access to the current snake robot as well as a couple of disassembled parts to help gain a better understanding of the previous construction. This of course came along with all of NTNU's previous research on the topic.

3.4 Time schedule and cost plan (Gantt-diagram)

To divide up the workload into smaller and more manageable parts we have decided to use the Gantt-diagram. It is shown in figure 6 and contains information about the different tasks which needs to be completed. For a regular bachelor thesis the expected workload for each participant is about 500-600 hours and the task have been divided with the intention of filling that amount. For explanation of each task, see the work packages which are shown under attachments.

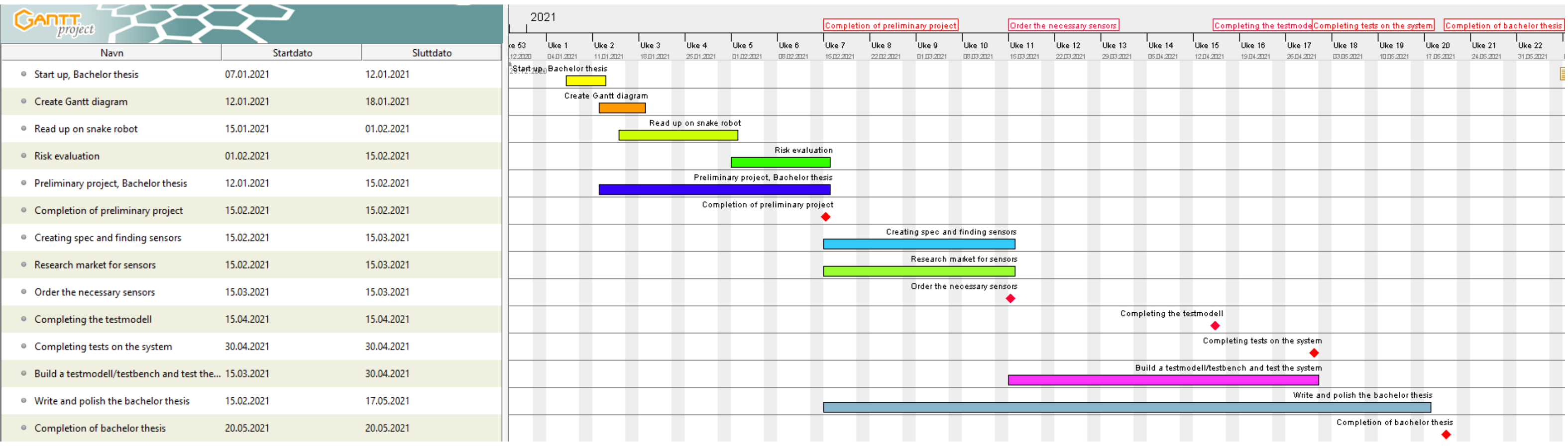


Figure 6: Gantt-Diagram

Activity	**Date/deadline**
Startup-meeting	Early in January (completed)
Submission deadline for the Preliminary Project report	february 15th
Establish the final Thesis title in norwegian and english	april 15th
Project submission (report and other documents)	may 20th
Oral presentation of the project(arranged with supervisor)	early june

Table 1: Important dates

3.5 Milestones

The milestones are shown in the Gantt-Diagram in figure 6. This section will iterate on each milestone.

3.5.1 Read up on snake robots

To identify existing problems, and to determine the specifications of the project and sensor.

3.5.2 Preliminary project report

Completing the preliminary project and deliver it for evaluation. Deadline: 15.February.

3.5.3 Create specification

Creating a useful specification to help rule out sensores and help convince the client of which sensor is necessary. Deadline: 20.February.

3.5.4 Determining a sensor type, and ordering one along with other components.

Deadline for ordering sensors and components: 15.March

3.5.5 Implementing the sensor system on a test bench

Actually building the prototype sensor system to be able to run tests on. Deadline 15.April

3.5.6 Assessment

Completing the same tests which where done in the last experiment to prove the new system works as intended. Deadline: 30.April.

3.5.7 Completing the bachelor thesis

Finishing the bachelor thesis and deliver it for evaluation. Deadline: 15.Mai

3.6 Risk evaluation and managment

Risk evaluation

Business/Department:

NTNU-ITK

Responsible party:

Jostein Løwer/Pål Mathisen

Nr.	What can go wrong?	What are the consequences?	How often does it occur?	Severity	Considered by/Date:
1	Infected by COVID-19	Being unable to work and risk of permanent damage	Rare	Serious	Oscar Mørk, 05.02.2021
2	Electrocuted	Damage to tissue, risk for permanent damage	Extremely Rare	Serious	Oscar Mørk 05.02.2021
3	Shorting a circuit or a sensor	Burn damage or damage due to inhalation of dangerous substances	Uncommon	Less serious	Oscar Mørk 05.02.2021
4	Snake robot clamps a limb/finger/arm of someone	Possible severe damage for region that gets hit	Extremely rare	Serious	Oscar Mørk 05.02.2021
5	Getting a cut from a circuit board or sensor	Some pain and risk of infection	Uncommon	Not serious	Oscar Mørk 05.02.2021

A Attachments

A.1 Work package: Start up, bachelor thesis

NTNU

Department of Engineering Cybernetics,
Field of study: automation technology

Subject: TELE 3031			**Date: 12.01.21**
Project: Bachelor thesis, Hybrid Obstacle-Aided Locomotion (HOAL)			
Activity: Start up, Bachelor thesis			**Activity nr:** 01
Start date: 07.01.2021		**End date:** 12.01.2021	
Dependency:	**Previous activity:** None		
	Next activity: Create Gantt diagram		
Goal: To discuss both with the group and the supervisor/employer about the project to gain an overview of the amount of work and assignments.			
Job Description: Hold an internal meeting with the group to talk about the assignment. Schedule a meeting with the group, the employer, and the supervisor. Complete the meeting with the group, the supervisor and the employer as well as taking notes.			
Number of hours: 4 h		**Distribution:** Entire group	
Cost: Time			
Resources: PC			
Risk:			
Academic responsibility: Jostein Løwer (JL)/Pål Mathisen (PM) **Project participants:** Joel Mörlin (JM) Victor Melhuus (VM) Oscar Mørk (OM)			

A.2 Work package: Gantt diagram

NTNU

Department of Engineering Cybernetics,
Field of study: automation technology

Subject: TELE 3031			**Date: 12.01.21**
Project: Bachelor thesis, Hybrid Obstacle-Aided Locomotion (HOAL)			
Activity: Gantt Diagram			**Activity nr:** 02
Start date: 12.01.2021		**End date:** 18.01.2021	
Dependency:	**Previous activity:** Start up, Bachelor thesis.		
	Next activity: Read up on research about the snake robot.		
Goal: To create an overview of expected time consumption and expected deadlines such that the assignments become clearer.			
Job Description: Write a detailed schedule which provides an overview over amount of work and expected time of completion (Gantt diagram) Figure out reasonable deadlines for the different under assignments of the thesis. Figure out an expected time consumption for the different under assignments of the thesis.			
Number of hours: 25 h		**Distribution:**Entire group	
Cost: Time			
Resources: Gantt program			
Risk:			
Academic responsibility: Jostein Løwer (JL)/Pål Mathisen (PM) **Project participants:** Joel Mörlin (JM) Victor Melhuus (VM) Oscar Mørk (OM)			

A.3 Work package: Read up on research

NTNU

Department of Engineering Cybernetics,
Field of study: automation technology

Subject: TELE 3031			**Date: 12.01.21**
Project: Bachelor thesis, Hybrid Obstacle-Aided Locomotion (HOAL)			
Activity: Read up on previous research and information about the snake robot			**Activity nr:** 03
Start date: 15.01.2021		**End date:** 31.01.2021	
Dependency:	**Previous activity:** Gantt diagram.		
	Next activity: Write risk evaluation.		
Goal: Becoming familiarized with the Mamba robot as well as with previous research to create a basis for further work.			
Job description: Read through available literature on the mamba project and write down key aspects for future discussions.			
Number of hours: 50 h		**Distribution:** Entire group	
Cost: Time			
Resources: PC, Literature provided by employer.			
Risk:			
Academic responsibility: Jostein Løwer (JL)/Pål Mathisen (PM) **Project participants:** Joel Mörlin (JM) Victor Melhuus (VM) Oscar Mørk (OM)			

A.4 Work package: Risk evaluation

NTNU

Department of Engineering Cybernetics,
Field of study: automation technology

Subject: TELE 3031		**Date: 15.01.21**
Project: Bachelor thesis, Hybrid Obstacle-Aided Locomotion (HOAL)		
Activity: Write a risk evaluation		**Activity nr:** 04
Start date: 01.02.2021	**End date:** 15.02.2021	
Dependency:	**Previous activity:** Read up on snake robot.	
	Next activity: Write preliminary project.	
Goal: To create a structured and comprehensible risk evaluation which will be added to the preliminary project.		
Job description: Create a structured and comprehensible risk evaluation using a risk diagram.		
Number of hours: 10 h	**Distribution:** Entire group	
Cost: Time		
Resources: PC		
Risk:		
Academic responsibility: Jostein Løwer (JL)/Pål Mathisen (PM) **Project participants:** Joel Mörlin (JM) Victor Melhuus (VM) Oscar Mørk (OM)		

A.5 Work package: Preliminary project

NTNU

Department of Engineering Cybernetics,
Field of study: automation technology

<table>
<tr><td colspan="3">Subject: TELE 3031</td><td>Date: 15.01.21</td></tr>
<tr><td colspan="4">Project: Bachelor thesis, Hybrid Obstacle-Aided Locomotion (HOAL)</td></tr>
<tr><td colspan="3">Activity: Preliminary project</td><td>Activity nr: 05</td></tr>
<tr><td colspan="2">Start date: 12.01.2021</td><td colspan="2">End date: 15.02.2021</td></tr>
<tr><td rowspan="2">Dependency:</td><td colspan="3">Previous activity:
Create Gantt diagram, read up on snake robot, Risk evaluation.</td></tr>
<tr><td colspan="3">Next activity:
Find relevant sensors.</td></tr>
<tr><td colspan="4">Goal:
Creating a detailed document which contains general information about the project, such as technical specifications and project management.</td></tr>
<tr><td colspan="4">Job description:
Create a LaTeX document for the preliminary project.
Divide the LaTeX document into multiple subchapters:
- Introduction
- Technical part
- Project management
Add the Gantt diagram and work packages to the preliminary project.</td></tr>
<tr><td colspan="2">Number of hours:
150 h</td><td colspan="2">Distribution:
Entire group</td></tr>
<tr><td colspan="4">Cost: Time</td></tr>
<tr><td colspan="4">Resources: PC, LaTeX</td></tr>
<tr><td colspan="4">Risk:</td></tr>
<tr><td colspan="4">Academic responsibility:
Jostein Løwer (JL)/Pål Mathisen (PM)

Project participants:
Joel Mörlin (JM)
Victor Melhuus (VM)
Oscar Mørk (OM)</td></tr>
</table>

A.6 Work package: Find relevant sensors or parts

NTNU

Department of Engineering Cybernetics,
Field of study: automation technology

Subject: TELE 3031			**Date: 15.01.21**
Project: Bachelor thesis, Hybrid Obstacle-Aided Locomotion (HOAL)			
Activity: Find relevant sensors or parts for the sensor system			**Activity nr:** 06
Start date: 15.02.2021		**End date:** 15.03.2021	
Dependency:	**Previous activity:** Preliminary project		
	Next activity: Research market for relevant sensors		
Goal: Getting familiar with wanted specifications for the mamba robot and find sensors and/or parts that fits the specifications.			
Job description: Become familiar with different sensors and parts which could be used for creating a fitting sensor system. Produce a list/document with information about the different parts/sensors which could be relevant and present them to the employer.			
Number of hours: 100 h		**Distribution:** Entire group	
Cost: Time			
Resources: PC, Specifications of mamba robot			
Risk:			
Academic responsibility: Jostein Løwer (JL)/Pål Mathisen (PM) **Project participants:** Joel Mörlin (JM) Victor Melhuus (VM) Oscar Mørk (OM)			

A.7 Work package: Research market for the necessary parts/sensors

NTNU

Department of Engineering Cybernetics,
Field of study: automation technology

Subject: TELE 3031		**Date: 18.01.21**
Project: Bachelor thesis, Hybrid Obstacle-Aided Locomotion (HOAL)		
Activity: Research the market for the necessary sensors		**Activity nr:** 07
Start date: 15.02.2021	**End date:** 15.03.2021	
Dependency:	**Previous activity:** Find relevant sensors for the sensor system.	
	Next activity: Construct and test out the sensor system.	
Goal: To find commercially available parts for the robot and sensor system so that production of the robot can be done with off the shelf parts.		
Job description: Become familiar with different sensors and parts which have been deemed necessary in creating the sensor system. Research the marked to see if the necessary parts either are available for purchase or if they can be built from smaller purchasable parts. Create a list over the different available parts.		
Number of hours: 100 h	**Distribution:** Entire group	
Cost: Time		
Resources: PC, Specifications of mamba robot		
Risk:		
Academic responsibility: Jostein Løwer (JL)/Pål Mathisen (PM) **Project participants:** Joel Mörlin (JM), Victor Melhuus (VM), Oscar Mørk (OM)		

A.8 Work package: Build a testbench in LabView

NTNU

Department of Engineering Cybernetics,
Field of study: automation technology

Subject: TELE 3031		**Dato: 18.01.21**
Project: Bachelor thesis, Hybrid Obstacle-Aided Locomotion (HOAL)		
Activity: Build a testbench in LabView for testing the snake		**Activity nr:** 08
Start date: 15.03.2021	**End date:** 15.04.2021	
Dependency:	**Previous activity:** Research the market for necessary sensors.	
	Next activity: Build a test model of the snake robot for testing.	
Goal: To create a testbench in LabView which can be used for testing of the sensor system.		
Job description: Shape and design a test program which can collect the necessary information about the system such as force and torque over time		
Number of hours: 100 h	**Distribution:** Entire group	
Cost: Time		
Resources: PC, LabView		
Risk:		
Academic responsibility: Jostein Løwer (JL)/Pål Mathisen (PM) **Project participants:** Joel Mörlin (JM) Victor Melhuus (VM) Oscar Mørk (OM)		

A.9 Work package: Build and test out model

NTNU

Department of Engineering Cybernetics,
Field of study: automation technology

Subject: TELE 3031			**Date: 18.01.21**
Activity: Build a test model of the sensor system and carry out a real-world test			**Activity nr:** 09
Start date: 15.03.2021		**End date:** 15.04.2021	
Dependency:	**Previous activity:** Research the market for available and purchasable sensors or parts.		
	Next activity: Check over and submit bachelor thesis.		
Goal: To build a test model for the sensor system and test it out in a real-world condition.			
Job description: Build a test model of the sensor system based on parts found in earlier work packages. Test out the sensor system in real world conditions.			
Number of hours: 300 h		**Distribution:** Entire group	
Cost: Time			
Resources: PC, Specifications of mamba robot			
Risk:			
Academic responsibility: Jostein Løwer (JL)/Pål Mathisen (PM) **Project participants:** Joel Mörlin (JM) Victor Melhuus (VM) Oscar Mørk (OM)			

A.10 Work package: Write and complete bachelor thesis

NTNU

Department of Engineering Cybernetics,
Field of study: automation technology

Subject: TELE 3031		**Date: 18.01.21**
Project: Bachelor thesis, Hybrid Obstacle-Aided Locomotion (HOAL)		
Activity: Write and look through the bachelor thesis		**Activity nr:** 10
Start date: 15.02.2021	**End date:** 15.05.2021	
Dependency:	**Previous activity:** Build a test model and test it out.	
	Next activity: Prepare presentation of bachelor thesis.	
Goal: Create a structured and comprehensible rapport which contains information about all the completed work that has been produced during the bachelor thesis.		
Job description: Create a structured and comprehensible LaTeX document for the rapport. Include all relevant data, figures and information developed during the thesis work. Look over rapport for eventual errors before submission.		
Number of hours: 300 h	**Distribution:** Entire group	
Cost: Time		
Resources: PC		
Risk:		
Academic responsibility: Jostein Løwer (JL)/Pål Mathisen (PM) **Project participants:** Joel Mörlin (JM) Victor Melhuus (VM) Oscar Mørk (OM)		

NTNU

FAKULTET FOR INFORMASJONTEKNOLOGI OG ELEKTROTEKNIKK

AVTALE

Avtale for gjennomføring av bacheloroppgaven mellom NTNU, oppdragsgiver (firma, etat) og student(er).

Avtalepartnere

NTNU Institutt for elektroniske systemer / elkraft / teknisk kybernetikk	Veileders navn/telefon/e-postadresse.: Pål Mathisen, 41083804, Pal.mathisen@ntnu.no
Oppdragsgiver (Firma/etat): NTNU-ITK	Kontaktperson/navn: Jostein Løwer Telefon/e-postadresse/adresse: Josteilo@stud.ntnu.no, 40204742
Student: Victor Shaw Melhuus, 48208879, Victor.melhuus@gmail.com	
Student: Joel Mörlin, 48366000, Joel.morlin@gmail.com	
Student: Oscar Mørk, 92093543, Oscar.mork@hotmail.com	
Prosjekt-tittel/arbeidstittel	Bacheloroppgave om Hybrid Obstacle-Aided Locomotion (HOAL)
Prosjektnr.	26

Andre relevante dokumenter: Prosjektmanual Bacheloroppgaven.

Avtalen angir avtalepartenes plikter vedrørende gjennomføring av prosjektet og rettigheter til anvendelse av de resultater som prosjektet frembringer.

1.
Studenten(e)/prosjektgruppen skal gjennomføre prosjektet i perioden fra januar 20xx til yy. mai 20xx.

Studentene skal i denne perioden følge en oppsatt fremdriftsplan der NTNU og oppdragsgiver yter veiledning. Oppdragsgiver stiller til rådighet kunnskap og materiale som vil kunne bidra til gjennomføringen av prosjektet. Det forutsettes at de gitte problemstillinger det arbeides med er aktuelle og på et nivå tilpasset studentenes faglige kunnskaper. NTNU skal stille til rådighet egen veileder. Oppdragsgiver plikter å gi en evaluering/sensur av prosjektet vederlagsfritt.

2.
Kostnadene ved gjennomføringen av prosjektet dekkes på følgende måte:
Oppdragsgiver og NTNU dekker hver sin del av den veiledningstid som gis. Dekning av reiser og opphold langt fra studiested dekkes enten av studentene eller av oppdragsgiver ut fra den part som er aktiv for at reise og opphold er nødvendig. Studentene dekker evt. utgifter for trykking og ferdigstillelse av den skriftlige besvarelsen vedrørende prosjektet med mindre oppdragsgiver yter slik bistand.

3.
Eiendomsrett
Besvarelsens spesifikasjoner og resultat kan anvendes i oppdragsgivers egen virksomhet inklusiv publisering. Gjør studenten(e) i sin besvarelse, eller under arbeidet med den, en patentbar oppfinnelse, gjelder i forholdet mellom oppdragsgiver og studentene bestemmelsene i Lov om retten til oppfinnelser av 17. april 1970, §§ 4-10.

Eiendomsretten til eventuell prototyp tilfaller den som har betalt komponenter og materiell mv. som er brukt til prototypen. NTNU skal ha rett til vederlagsfri utnyttelse av besvarelsen og resultatene fra bachelorarbeidet til undervisnings- og forskningsvirksomhet inklusive publisering. Dette gjelder også data som underbygger resultatet i besvarelsen med mindre det vil være i strid med lov/forskrift eller godkjennelser som er gitt av Regional komité for medisinsk og helsefaglig forskningsetikk (REK), Norsk samfunnsvitenskapelig datatjeneste (NSD) eller andre institusjoner.

Hvis kandidaten skal utføre forskningsprosjektet som del av et større prosjekt, gjelder det som er avtalt om IP-rettigheter i dette prosjektet. Dette beskrives her:

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AVTALE

4.
Hvis arbeidet medfører publisering og studentenes bidrag tilfredsstiller Vancouver-konvensjonens krav til medforfatterskap, skal studentene oppføres som medforfattere. Dersom bidraget deres ikke tilstrekkelig for medforfatterskap, skal de anerkjennes for bidraget.

5.
NTNU står ikke som garantist for at det oppdragsgiver har bestilt fungerer etter hensikten. Prosjektet må anses som en eksamensrelatert oppgave som blir bedømt av faglærer/veileder og sensor.

6.
Offentliggjøring.
Papirkopi av besvarelsen registreres og plasseres i et åpent arkiv ved instituttet. Oppdragsgiver kan ved prosjektstart kreve at prosjektet skal behandles som *lukket prosjekt* det vil si ikke publiseres eller plasseres i det åpne arkivet dersom dette kan begrunnes i lov eller forskrift eller ut fra kommersielle hensyn. I tilfelle av lukket prosjekt, skal allikevel besvarelsen normalt kunne publiseres og plasseres i åpent arkiv etter en på forhånd avtalt periode, som normalt ikke skal overskride 3 år.

7.
Når NTNU også opptrer som oppdragsgiver, trer NTNU inn i kontrakten både som utdanningsinstitusjon og som oppdragsgiver.

8.
Taushetserklæring
Ved underskrivelse av denne avtalen erklærer studentene ved sin underskrift alminnelig taushetsplikt vedrørende tekniske innretninger, fremgangsmåter, drifts eller forretningsforhold hos oppdragsgiver som det er av betydning å behandle konfidensielt.

9.
Eventuell uenighet vedrørende forståelse av denne avtale løses ved forhandlinger avtalepartene imellom. Dersom det ikke oppnås enighet, er partene enige om at tvisten løses av voldgift etter LOV 2004-05-14 nr. 25: Lov om voldgift.

10.
Denne avtalen utferdiges med et eksemplar til hver av partene. Signert dokument godtas på pdf-fil. På vegne av NTNU er det intern veileder som godkjenner avtalen.

11. Annet

12.
Signaturer

Dato/ Veileder NTNU Institutt for elektroniske systemer/elkraft/teknisk kybernetikk Pål Mathisen
Dato/Oppdragsgiver/kontaktperson 10/2 2021 Jostein Iversen
Dato/Student 15.01.21 Victor Shaw Melhus
Dato/Student 18.01.21 OSCAR MORK
Dato/Student 18.01.21 Joel Caro Mörlin

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