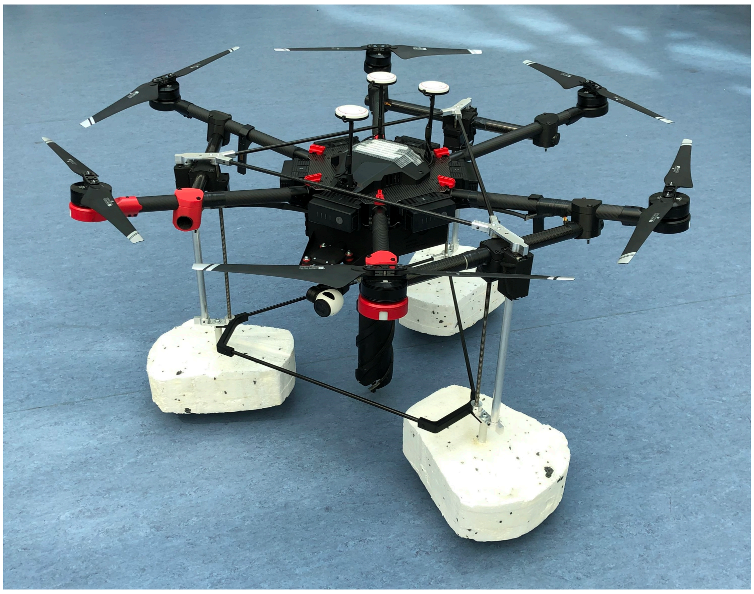
# *SAIDD - Semi Autonomous Icecore Drilling Drone*



MECHATRONICS CHALLENGE F19
GROUP 4
MTMEC-02 INTRODUCTION TO MECHATRONICS
AARHUS UNIVERSITY SCHOOL OF ENGINEERING
MAY 21 2019

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**Title:**

SAIDD

**Project:**

Mechatronics Challenge

**Project period:**

February 2019 - May 2019

**Project group:**

4

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# Preface

This report has been developed by group 4 in the course "F19 - MTMEC-02 Introduction to Mechatronics" at Aarhus University School of Engineering.

The project is based on a previous bachelorproject from Aarhus University School of Engineering. This report contains a description of the further development and construction of a semi-autonomus ice core drilling drone for use by Arctic Research Centre on Greenland. The project has been ongoing in the period February - May 2019.

The group would like to express its gratitude towards the academic supervisor, **Claus Melvad** and project holder **Daniel Frazier Carlson**.

Furthermore the group would like to thank the workshop located at Navitas for the help with construction of many mechanical parts.

**Danish Technological Institute** has also been a supplier of polymer and metal 3D-printed parts for use in the project for which the group is grateful.

## Reading guide

The report consists of a main report and an related appendix. The main report contains a problem description, technical information, a discussion, a conclusion and a bibliography. The appendix consists of data sheets, test reports, pictures and some calculations. The appendix is structured so that the order of the appendix follows the references throughout the report, except for the technical drawings which are the last appendix M on page 84.

The references throughout the report are according to the Harvard Method [Surname, Year]. These refers to the bibliography in the back of the report. Internet pages are mentioned by writer, title and date, while books are mentioned by writer, title, edition and publisher.

Figures and tables are numbered according to the respective chapter. This means the first figure in chapter 5 is has the number 7.1, the second 7.2 and so on. Explanatory text can be found underneath each picture and table. Through the report, "bach. report", "bachelor report" and "earlier project" refers to [Pasma og Jacobsen, 2018].

Mads Holm Hansen

Steffen Thomsen

Jeppe Pinholt Lillethorup

Frederik Sebastian Tirsgaard

Adam Flytkjær

# Work distribution table

Table 1 shows the distribution of work in % for each person in the group.

Table 1: Work distribution table

| | Adam Flytkjær | Steffen Thomsen | Jeppe Pinholt Lillethorup | Frederik Sebastian Tirsgaard | Mads Holm Hansen |
|---|---|---|---|---|---|
| | | Report | | | |
| Introduction | 20 | 20 | 20 | 20 | 20 |
| Spec. of requirements | 20 | 20 | 20 | 20 | 20 |
| Use cases | 20 | 20 | 20 | 20 | 20 |
| Morphology | 20 | 20 | 20 | 20 | 20 |
| Part conclusion | 20 | 60 | 5 | 10 | 5 |
| Electronics box | 95 | 5 | | | |
| Floats | | 5 | 90 | | 5 |
| Spikes | | 5 | 90 | | 5 |
| Design of quick release | | 10 | 5 | 5 | 80 |
| Drill changes | 5 | 90 | | 5 | |
| Main processor and programming | 20 | 10 | | 70 | |
| Brushless DC motor | 20 | 10 | 10 | | 60 |
| Landing gear actuator | 20 | 15 | 15 | 25 | 25 |
| BigEasyDriver | 35 | 15 | | 15 | 35 |
| Microswitches | 10 | | 30 | 25 | 35 |
| Extraction of GPS from A3 | 5 | 15 | 20 | 30 | 30 |
| LiDAR | 10 | | 45 | 45 | |
| Ammeter | 10 | 70 | 10 | 10 | |
| SPI to 4xUART | | 90 | | | 10 |
| Actuator for beacon and QR | 5 | 10 | 70 | | 15 |
| Gimbal - servo and image processing | 25 | | 75 | | |
| Digi Xbee SX 868 | 90 | | 5 | 5 | |
| Circuit diagram and rounting | 5 | 5 | | | 90 |
| Labview walkthrough | 10 | | | 80 | 10 |
| Roll detection | 10 | | | 90 | |
| Drilling process | 15 | | | 70 | 15 |
| Final prototype | 20 | 20 | 20 | 20 | 20 |
| Conclusion | 20 | 20 | 20 | 20 | 20 |
| Design evaluation | 20 | 20 | 20 | 20 | 20 |
| | | Components & software | | | |
| Electronics box | 90 | 10 | | | |
| Floats | 15 | | 85 | | |
| Spikes | 15 | | 85 | | |
| Design of quick release | | 10 | | | 90 |
| Drill changes | 20 | 80 | | | |
| Brushless DC motor | 10 | | 40 | 50 | |
| Landing gear actuator | | | | 30 | 70 |
| BigEasyDriver | | | | 30 | 70 |
| Microswitches | 33 | | 33 | | 33 |
| Extraction of GPS from A3 | | 20 | 10 | 35 | 35 |
| LiDAR | 60 | 40 | | | |
| Ammeter | 40 | 60 | | | |
| SPI to 4xUART | | 90 | 10 | | |
| Actuator for beacon and QR | | | 80 | 20 | |
| Gimbal - servo and image processing | | 10 | 90 | | |
| Digi Xbee SX 868 | 95 | | | 5 | |
| Perfboard and rounting | | 50 | | | 50 |
| Labview Main program | 25 | | | 75 | |
| Roll detection | 10 | | | 90 | |
| Drilling process | | | | 60 | 40 |

# Table of contents

# 1 Introduction

This mechatronic challenge project is made in collaboration with Arctic Research Center (ARC). ARC's focus is on the melting cryosphere and it's feedback on the climate system and effects on ecosystems and societies [Arctic Research Center, AU, 2019]. The area of interest is the arctic area around Greenland and the area north of Canada, see 1.1. Ice drilling plays a huge part in understanding and possibly preventing climate related catastrophes. Ice cores sampled from icebergs and glaciers are used to give an understanding of how the climate has changed over the centuries. It is possible to make better predictions of how the climate will change in the future by understanding how the climate has changed in the past. The big problem of making the ice samples is the safety risk involved when taking the samples on glaciers and icebergs. It's hard to reach these places and when taking the samples there is always a risk of the glacier collapsing or the iceberg rolling over. That's where the SAIDD comes in. It'll be able to reach hard to get places high or low without putting anyone at risk. When points of interest on the icebergs or glaciers has been reached the SAIDD will be able to extract an ice sample and the fly back to the operator in safety.

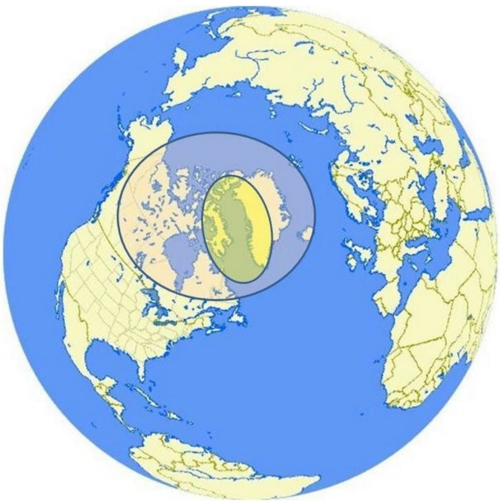


Figure 1.1: Arctic area around Greenland and the area north of Canada.

# Problem description 2

How to reach high-risk and difficult places and take ice samples? A semiautonomous drone would be a top pick! Such a drone would able to fly and make a ice sample without putting people at risk. The drone could potentially make 3D-scannings or use computer-vision systems in order to scan icebergs and ice flakes and autonomously performing ice drillings to bring back samples for the research team.

This would put people at an appropriate safety distance from otherwise dangerous situations such as tipping icebergs or bergy bits. The researchers would be able to successfully retrieve samples from places not accessible to man. Further, the 3D-scan would contribute to knowledge regarding size or geometry of the ice and perhaps the best places for drilling. This project is based on a former bachelor project from Aarhus School of Engineering with the purpose of optimizing the drone within following aspects:

- Improving the speed of the drilling operation
- Redesigning the electronics enclosure to protect from weather and make service easier
- Improving the success rate of keeping the sample in the drill canister for retrieval
- Be able to release the drill quickly
- Be able to autonomously make 3D-models of the ice
- Have a row of LEDs to showcase errors either on the drone or in program
- Progress bar indicating how far into the drilling process the drone is
- Improving landing gear and floats for more stability and controllability

## 2.1 Problem statement

The problem description leads to the following problem statement:

How is it possible for a group of students from Aarhus University School of Engineering to successfully build an ice drilling drone to safely recover ice samples, at a high rate, from high-risk areas with starting point in an earlier project?

## 2.2 Project limitation

- The existing solution will be used as a steppingstone for the new. Included in this is the commercial drone and eventually pieces from the existing code.
- The drone shall be able to fly in good conditions with minimum wind and rain.
- Maneuverability of the drone stays manual, while the focus of the autonomous studies will be making the drilling- and 3D-scanning operations autonomous in nature.

# 3 Specification of requirements

In the following chapter both the functional and product requirements are specified. These specifications are mainly derived from the previous work done with this drone project by the previous bachelor group. Specifications which are taken directly from this report and have not been changed are marked with either (Bach. report) or (Bach. group). The specification of requirements has been divided into "Functional requirements" and "Product requirements" and entered into tables that divide each requirement by the MoSCoW-principle: "Must have", "Should have", "Could have" and "Won't have".

The specification of requirements can be seen on table 3.1 through 3.7.

Table 3.1: Functional requirements.

| Functional requirements | | | | | | |
|---|---|---|---|---|---|---|
| **Description of requirement** | **Must have** | **Should have** | **Could have** | **Won't have** | **Verification of requirement** | **Source of requirement** |
| **The drone should be able to be operated from a boat** | Operation from a modified boat. | | Operation from a boat with no modifications. | | Site assembly test. (SAT) | Bac. report (Dan Carlson). |
| **The drone should be able to operate in the arctic environment** | Operate in light rain and mist, with slightly higher windspeeds. | | | Flight in snowy weather, heavy fog and heavy wind. | Inhouse test. | Claus Melvad. |
| **If complications occur, the drone should not be lost** | The drone can be rescued. | | | The drone can rescue itself. | Inhouse test. | Claus Melvad. |
| **The drone should be able to extract an ice sample of a desired weight and transport it back to the boat** | The drone has (semi-) autonomous function for taking the sample when landed. | | | Can transport the ice sample back autonomous. | Extracting test, Flight test. | Claus Melvad. |
| **The drone should be able to fly unhindered with the required payload** | Be able to fly with drill and ice sample. | Be able to fly with GPS beacon. | | | Datasheet for drone. Flight test. | The group. |
| **The operator should be able to inspect if the tools are working properly when on mission** | Video feed to inspect operations and LED indicators on operation PC. | Monitoring operation data from the tools (rpm, drilling speed, amps). | | | Extraction test. | The group. |

Table 3.2: Functional requirements.

| Functional requirements | | | | | | |
|---|---|---|---|---|---|---|
| **Description of requirement** | **Must have** | **Should have** | **Could have** | **Won't have** | **Verification of requirement** | **Source of requirement** |
| **The drone should be able to have a flight time which is enough to get it safely to and from the iceberg** | The drone can fly to and from a nearby iceberg | The drone can fly to and from an iceberg with a safety distance | | | Datasheet for drone, flight test | Dan Carlson |
| **The drone should be able to land and take off from an iceberg** | Flat and almost level surface on the iceberg, no snow | More rough surface with a slight angle, little snow | | Icebergs covered in deep snow | Take off and landing test | Claus Melvad & Dan Carlson |
| **The drone should be able to transport and drop an EXITE GPS beacon onto the iceberg** | The controls will be operated completely by the user via remote control | | | The drone has (semi-) autonomous function for releasing GPS | Flight test, drop test | Dan Carlson |
| **It should be easy for the operator to assemble the drone and get it ready to fly as well as disassemble the drone and pack it down for transport** | The drone will require several people to setup and pack down | The drone can be setup and packed down by one operator in decent time | | | SAT | The group |
| **The operator should be able to test all of the drones functions before take off** | The drone will have a fully automatic test program | | | | SAT | The group. |
| **The drones landing gear should be stable and steady, with no sliding** | The drone can stand on the iceberg with only little tipping | The drone can stand on the iceberg without sliding | | | Take off test, landing test. | The group. |

Table 3.3: Functional requirements.

| Functional requirements | | | | | | |
|---|---|---|---|---|---|---|
| **Description of requirement** | **Must have** | **Should have** | **Could have** | **Won't have** | **Verification of requirement** | **Source of requirement** |
| **The drone should be delivered with a user manual** | A thorough paper | | A video guide | | SAT | Dan Carlson |
| **The drone should be able to release the drill, if it gets stuck** | The operator can release the drill if it gets stuck | The drone can detect if the drill gets stuck and iceberg rolling. | | | Extraction test | Claus Melvad |
| **The drone should not be of any hazards to the users or surrounding environment** | FMEA should be made to minimize risks | | | | SAT | The group |
| **The drone should have an alarm that signals if the iceberg is rolling** | The program can detect and alarm the operator through the operation PC. | | | | Rolling iceberg test | Dan Carlson. |
| **The drone should be able to fly several missions each day of operation** | The batteries should be rechargeable and there should be provided more than 1 battery pack | The batteries should be rechargeable and changeable on the boat | | | Datasheet for drone batteries, datasheet for battery charger | Dan Carlson |
| **The drone should be able to send a video feed back to the operator** | The video feed should be in usable quality with no or few vibrations | High quality video feed | | | Datasheet for drone camera, extraction test | The group. |

Table 3.4: Functional requirements.

| Functional requirements | | | | | | |
|---|---|---|---|---|---|---|
| **Description of requirement** | **Must have** | **Should have** | **Could have** | **Won't have** | **Verification of requirement** | **Source of requirement** |
| **The drone should be able to measure the core temperature of the iceberg** | | | The measurement will be done by the operator manually on the ice sample | The drone has a tool for measuring core temperature | Extraction test | Dan Carlson |
| **The drone should be able to measure the reflection from the iceberg with a light calibrated camera** | | | The drone can take photos of the surface which can be analyzed | | SAT | Dan Carlson |
| **The drone can circle the iceberg and take photos for a 3D scan** | The operator should be able to manually do a 3D scan | The drone should be able to autonomous control the camera for optimal 3D-scan | | | SAT | Dan Carlson |
| **The drone should be able to take an ice sample without contaminating it with iron particles** | The drone will not contaminate the ice with iron | | | | Extraction test | Dan Carlson. |
| **The drone should able to be disassembled back to normal working condition** | The drone can come back to stock form | | | | SAT | Claus Melvad |
| **The price of the final device, should not exceed the budget** | The price of the device must be within budget | High quality video feed | | | Final costs | The group. |
| **Flying the drone must be done by** | VLOS (Visual Line Of Sight) | VLOS + FPV (First Person View) | | | SAT | Dan Carlson |

Table 3.5: Functional requirements.

| Functional requirements | | | | | | |
|---|---|---|---|---|---|---|
| **Description of requirement** | **Must have** | **Should have** | **Could have** | **Won't have** | **Verification of requirement** | **Source of requirement** |
| **The drone must be transportable** | Safe carrying case for the drone an carrying case for the tool/tools | Safe carrying case for the drone with the tool/tools mounted | | | SAT | Claus Melvad |
| **Drill extraction** | The drill must be able to extract an ice sample in less than 5 minutes. | The drill should be able to extract an ice sample in less than 2 minutes and autonomously | | | Extraction test | Claus Melvad |
| **Long range data communication** | Possibility of sending communication to the drone | Possibility of communication from the drone | | | Flight test | The group |

Table 3.6: Product requirements.

| Product requirements | | | | | | |
|---|---|---|---|---|---|---|
| **Description of requirement** | **Must have** | **Should have** | **Could have** | **Won't have** | **Verification of requirement** | **Source of requirement** |
| The equipment should work in arctic temperatures | Operation temp: 0°C | Operation temp: -10°C | Operation temp: -15°C | - | Datasheet for electronics | Average day winter temperature in Greenland: -10°C |
| The drone should be able to fly in moderate winds | Avg. windspeed: 5m/s | Avg. windspeed: 10m/s | Avg. windspeed: 15m/s | | Datasheet for drone | Dan Carlson (bac. report) |
| If the drone has to land on water | Float so it will not sink with a weight of 16kg | | Landing gear with water landing capability weight of 16kg | | Buoyancy calculations, (Water test) | Claus Melvad |
| If the drone looses signal to the radio | | Fly to home and hover within a range of 100m from the boat | Fly to home and hover within a range of 10m from the boat | | Datasheet for drone | Bac. report |
| Ice sample weight when delivered | Between 500- 1000g | | Over 1000g | | Extraction test | Dan Carlson (bac. report) |
| The drone should have a payload that fit the rough estimates of the weight calculations | 4kg | 6kg | | | Datasheet for drone, Weight estimations | Bac. group |
| Camera feedback | | The camera can be controlled in 1 direction, tilt | The camera can be controlled in 2 directions, rotate | | Datasheet for Gimbal | Bac. group |
| The battery capacity should allow the drone to fly to and from iceberg | 100m away from the boat | | 2km away from the boat | | Datasheet for drone, Flight test | Dan Carlson (Bac report) |
| The radio transmitter should have a range of at least | 200m | | 2,5km | | Datasheet for transmitter | Bac. report |
| The drone should be able to land and take off from an angled iceberg surface | | 5° angle from water level | 10° angle from water level | | Take off and landing test | Dan Carlson (Bac. report) |
| Recesses, snow and grooves on the surface of the iceberg may not exceed | | 2cm in depth | 5cm in depth | | Take off and landing test | Dan Carlson (Bac. report) |
| The type of sediment in the ice sample | | Sand and stones <0,2cm in diameter | Sand and stones 1-2cm in diameter | Sand and stones >2cm in diameter | Extraction test | Dan Carlson (Bac. report) |
| The drone should be able to carry a EXITE GPS beacon | Weight: 800g | Weight : 1500g (extra housing?) | | | Datasheet for drone, Drop test | Dan Carlson (Bac. report) |
| Setup/pack down time for the drone | 1 hour with help from several users | 30 minutes for one user | | | SAT | Bac. group |
| The user can test the drones functions before flight | | Test takes under 15 minutes | Test takes under 5 minutes | | SAT | Bac. group |
| When landed on ice, the drone may not slide before drilling more than | | 10cm from landing spot | 1cm from landing spot | | Take off and landing test | Bac. group |
| The camera angling can be used to monitor the extraction | | Tilt on camera: <90° | Tilt on camera: 180° | | Datasheet for Gimbal | Bac. group |
| The drone should be able to detach its tools if stuck within | | 2 minutes | 30 seconds | | Extraction test | Bac. group |

Table 3.7: Product requirements.

| Product requirements | | | | | | |
|---|---|---|---|---|---|---|
| The rolling alarm should have a sampling time of | | Sampling time: 10Hz | Sampling time: 100Hz | | Datasheet for sensor | Bac. group |
| The rolling alarm should have a sensitivity of | | Sensitivity: +- 1° | Sensitivity: +- 0,5° | | Datasheet for sensor | Bac. group |
| Video feed quality | | Quality: 420p@15FPS | Quality: 720P@30FPS | | Datasheet for drone camera | Dan Carlson (Bac. report) |
| The sampling rate of reflection photos | | 2 megapixel @1FPS | 5 megapixel @1FPS | | Datasheet for reflection camera | Dan Carlson (Bac. report) |
| The sampling rate of 3D scan photos | | 2 megapixel @1FPS | 2 megapixel @1FPS | | Datasheet for 3D scan camera | Dan Carlson (Bac. report) |
| Iron contamination less than | | 0,1µg iron per 1g ice? | 0,01µg iron per 1g ice? | | Chemical test | Mikeal Sejr (Bac. report) |
| The drone should be able to fly safely even if there is interference from the boat or from the poles | The drone should be able to fly back | | The drone should be immune against interference | | Datasheet for flight controller with GPS/Compass, Flight test | Claus Melvad (Bac. report) |
| The drone should be able to fly back with engine breakdown | 1 engine breakdown | | 2 engine breakdown | | Datasheet for drone | Claus Melvad (Bac. report) |
| The ice sample should have a depth of | At least 10cm | | 20cm | | Extraction test | Dan Carlson (Bac. report) |
| Time between missions | | 2 hour between test, for recharging batteries | 30 minutes if batteries can be swapped | | Datasheet for battery charger | Bac. group |
| The price of the final device, should not exceed 100.000DKK | The price of the device must be under 100.000DKK | | The price of the device should be under 50.000DKK | | Final costs | Claus Melvad ( Bac. report) |
| The price of the flying platform (drone) should not exceed 50.000DKK | | The price of the device must be under 50.000DKK | The price of the device should be under 25.000DKK | | Final costs | Bac. group |
| Flying capabilities in high relative humidity (100%RH) | | Flight in mist (impaired visibility) | | Flight in fog (less than 1 km visibility) | SAT | Dan Carlson (Bac. report) |
| The drone must have a weight under | 25kg as per Danish law | | | | SAT | Claus Melvad (Bac. report) |
| The drone must be transportable | Safe carrying case for the drone | Safe carrying case for the drone an carrying case for the tool/tools | Safe carrying case for the drone with the tool/tools mounted | | SAT | Claus Melvad (Bac. report) |
| For the drone to be operated from a boat, it may not exceed | 2x2m in width and depth, and 1,5m in height | | | | SAT | Dan Carlson (Bac. report) |

# 4 Design choice description

## 4.1 Use cases

Usecases are used in order to give an overview on what design choices to be made are wanted and needed. The following is a walkthrough of the process. Use cases are mainly focused on software related subjects.

### 4.1.1 Actors

Major actors in the interaction with the drone are as follows:

- Drone operator
- Drone (autonomous functions)
- Service personal

### 4.1.2 Use cases for actors

Table 4.1 shows the primary use cases for the above mentioned actors.

Table 4.1: Usecases for the actors.

<table>
<tr><th>Drone Operator</th><th>Service Personnel</th><th>Drone</th></tr>
<tr><td>Functionality check</td><td>Functionality check</td><td>-</td></tr>
<tr><td>Initiate drilling process</td><td>Test drilling process</td><td>Drilling process</td></tr>
<tr><td>Release GPS Beacon on iceberg</td><td>Test release mechanism</td><td rowspan="2">-</td></tr>
<tr><td>Release tools</td><td>Release tools</td></tr>
<tr><td>Tilt view camera</td><td>Test camera</td><td>Tilt scanning camera</td></tr>
<tr><td>Take off from boat</td><td rowspan="2">Test take off</td><td rowspan="5">-</td></tr>
<tr><td>Take off from iceberg</td></tr>
<tr><td>Flying to and from iceberg</td><td rowspan="2">Test flying</td></tr>
<tr><td>Landing on iceberg</td></tr>
<tr><td>Landing on boat</td><td>Test landings</td></tr>
<tr><td>Roll Detection feedback</td><td>Test roll detection</td><td>Roll Detection</td></tr>
<tr><td rowspan="2">Selection of iceberg</td><td rowspan="2">-</td><td>Identify iceberg</td></tr>
<tr><td>Keep focus on selected iceberg</td></tr>
<tr><td>-</td><td>Software update</td><td>-</td></tr>
</table>

### 4.1.3 Identify reuse opportunities

To streamline code flow, it is imperative to identify reusable program structures. The overlapping use cases, which dictate such functions, are outlined below:

- Test program before takeoff, program for replacing parts
- Given by flight controller
  - Takeoff; from boat and iceberg
  - Landing; on boat and iceberg
  - Flying to and from iceberg
  - Tilt view camera

### 4.1.4 Overview, complexity, priority

In table 4.2 all the use cases for the drill drone can be seen. The complexity and priority for each use case has rated as either low, medium or high.

| ID | Name | User | Complexity | Priority |
|---|---|---|---|---|
| **1** | **Test for functionality check** | **Drone operator / Service personnel** | **Low** | **High** |
| 2 | Initiate extraction process when on mission | Drone operator | Low | High |
| 3 | Release GPS Beacon on iceberg | Drone operator | Low | High |
| **4** | **Release tools (drill) if stuck on iceberg** | **Drone operator** | **High** | **High** |
| 5 | Roll Detection (feedback) | Drone operator | High | High |
| 6 | Selection of iceberg | Drone operator | Medium | Medium |
| **7** | **Identify iceberg** | **Drone** | **High** | **Medium** |
| 8 | Keep focus on selected iceberg | Drone | High | Medium |
| 9 | Tilt scanning camera | Drone | High | High |
| **10** | **Roll Detection** | **Drone** | **High** | **High** |
| **11** | **Drilling process** | **Drone** | **High** | **High** |
| 12 | Release tools | Service personnel | Low | High |
| 13 | Software update | Service personnel | Low | Medium |
| 14 | Test take off | Service personnel | Low | High |
| 15 | Test flying | Service personnel | Low | High |
| 16 | Test camera | Service personnel | Low | High |
| 17 | Test roll detection | Service personnel | Low | High |

Table 4.2: Use cases.

### 4.1.5 Identify key components

**Use case - ID 1**

| | |
|---|---|
| ID | 1 |
| Name | Test for functionality check |
| Actor | Drone operator / Service personnel |
| Precondition | Start Test program = True, drone is grounded = True |
| Success | Test program completed w. no errors |
| Description | Drone has a self-test procedure which initiates all autonomous systems to check functionality in service and-preflight |
| Inputs | Start Test program = True, drone is grounded = True |
| Outputs | Buzz sound, and a True (fx a LED) |

**Use case - ID 4**

| | |
|---|---|
| ID | 4 |
| Name | Release tools (drill) if stuck on iceberg |
| Actor | Drone operator |
| Precondition | In the middle of the drilling process |
| Success | Release of the drill |
| Description | Ability to ditch drill during drilling process in case of malfunction or danger |
| Inputs | Release drill program = True, drone is drilling = True, Are you sure = True (Keep button down for 3 seconds) |
| Outputs | Release of drill and signal of so |

**Use case - ID 7**

| | |
|---|---|
| ID | 7 |
| Name | Identify iceberg |
| Actor | Drone |
| Precondition | Drone is flying = True, Camera is active = True, Computer Vision is active = True |
| Success | "Target identified" Feedback - eventually green box around live feed screen |
| Description | Ability to identify icebergs and other ice formations in mid-air, so that the camera scan process can begin |
| Inputs | Begin Computer Vision = True |
| Outputs | Visual green box on live feed indicating identified object |

**Use case - ID 10**

| | |
|---|---|
| ID | 10 |
| Name | Roll Detection |
| Actor | Drone |
| Precondition | Drone is grounded = True, Drilling is active = True |
| Success | Roll of the mounted iceberg is detected in time to salvage drone |
| Description | Roll Detection functionality which makes it possible to detect if the mounted iceberg is rolling over, endangering the drone. |
| Inputs | Roll Detection active = True |
| Outputs | Visual indication of Roll Detection on user interface, onboard LED flashing |

**Use case - ID 11**

| | |
|---|---|
| ID | 11 |
| Name | Drilling process |
| Actor | Drone operator |
| Precondition | Drone is grounded = True, Tool is released = False |
| Success | Drone extracts ice-core sample |
| Description | Drone autonomously drills out an ice-core sample and extracts it for study. Drill motor is initiated, drill is lowered down into the ice, when bottomed out the drill stops and drill is raised. |
| Inputs | Start drilling process = True |
| Outputs | When drilling process is finished, drill is raised, signal to operator |

## 4.2 Morphology

In this section the morphology diagram design process used in the project will be explained. The purpose of this is to brainstorm and determine the optimal solution to the various subsystems of the project, based on the specification of requirements.

The morphology process consists of 7 steps which are as follows:

- Divide the problem/solution into subsystems
- Brainstorm ideas within each subsystem without criticism
- Determine important selection criteria for each subsystem
- Assign points and weighting to each idea and eliminate unusable ideas
- Make a morphology diagram
- Look for correlations and select a few different solution tracks
- Evaluate the solution tracks and select the best contender

### 4.2.1 Subsystems

Here follows a list of the subsystem this product is divided into.

- Drilling process
- Extraction process
- Quick Release
- Camera for 3D scan
- Electrical box
- Alarm
- Roll detection
- Landing floaters
- Vibration dampers
- Distance and contact sensor
- Long range communication
- Beacon release

### 4.2.2 Brainstorm within each subsystem

A brainstorm on each of the 12 subsystems are made in order to list every possibility for the optimal solution. All suggestions from the brainstorm can be seen in table A.1 on page 54 in appendix A.

### 4.2.3 Selection criteria, weighting and points

Diagrams for each subsystem is made. These will show which selection criteria are associated with each subsystem, how these are weighted and how they score. Underneath each table, a few points about each idea is included, describing why they score as they do. As an example see figure 4.1. The rest of the diagrams and weighting can be seen in figure B.1 on page 55 through B.11 on page 60 in appendix B.

#### Drilling process

| Drilling process | Price | Complexity | Speed (needs testing) | Deploy drill speed | Delivery time | New Components (Boolean) | Weight | Stability during flight | Test posibilities | Sample contamination | Sum |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Weighting** | 1 | 2 | 4 | 4 | 2 | 2 | 2 | 1 | 1 | 3 | |
| Raise rpm when current raise - back EMF | 5 | 3 | 5 | 4 | 5 | 5 | 5 | 5 | 4 | 5 | 101 |
| High constant rpm | 5 | 3 | 3 | 1 | 5 | 5 | 5 | 5 | 4 | 5 | 81 |
| Larger center drill | 3 | 4 | 2 | 4 | 3 | 1 | 4 | 5 | 4 | 4 | 72 |
| Better cutting blade/edge | 2 | 3 | 4 | 2 | 2 | 1 | 4 | 5 | 4 | 5 | 70 |
| Optimize flutes | 4 | 3 | 3 | 3 | 3 | 1 | 5 | 5 | 4 | 5 | 76 |

Figure 4.1: Drill Process.

- **Raise RPM** - Software based improvement, which means no additional cost.
- **High constant RPM** - Software based improvement, which means no additional cost.
- **Larger center drill** - A larger center drill is not very expensive (ranging from 100 - 1000dkk depending on size and material choice).
- **Better cutting edge/blade** - Better cutting edges requires a lot of development and testing of different prototypes which will all have to be custom made.
- **Optimize flutes** - This will cost a bit, but a new drill is needed in any case.

### 4.2.4 Morphology diagram

In figure 4.2, is the morphology diagram shown, with green and red arrows indicating any synergies and dis-synergies.

| Sub system | | | | |
|---|---|---|---|---|
| Drilling process | Raise RPM, when current raise | High constant RPM | | |
| Extraction process | Contra valve | Vacuum | Hooks | Chipmunk drill |
| Quick release | Solenoid | Actuator | | |
| Camera for 3d scan | Gimball | Actuator, encoder to control rotation | | |
| Electrical box | Square | Hexagon | | |
| Visual alarm | Row of LED status bar operator | buzz sound operator | | |
| Roll detection | Accelerometer myRio | External compass | | |
| Landing floaters | One big circular plate | Flamingo | | |
| Vibration dampers | Rubber sticks | | | |
| Distance contact sensor | Laser | IR | LIDAR | Ultrasonic |
| Long range communicatioi | RF | Satellite connection | | |
| Beacon release | Solenoid | actuator | | |

Figure 4.2: Morphology diagram.

### 4.2.5 Solution tracks

Figure 4.3 on the following page shows 11 different solution tracks, 9 of which are marked red which means that these has been eliminated in the evaluation process. This leaves two solution tracks, which will be used in the following.

| | Drilling process | Extraction process | Quick release | Camera for 3d scan | Electrical box | Visual alarm | Roll detection | Landing floaters | Vibration dampers | Distance contact se | Long range c | Beacon release |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Solution track 1** | Raise RPM | Hooks | Actuator | Gimbal | Hexagon | Row of LED | Accelerometer MyRio | Flamingo | Rubber sticks | LIDAR | RF | Actuator |
| Solution track 2 | High Constant RPM | Vacuum | Actuator | Actuator, encoder | Square | Buzz sound | External compass | One big circular plate | Rubber sticks | Laser | Satelite conn | Actuator |
| Solution track 3 | Raise RPM | Contra valve | actuator | Gimbal | square | buzzsound | External compass | One big circular plate | Rubber sticks | Ultra sonic | Satelite conn | Actuator |
| Solution track 4 | Raise RPM | Chipmunk drill | solenoid | Actuator, encoder | Hexagon | Row of LED | External compass | Flamingo | Rubber sticks | Lidar | RF | Solenoid |
| Solution track 5 | High Constant RPM | Hooks | Solenoid | Actuator, encoder | Hexagon | Buzz sound | Accelerometer MyRio | Flamingo | Rubber sticks | LiDAR | RF | Solenoid |
| Solution track 6 | High Constant RPM | chipmunk drill | Actuator | Actuator, encoder | Square | Row of LED | Accelerometer MyRio | Flamingo | Rubber sticks | IR | Satelite conn | Actuator |
| Solution track 7 | Raise RPM | Vacuum | Solenoid | Gimbal | Hexagon | Row of LED | Accelerometer MyRio | Flamingo | Rubber sticks | LIDAR | RF | Solenoid |
| Solution track 8 | Raise RPM | Hooks | Actuator | Actuator, encoder | Square | Buzz sound | External compass | One big circular plate | Rubber sticks | IR | Satelite conn | Actuator |
| Solution track 9 | High Constant RPM | Contra valve | Solenoid | Actuator, encoder | Hexagon | Row of LED | Accelerometer MyRio | Flamingo | Rubber sticks | LiDAR | RF | Solenoid |
| Solution track 10 | High Constant RPM | Chipmunk drill | Solenoid | Gimbal | Square | Row of LED | External compass | Flamingo | Rubber sticks | Ultra sonic | RF | Solenoid |
| **Solution track 11** | Raise RPM | Chipmunk drill | Actuator | Gimbal | Hexagon | Buzz sound | Accelerometer MyRio | Flamingo | Rubber sticks | LIDAR | RF | Actuator |

Figure 4.3: Solution tracks.

In the final two solution tracks, Lidar, Gimbal and linear actuators are all present. Since these are quite broad terms, there has been created charts with selecting criteria weighting and points for each of the three, these follows here in Figure 4.4, 4.5, and 4.6. Underneath each follows the weighting criteria.

| Lidar | Price | Size | Accuracy | Minimum resolution | Communication interface | Range | Weatherproof | Sum |
|---|---|---|---|---|---|---|---|---|
| **Weighting** | 1 | 4 | 5 | 4 | 5 | 3 | 2 | |
| Seeedstudio Grove - TF Mini LiDAR | 5 | 5 | 1 | 4 | 3 | 4 | 2 | 77 |
| LIDAR-Lite 3 Laser Rangefinder High Performance | 1 | 3 | 2 | 4 | 4 | 5 | 5 | 84 |
| Benewake TFMINI Micro LIDAR Module UART | 5 | 5 | 5 | 4 | 5 | 5 | 3 | 112 |
| TFMINI - MICRO LIDAR MODULE | 3 | 5 | 5 | 5 | 4 | 3 | 3 | 103 |
| LIDAR-LITE V3 | 1 | 3 | 2 | 4 | 5 | 5 | 3 | 85 |

Figure 4.4: Lidar sensors.

- Range (1: 0,5-5m - 5: 0,3-12m).
- Communication interface (0: Unknown - 1-2: UART, I2C, SPI with bad or none protocol - 3-5: UART, I2C, SPI with good protocols).
- Accuracy (1: 10mm - 5: 5mm).
- Minimum resolution (1: 5cm - 5: 0,1mm).
- Price (1: Above 1000dkk - 5: Below 300dkk).
- Size (1: 200x200x200mm 5: 40x40x40mmm).
- Weather proof (1: Not possible to weather proof - 5: IP67).

| Gimbal | Price | Weight | Complexity | Movement resolution | Type | Weather proof | Availability | Sum |
|---|---|---|---|---|---|---|---|---|
| **Weighting** | 1 | 3 | 4 | 3 | 1 | 3 | 3 | |
| Andoer 2D Lightweight Gimbal | 4 | 5 | 2 | 2 | 3 | 1 | 4 | 51 |
| Helistar HB-HIi-01 | 5 | 5 | 2 | 2 | 3 | 1 | 3 | 49 |
| Tarot GoPRO 2 | 4 | 4 | 2 | 3 | 3 | 1 | 2 | 45 |

Figure 4.5: Gimbal.

- Prize (1: 2500dkk - 5: 500dkk).
- Weight (1: 500g - 5: 100g).
- Complexity (1: 20h - 5: 1h).
- Movement resolution (1: 200ppr - 5: 2000ppr).
- Type (1: Servo - 5: Open BDC).
- Weather proof (1: No IP class - 5: IP67).
- Availability (1: 8-10days - 5: 1-2 days).

| Actuator (linear) stroke 20-30mm | Price | Weight | Complexity | Mounting space required | Execution speed | Weather proof | Reuseability | Availability | Sum |
|---|---|---|---|---|---|---|---|---|---|
| **Weighting** | 1 | 3 | 2 | 4 | 2 | 3 | 4 | 3 | |
| PQ 12 - 20mm - 100:1 | 4 | 5 | 4 | 4 | 4 | 4 | 5 | 4 | 95 |
| Mighty Zap Linear Servo 30mm | 3 | 3 | 3 | 3 | 5 | 4 | 5 | 1 | 75 |
| Solenoid Framed 2924 12V | 5 | 5 | 4 | 4 | 5 | 3 | 4 | 4 | 91 |

Figure 4.6: Linear actuators.

- Price (1: Above 1000dkk - 5: Below 200dkk).
- Weight (1: 100g - 5: 15g).
- Complexity (1: Complex coding 5: Easy coding).
- Mounting space (1: 80x80x30mm - 5: 20x20x10mm).
- Execution speed (1: 1mm/s - 5: 90mm/s).
- Weather proof (1: No IP class - 5: IP67).

# 4.3 Part conclusion

## 4.3.1 Final design description.

Through morphology diagrams and previous design inputs, the final design of the drone has been decided on. The Drone will be built around a commercial DJI Matrice 600 Pro drone chassis, including its standard Zenmuse X3 camera setup. The main processor and programming will be a NI myRIO-1900 with LabVIEW programming. An RF unit, functioning at 868MHz will be used for long range communication. The linear actuator setup, to raise and lower the drone, will be driven by 3x stepper motors on Lead Screws. LiDAR units on each corner of the base frame triangle will determine distance to ground. The mechanical cup drill will be driven by the same Brushless DC motor and gearing, while the drill itself and its operations will be optimized from the previous design. The floats at the base of the frame will be optimized for the drones current weight. A camera gimbal will be used for iceberg recognition and 3D-scanning. A quick release mechanism driven by a linear actuator will enable the drone to ditch its drill if needed. A second linear actuator will be able to drop an attached payload. A sketch of the drone can be seen on figure 4.7.

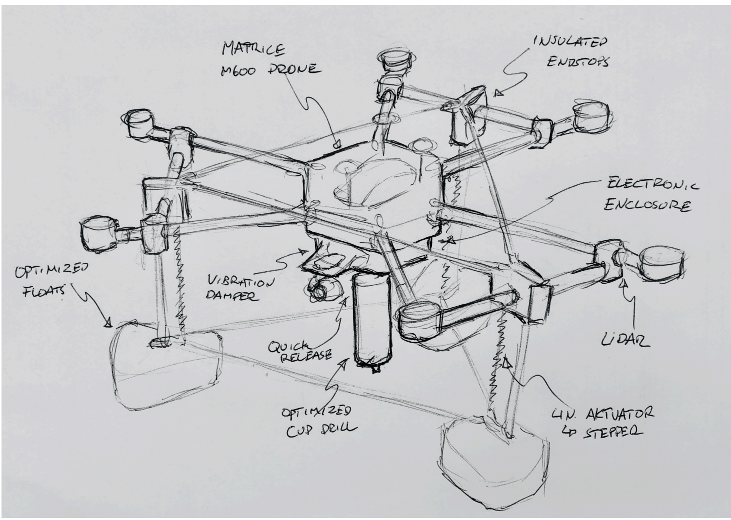



Figure 4.7: Sketch of final design.

# Development and construction 5

## 5.1 Mechanical

### 5.1.1 Electronics box

The purpose of the electronics box is to assemble all the electronic components such as the main print board, the myRIO, the XBee module, the ESC and battery for the DC-motor driving the drill. Furthermore, it will serve as a mount for the DC-motor and drill suspension, the servos for the gimbal and the Zenmuse camera. Accordingly, it will serve as an important part for the mechanical parts as well as the electronics.

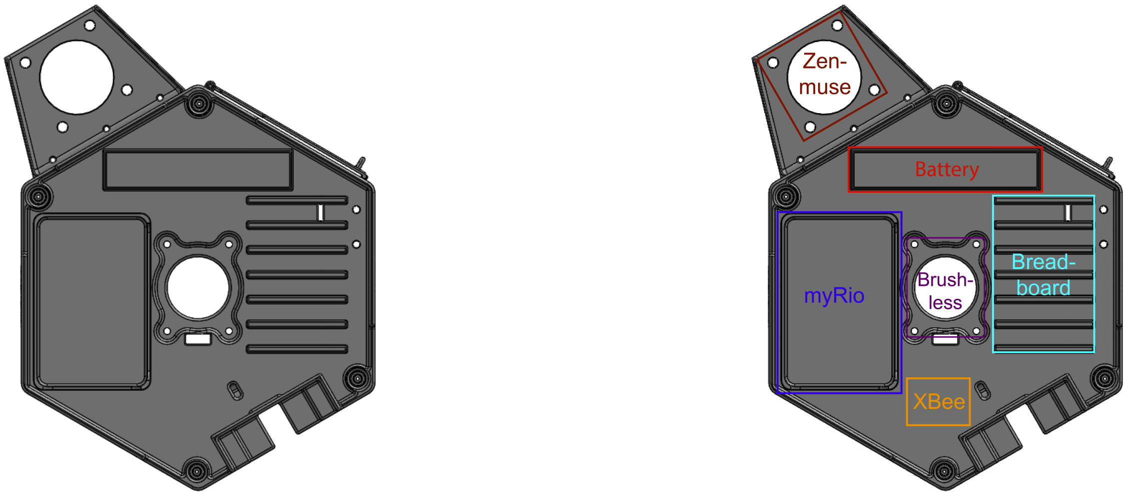
The design of the electronics box has been made with focus on easy assembly/disassembly, protection from all kinds of weather, and mechanical endurance. Because of the many different requirements for the box it has been decided that the box will be made from nylon (PA 2200) and will be manufactured by SLS 3D-printing as this technology offers very few design limitations and fast delivery.

The shape of the box is a six-sided polygon that matches that of the drone which will make the overall design visually appealing, and will make the assembly of the drone and box easier, see figure 5.1a on the next page.

The inside of the box is designed so that the respective electronic components fit inside the defined areas. These are made for the myRIO, the print board, the drill battery and the XBee, see figure 5.1b on the facing page.

Furthermore, small holes have been made for the wires that have to go in and out of the box. As a special feature, a small door have been made in the box. This is primarily to make the battery change easy without having to disassemble the whole box, see figure 5.2 on the next page. From figure 5.2 on the facing page it is also possible to notice a slot for the fan to blow out air from the inside of the box to prevent the electronic components from overheating. Especially the stepper drivers and the DC-motor which produce significant amounts of heat during operation.

To ensure that the box has the required strength to sustain the torque applied by the drill motor, a FEM study has been made. This can be seen on appendix C on page 61.




(a) Electronics box from top. (b) Electronics box with area for components.

Figure 5.1: The electronics box.

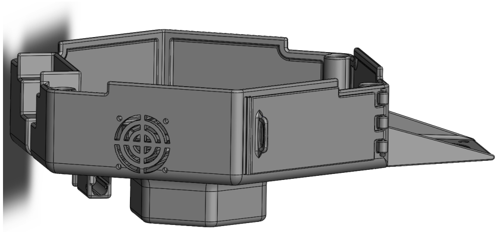


Figure 5.2: Electronics box with small door and room for fan.

### 5.1.2 Floats

The old design of the floats was through the morphology diagram B.7 on page 58 chosen as the shape most suitable for the construction of the drone. They offer the best stability without using up too much space under the drone where drilling operations will take place. The shape also allowed for the Lidars to measure the distance to the ground without making any major mechanical solutions 5.2.7 on page 30. In the calculations made to make the floats smaller in size the change in weight of the floats are considered indifferent because of the low density of the expanded polystyrene (EPS). The floats are made of EPS with a density of 11-28 $\frac{kg}{m^3}$ which is very low and thus seen as insignificant. As seen in the calculations in appendix D on page 65 the height of the floats is changed from 200 mm to 120 mm. The new float can be seen in Figure 5.3. With the new height of the floats the floats can lift 27 kg. This assumes using the expected weight of 18 kg with a safety factor of 1,5.

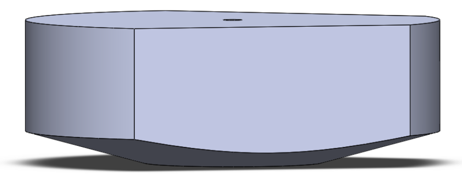


Figure 5.3: Float with a new height of 120mm.

### 5.1.3 Spikes

The spikes on the end of the landing gear has been modified and now have stainless steel track and cross country spikes [Amazon.com, 2019] at the tip of the 3D-printed PLA base see Figure 5.4. Previously the bachelor group reported problems with metal spikes freezing to the ice making it impossible to fly away with the drone. In an attempt to prevent this from happening the diameter of the 3D-printed part is smaller than the diameter of the aluminum tube it will be assembled with. Using medium strength Loctite to glue the two parts together the drone should be able to detach itself from the spikes if they freeze to the ice. More testing is needed to find the right amount of Loctite needed for the drone to detach itself easily while securing the spikes during normal operation.

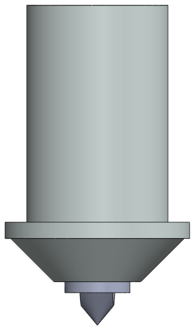


Figure 5.4: New spikes with 3D-printed base and stainless steel spikes at the tip.

### 5.1.4 Design of Quick release

In the following chapter, the purpose, requirements, and construction of the Quick Release mechanism will be explained. Technical drawings of the components created for this mechanical design, can be found in appendix M on page 84.

**Purpose**

The need of a quick release mechanism, was made clear in the chapter containing use cases 4.1.4 on page 12. After the drill has been redesigned to grab the ice sample better (Using the chipmunk style drill 5.1.5 on page 24) there's a risk that it can get stuck in the iceberg. This could cause a major problem in an emergency situation, where for example the iceberg starts to roll, and the drone needs to escape quickly.

**Requirements**

There are a couple requirements for a successful quick release mechanism, these are as follows:

- The quick release mechanism shall be controlled from the drone operator's controller
- Has to grab the drill, securely while attached.
- The drill shall not be able to wobble more than a maximum of 0.5mm at the tip.

Figure 5.5: NITO Coupler used in the Quick release mechanism.

### Final design

The final design, is build around the principles of a NITO coupler, usually used in attachments of hoses in compressed air systems. this coupler can be seen in figure 5.5.

This mechanism is chosen because it is a proven design, which has been tested thoroughly, and improved over several years.

On figure 5.6 a cross-section of the complete assembly of the mechanism is shown. Here it is seen how the parts fit together. The main areas of this assembly is how the NITO coupler, shaft and bearing plates work together, this ensures that the construction fulfils the requirements specified if section 5.1.4.

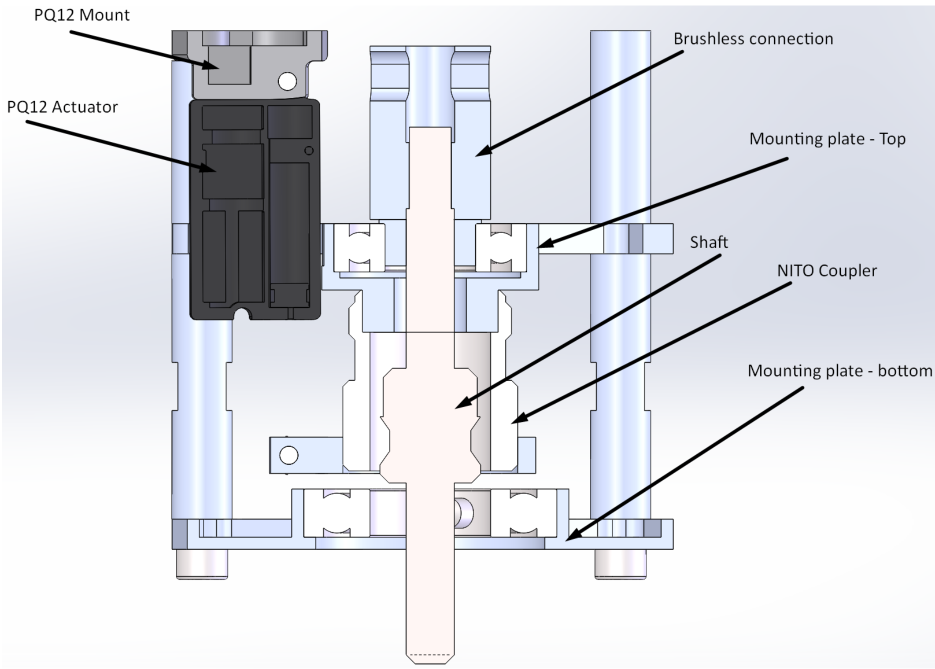



Figure 5.6: Cross-section of final QR assembly.

In the following the major components and their features will be explained.

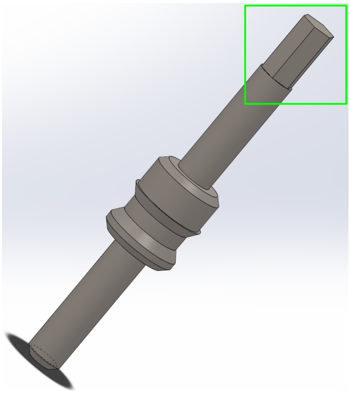
### Shaft design and fits

The shaft is one of if not the most significant part(s) in this assembly. It holds several important features. The requirements for these parts are as follows:

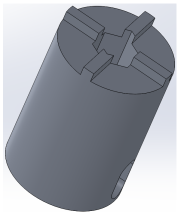
- Transfer torque from a brushless DC motor to the drill

- Secure the drill to the drone
- Be able to detach, in case of emergency

To fulfil the first requirement, the shaft is milled to a hexagon shape in the top (see green section on figure 5.7(a). This hexagon created with tolerances which ensures at tight but sliding fit with the brushless connector 5.7(b), which has an internal hexagon shape.



(a) Shaft.



(b) Brushless connector.

(c) Male part of NITO coupler.

Figure 5.7: Shaft and associated parts.

To secure the drill to the drone, the NITO coupler is used. In order to make this work, the shaft needs the correct geometry to fit the NITO coupler. On figure 5.7(c) the male part of a NITO coupler is shown, this geometry is copied to the shaft.

In order to make the manufacturing process of the shaft less complicated, there are no fine tolerances on the part of the shaft which engages with the NITO coupler. However there are some tight tolerances both above and below, where the shaft runs in bearings. The relative long distance between the bearing also means that the deflection at the bottom of the drill is less than the specified 0.5mm (5.1.4). The exact measurements and tolerances can be seen on the technical drawings in appendix M on page 84. Likewise, the calculations which determines the maximum deflections at the drill tip, is described in appendix E on page 68.

To attach the drill to the shaft, the shaft is created with a M8 thread at the bottom, where the top of the drill is mounted to the shaft, the top of the drill is made with such tolerances that it fits tight into the bottom bearing, this tolerance also contributes to the reduced deflection.

### 5.1.5 Ice Core Drill Design Changes

The main design for the Ice Core Drill for this project builds of off the shape and critical measurements from the previous bachelor project. This includes the length of the drill, inner and outer diameters, cutting angles and number of cutters. In the figures in the following sections describing the changes made to the Top, Body and Head of the drill – The V3 prototype, from the previous bachelor project, will be on the left while V4 will be on the right.

**Drill Top**

On the top section see;

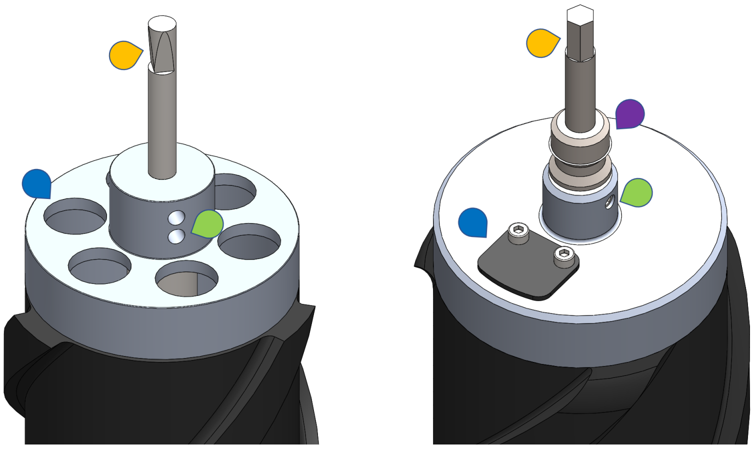


Figure 5.8: Drill top, V3 (left) and V4 (Right).

- V3 features a slotted axle [yellow] which transfers torque from the drill motor through set screws, for V4 the torque transfer has been changed to a 7mm hexagon which does not require set screws.
- Large openings in the upper face [blue] to reduce weight, these have been exchanged for a single one-way vent closed by a rubber membrane. Which should aid in ice-core retention post-drill.
- On V3 four set screws [green] lock the outer barrel to the axle, the number of set screws have been reduced from four to two due to a design change of the axle to where it threads onto an internal connector, reducing the need for external axle retention.
- Additionally, V4 features a quick release mechanism [purple], which allows the drill to drop away if needed, this feature is described in further detail in the Quick Release Chapter.

**Drill Body**

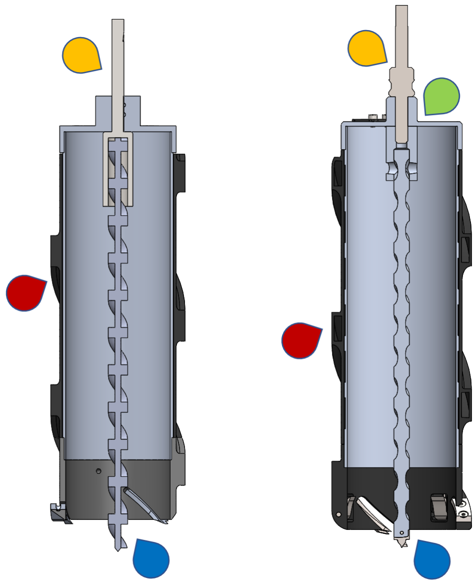


Figure 5.9: Drill Body, V3 (left) and V4 (Right).

As described previously, the overall dimensions of the drill remain the same from V3 to V4. The construction of the drill however sees some critical changes.

- The drive axle [yellow] has gone from a single piece construction with screws securing the center bit [blue], to a two-piece construction where the axle screws into a connector [green] which secures the center bit onto the drill body.
- Additionally, the fluted outer jacket of the drill [red] has been changed from a solid construction to a hollow one to save weight.

### Drill Head

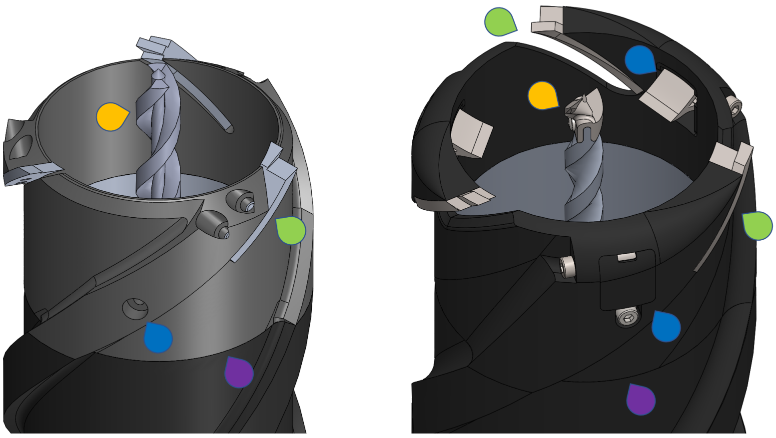


Figure 5.10: Drill Head, V3 (left) and V4 (Right).

The head has undergone the most dramatic changes:

- Ice packing behind and in front of the cutting teeth [green] were reported by the bachelor project on the V3 design. On V4 the tooth securing method has been updated to countersunk screws located in the top face of the tooth. See figure 5.11. This simplifies the geometry behind the tooth which has been changed from a straight chamfer to a variable fillet. Clearance between the body of the head and the tooth has also been increased to avoid material jamming.
- The tip of the center bit [yellow] has been updated to a two-piece design which enables two different materials to be utilized for the center bit, see section 5.1.5.
- The static set screws [blue] intended as a core-retaining mechanism on V3 has been replaced with a spring-loaded Chipmunk-tooth mechanism which is designed to grab and break off the ice core. For further details see section 5.1.5.
- The joint between the head and fluted sleeve remains unchanged [purple] with the threaded inner aluminum sleeve as well as the teeth's staggered tip design.

### Center Bit

As touched upon previously, the center bit has been changed from a single piece, to a two-piece design. Where a sharpened tip [yellow] screws onto the body of the bit [green] with a securing screw [blue]. This is done to enable different materials to be used for the tip and body.

### Chipmunk Teeth

As mentioned previously, the static set screw mechanism on the head of the drill has been changed to a spring-loaded chipmunk-tooth mechanism seen on Figure 5.13 on page 26. This consists of the

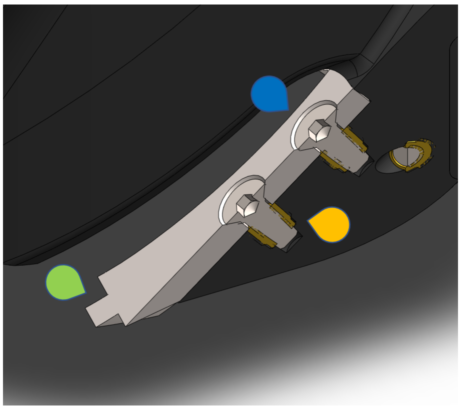


Figure 5.11: Drill Head Tooth depicting; securing screws [blue], cutting tooth [green] and threaded inserts [yellow].

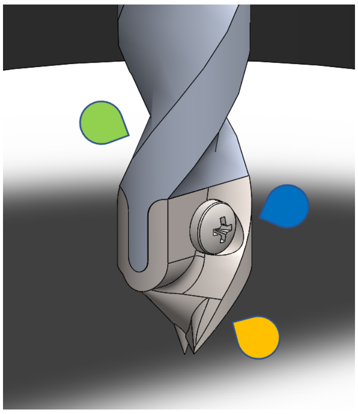


Figure 5.12: Tip of Drill Center Bit.

sharpened metal tooth [green], which swivels on a retaining screw [purple] and is spring-loaded by a u-shaped leaf-spring style 1mm wire spring [yellow] retained by a set screw.
This spring-loading forces the tooth to skate along the ice-core as it enters the drill body. Once the drill is retracted, the sharpened upper edge of the tooth engages with the ice-core, and as the retraction continues, drives the tooth further into the core, severing it from the iceberg. Once retrieved, cut-outs on the tooth [red] enable the operator to swivel the tooth out to release the ice core. The whole mechanism is protected from ice and snow-intrusion by a cover, situated around the mechanism [blue], as seen on figure 5.10. This cover can easily be pried off via built in slots designed for the tip of an ordinary flat faced screwdriver.

**Material Choices**

On the V3 drill, the final prototype body was constructed out of FDM 3D printed PLA plastic coated in ski-wax and machined aluminum for the top and inner sleeve. The teeth, center bit and axle being machined out of high-carbon steel covered in a ceramic coating. The teeth were additionally hardened and tempered. Set screws and other hardware was standard 8.8 grade zinc-coated steel.
On receiving the previously used prototype, it became clear that the coating, developed in the bachelor project, had not held up as intended. On the cutting edges the coating was entirely worn off and teeth and center bit were spotted with rust from salt incursion. This is a major problem,

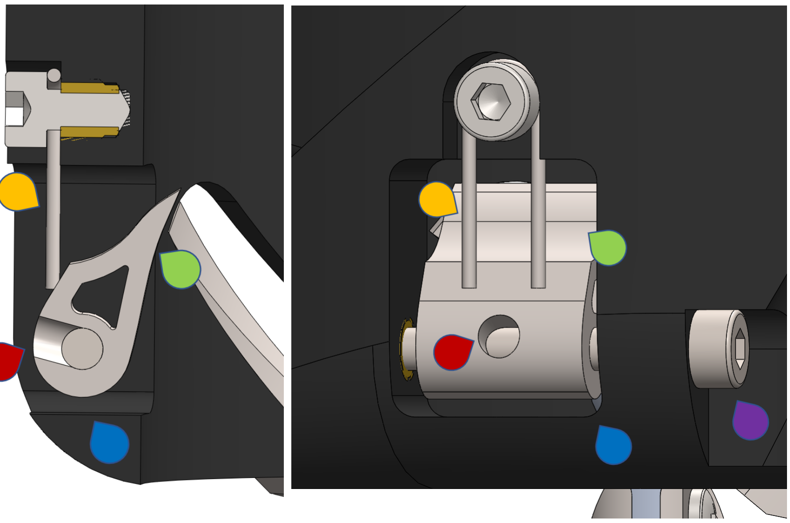


Figure 5.13: "Chipmunk" Tooth mechanism, side view (left) and external (Right).

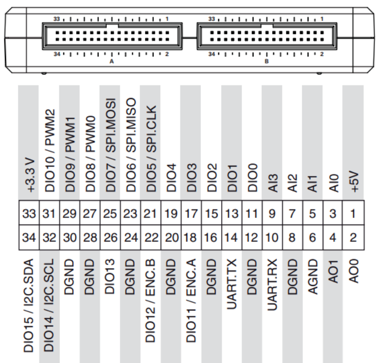
as the retrieved ice cores would be contaminated with iron particles by the exposed steel and rust, which is unacceptable. The final material changes center on the removal of all iron from the body and head of the drill and are further explained table F.1 on page 70 in appendix F.

## 5.2 Electronics

Since this project is based on a previous Bachelor project, it makes sense to reuse some of the components, which was used previously. A description of these components and the reason why they are reused will follow in this chapter.

### 5.2.1 Main Processor and programming

(a) myRIO-1900 Unit.




(b) myRIO-1900 MXP A/B connector pinout.

Figure 5.14: myRIO unit and pins.

#### NI myRIO-1900

The main processor chosen for the on-board calculations and programming, is a National Instruments myRIO-1900 unit, see figure 5.14a. This unit provides a power-full Xilinx processor, integrated Wifi and FPGA and more than enough IO ports for this application. The myRIO-1900 unit was kindly provided by the Instrument Depot at Aarhus University.

Specifications: [National Instruments, 2018]

- Xilinx Z-7010 processor 667 MHz (ARM Cortex A9 x2 cores 28 nm)
- Memory: NV: 256 MB, DDR3 512MB, 533 MHz, 16 bits.
- FPGA type same as processor.
- Wireless: IEEE 802.11 b,g,n ISM 2.4 GHz 20 MHz.
- 1x USB 2.0 Hi-Speed.
- Breakout Board support.
- 2 MXP - 16 Digital I/O lines, 4 Analog Input and 2 Analog Output.
- 6-16V/14W Input Supply, 2x 3.3V/150mA and 5V/100mA output.

#### NI LabVIEW

The programming suite supported by the NI myRIO-1900 unit is called LabVIEW, [National Instruments, 2019a]. Developed by National Instruments; LabVIEW is a visual programming suite, which via visual flow diagrams and line connections program underlying code to perform complex tasks without the need for written code. LabVIEW supports thousands of different data operations and functions and greatly simplifies project flow through its visual interface.

### 5.2.2 Brushless DC - Drill motor

In the previous project it was decided that the drill, should operate at 500-800 RPM. In the bach. report it is calculated that without load, and a 67:1 gearing, the motor will run at 645 RPM. The chosen motor for this application is a LRP Vector K7 10.5T 3600KV.

The motor provides $P_W = 280\text{W}$ of power at $n = 26640\text{rpm}$, which yields $T_{Nm} = \frac{P_W \cdot 0.9549}{n} = 0.096\text{Nm}$ torque, [Lautenbach Racing Products GmbH, 2015] and [Engineering ToolBox, 2009]. After the gearing of $r = 67$ this equals 6.42Nm. See calculation 5.1.

$$T_{Final} = T_{Nm} \cdot r = 6.421\text{Nm} \tag{5.1}$$

### 5.2.3 Landing gear actuator

The landing gear and drill process is working together in the design from the bach. project. This means that the drone will be lowered in the landing frame. To do this there has been chosen 3 hollow axle stepper motors from [RobotDigg.com, 2019] running on lead screw axles. These work great in conjunction with the "Big Easy Drivers" described in the next section 5.2.4

### 5.2.4 BigEasyDriver

The stepper motors are controlled using "Big Easy Drivers", these have a couple great benefits which we utilize in this project. First of they are very small, and easy to configure, in this project the pins connected can be seen on table 5.1 on the following page.

Table 5.1: Connection of the Big Easy Drivers.

| **Big Easy Driver** | A | A | B | B | MS2 | MS3 | VCC | DIR | Step | GND | M+ | M-GND | EN |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Electronic setup** | Stepper coil A | Stepper coil A | Stepper coil B | Stepper coil B | GND | GND | 5V | DO | PWM | GND | 18V | GND | DO |

Each of the 3 steppers, are controlled with their own driver, and their DIR and STEP pins are controlled from the same output on the myRIO, this ensures that they run at the same time. However there are a possibility that the steppers can run out of sync with each other, therefore there are added micro switches at the top and bottom, for all 3 actuators, and the Enable pin on the drivers are run separately from the myRIO. In the following section(5.2.5), the micro switches will be described. The MS pins on the driver are used to control how the stepper runs, in this case MS2 and MS3 are connected to ground, which means that the stepper runs in "half step"-mode.

### 5.2.5 Micro switches

The micro switches are used as endstops on the linear axis'. The switches used in this project are DB1-A1LB, and matches those of the bachelor project. When a micro switch is pressed, it means the stepper has either reached the bottom or the top of the landing gear frame, and the actuator needs to stop. This micro switch sends a signal through LabVIEW to the corresponding Big Easy Driver, pulling the enable pin high, which causes the stepper to stop.

### 5.2.6 Extraction of GPS from A3 controller

The collecting of the GPS coordinates is done through the drone's A3 Flight Controller.

Through the A3, among many other data outputs, the GPS Coordinates are accessible. To make the reading simpler several setups are made. Firstly, on the DJI Flight Assistant all other outputs are turned off, and the output frequency of the GPS signal is set to 10Hz as seen on Figure 5.15.

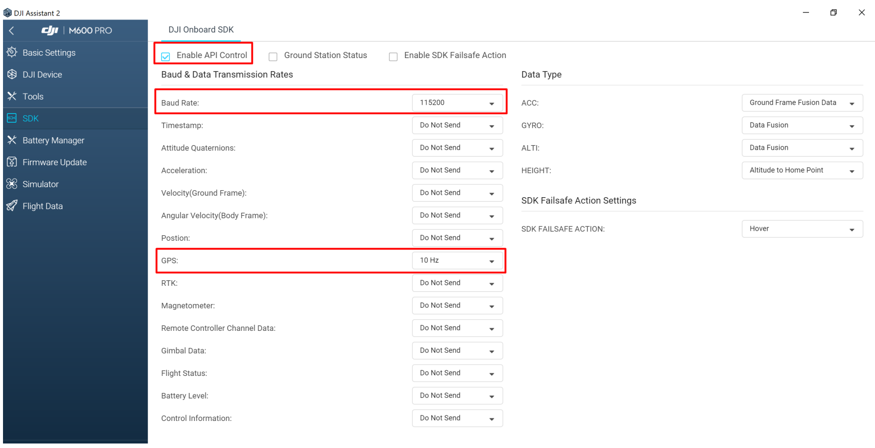



Figure 5.15: DJI Assistant UART Setup.

Then for the output, which is UART, LabVIEW searches after strings with content, and build these into an array before indexing the latest usable string and passing this to the decoding SubVI to extract the exact GPS Coordinates. The LabVIEW program as seen in Figure 5.16 on the facing page uses a while loop to showcase the principle. In the main program it uses one big while loop

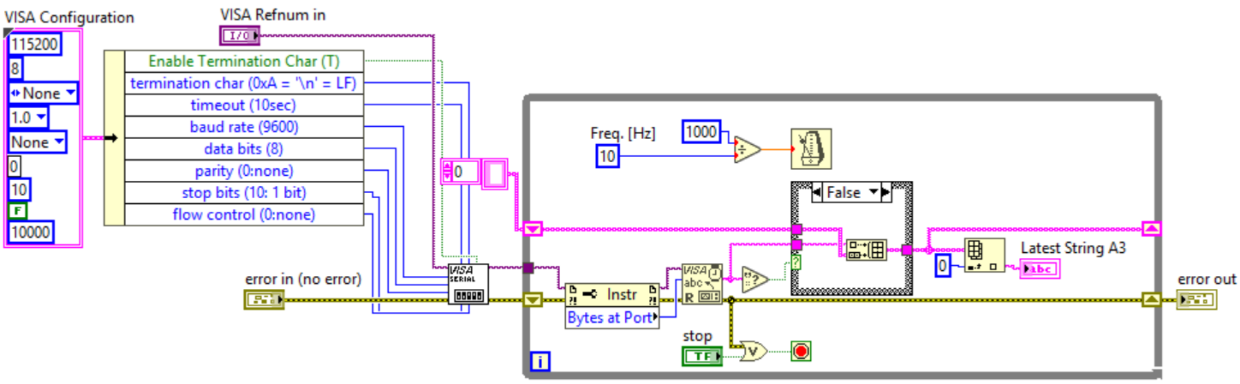



Figure 5.16: A3 extraction SubVI.

for extracting and decoding. The A3 is connected to the myRIO through the A3 UART connector, see Figure 5.17.

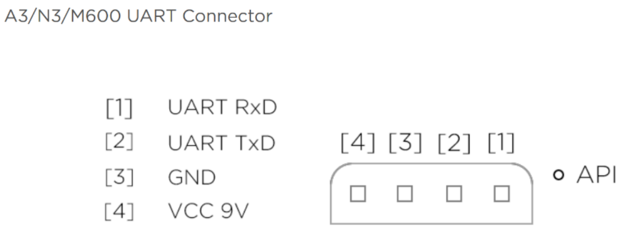



Figure 5.17: A3 UART connector.

### Decoding

The data output from the A3's UART API connection, is transmitted as a string of Hexadecimal Chars. This stream can be decoded according to DJI's Onboard SDK Open Protocol [DJI] However, early efforts towards this yielded very little. When bit-banging a recorded dataset from the API UART output, it became clear that the individual data bytes are arranged according to "Little Endian" byte order.

Without this knowledge, the extracted GPS coordinates presented with a significant positioning error of 5-50km. When accounting for this the included data was provided with U32 precision according to the Open Protocol, see above reference.

Little Endian distribution functions as on Figure 5.18 on the following page.

Where a typical Least- or Most Significant Bit first approach focusses on the direct order of the presented string of data bits. Big- and Little-Endian order focuses on the order of bytes within the data package contained in the string.

The LabVIEW code flow for the decoding operation is as seen in Figure 5.19 on the next page.

The main functions of the program are to; First extract the data stream without spaces or padding. Second, to break the data stream into four-byte words. Third to cast the words into U32 format. Forth to correct for Little Endian byte order. For a more detailed walkthrough of the decoding operation, please see the DJI A3 connectivity guide.

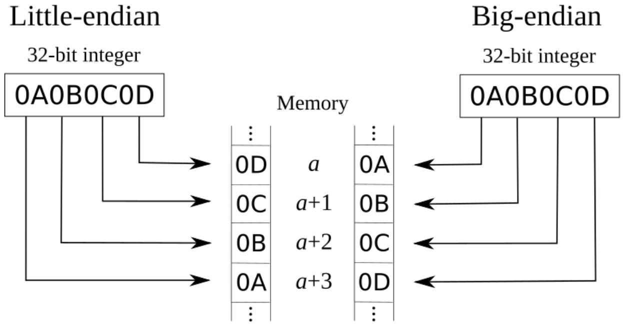



Figure 5.18: Little-endian distribution.

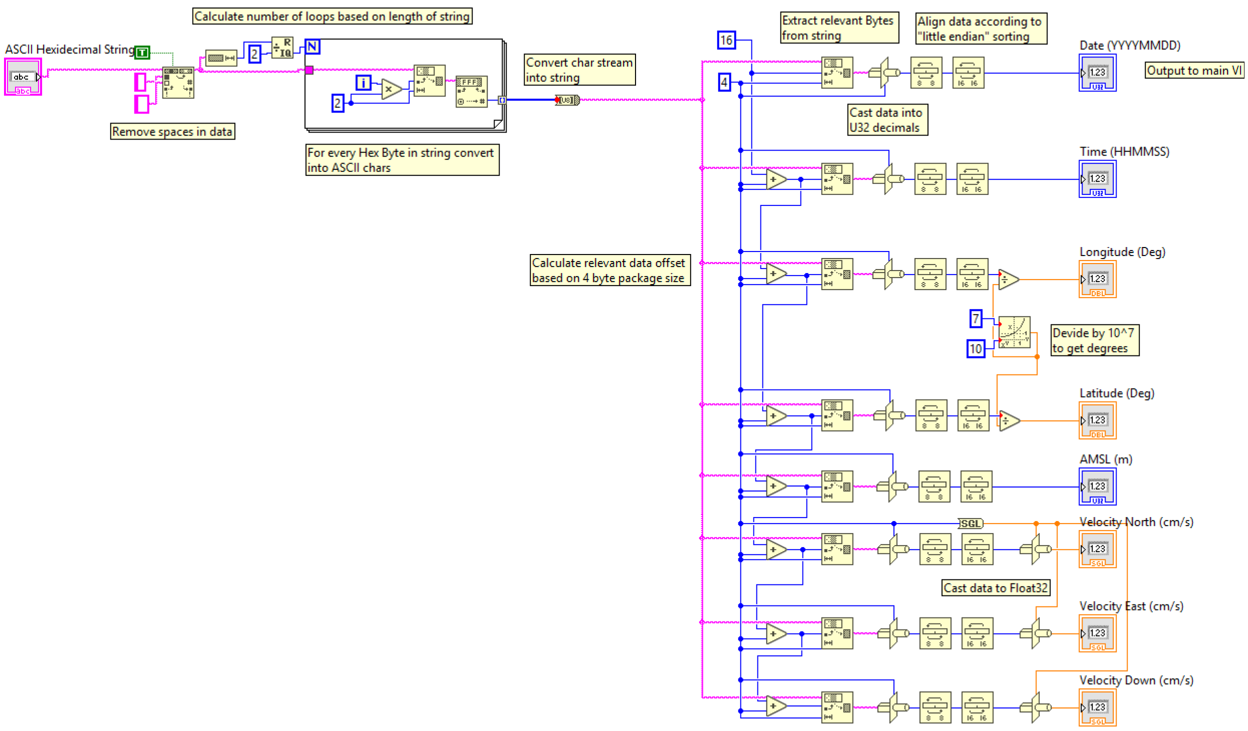



Figure 5.19: A3 decoding SubVI.

### 5.2.7 LiDAR

The LiDARs on the drone is used to different measuring purposes. The LiDAR's used are the Benewake TFMINI Micro LiDAR Module UART (12 m), see figure 5.20 on the facing page. 3 of these LiDAR's will be installed on 3 different drone arms.

The first purpose is when the drone is about to land. Since there's three LiDARs around the drone, these can be used to measure the evenness of the surface the drone is about to land on. If the measurements aren't close to each other, the surface is uneven or is a slope, and the drone should land elsewhere.

The other purpose of the LiDARs is to give an estimated indication of how deep/far the into the iceberg the drone is drilling. This tells how far into the drilling process the drone is currently at, this will show up on the ground station computer in form of a progress bar.

The reading of the LiDAR is made through UART with LabVIEW. This is done through HEX

Figure 5.20: The Benewake TFMINI Lidar.

reading turned into an U8 Byte Array. Then the different parts of the output are separated, and the set together to give a measuring output in cm. Furthermore, there's incorporated a function which detects if LabVIEW receives an actual reading. If the reading is bad, the drone will react after the latest useful measuring.

For pin-setup see [DFRobot Inc., 2018].

### LiDAR software

LiDARs implementation in the main is pretty straight forward. The extraction is just a simple UART communication with Read all available and a baudrate at 115.200, see figure 5.21.

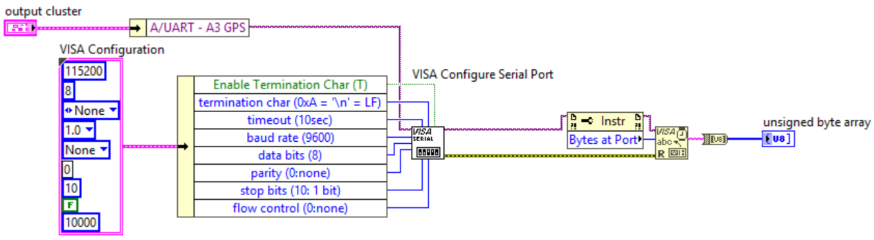



Figure 5.21: Initializing LiDAR data.

The output of this, is a U8 Byte Array. This array is indexed to separate the parts indicating distance with LSB first. First byte is checked to verify whether the upcoming data is valid or not. If invalid the latest valid distance is used. Byte 2 and 3 are extracted and the third byte is multiplied with 256 since this is the max number for U8 ($2^8 = 256$). This is then added with the second byte to get the actual distance, see figure 5.22.

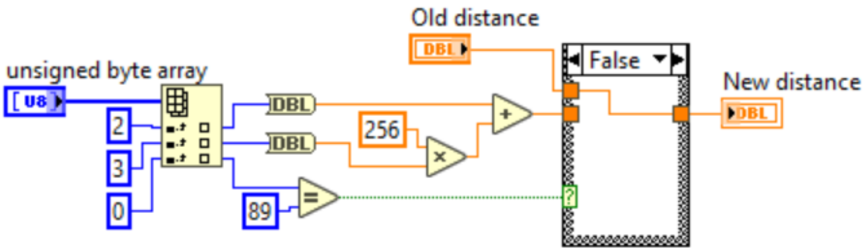



Figure 5.22: Extracting LiDAR data.

### 5.2.8 Ammeter

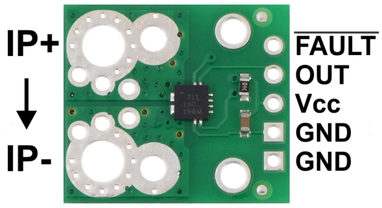



Figure 5.23: Pinout of Polulu ACS711EX current sensing board utilized.

To gain autonomy over the drilling process, it is decided to implement a current sensor on the positive lead between the drill battery and ESC. This enables autonomy by giving the software feedback on operating load on the drill, enabling different actions to be taken depending on load conditions and events. The sensor selected for this purpose is a Polulu distributed board [Polulu Corporation] based on the Allegro ACS711EX hall-effect current sensor [Allegro Microsystems LLC]. Based on the report provided from previous bachelor project, the maximum current seen during operation was 14 Amps DC. As such the selected board provides a current rating of +/- 31 Amps DC and a voltage range of 100 Volts DC, which affords a suitable safety margin of 2.2 for current spikes during motor start-up and stall conditions while providing constant measurement capabilities.

#### Pin Connections

The pin connections are as follows:

- **[IP+]:** Current in; connect to positive wire from power source, a variety of either solder or screw connections can be used.
- **[IP-]:** Current out; Connect to positive wire to load, a variety of either solder or screw connections can be used.
- **[FAULT]:** High/Low (0/3.3V) latched output, latches Low when current outside of the sensors operating range is detected. Can ONLY be reset by powering off VCC.
- **[OUT]:** Analog voltage out reading. The analog voltage on the OUT pin is scaled linearly according to:

$$VOUT = \frac{Vcc}{2} + i * \frac{Vcc}{73.3\ A}$$

$$i = 73.3\ A * \frac{VOUT}{Vcc} - 36.7\ A$$

- **[VCC]:** Connect either to 3.3V or 5V depending on application. With the myRIO's analog pins being 5V tolerant, for this application VCC on the sensor is connected to 5V in order to utilize more of the myRIO's ADC operating range.
- **[2x GND]:** Ground connection for the sensor, connect to ground plane of power source to prevent potential buildup in circuit.

### 5.2.9 SPI to 4x UART converter

The three selected LiDAR units provide measurements over UART. Since the myRIO only features two hardware UART connections, which are already occupied by the XBee external communication unit and A3 controller internal communication, it is elected to utilize a development board to convert the three LiDAR UART connections into one SPI connection.


Figure 5.24: SPI to 4x UART board utilized.

The selected board is developed by Rowland Technologies and is based on the PIC24FJ microcontroller [Rowland Technology, 2018a]. The microcontroller is programmed to transfer the data received on the four UART lines over the SPI line as a slave device when prompted via command code. The microcontroller by default operates its hardware UART lines in 8N1 mode, which corresponds to the TFMini LiDAR modules setup [Microchip Technology Inc., 2018] and [DFRobot Inc., 2018]. According to the microcontroller's application code, the transmitted data is stripped of its Start, Stop and Parity bits prior to being broadcast on the SPI line [Rowland Technology, 2018b].

#### Pin Connections

The boards connection pins and their function is described below:

- **[GND]:** Ground connections for microcontroller.
- **[CS]:** Chip Select pin for SPI servant connection.
- **[SCK]:** Serial Clock signal.
- **[MOSI]:** Master Out Servant In, serial signal from master unit.
- **[MISO]:** Master In Servant Out, serial signal from servant.
- **[3V3]:** 3.3V supply to drive microcontroller operations.
- **[RX (1-4)]:** Serial Receive for UART channel 0-3.
- **[TX (1-4)]:** Serial Transmit for UART channel 0-3.

#### Command Code and usage

For the command code and usage, see G.1 on page 71 and G.2 in appendix G.

#### LabVIEW Code

The LabVIEW application code for the SubVI containing this operation is as seen in the figure below:

*Note: The CS line is driven externally!*

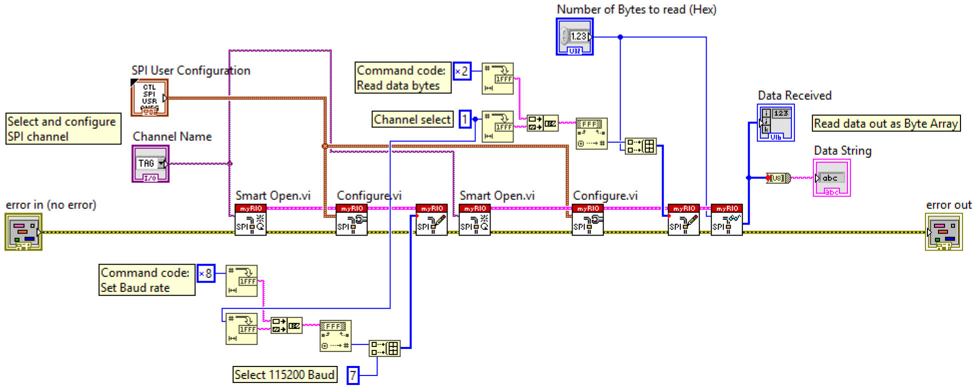



Figure 5.25: SPI to 4x UART LabVIEW SubVI code.

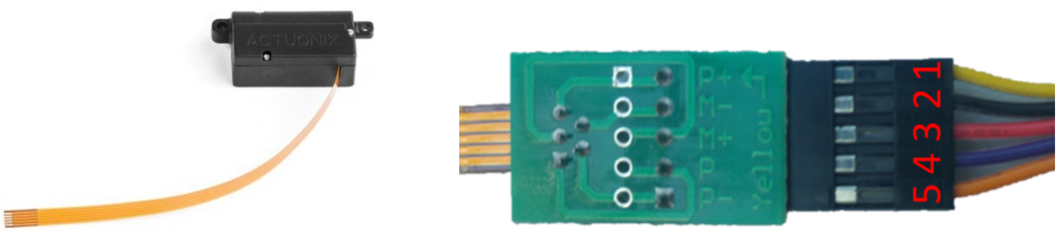
### Usage Case

However, for unknown reasons the data returned by this operation appears corrupted. Bit-banging operations – reversing bit order and/or applying “Little Endian” operations to the returned data yielded no usable results in recovering the data. It is possible that the microcontroller needed to be re-flashed with its original firmware, but a PIC programmer to program the onboard microcontroller was not on hand, so this theory was not tested.

## 5.2.10 Actuator for Beacon and Quick Release

### Actuator

Through the morphology diagram for the beacon and quick release a linear actuator is decided as most suitable for the two tasks. Because of the similarities in the two tasks the same type of actuator is chosen. The chosen actuator is the PQ12-100-12-P see Figure 5.26a. It has a gearing of 100:1 which results in a maximum force of 50N at 12V. The stroke length is 20mm. The IP rating of the actuator is IP 54 which means is dust protected and is resistant to water splashing. This makes it ideal for flying in light rain/snow.




(a) Image of the PQ12 actuator. (b) Pin layout for the PQ12 actuator.

Figure 5.26: PQ12 and pin layout.

The actuator has a built-in potentiometer which provides analog position feedback. In this section the pin layout will be described and shown in Figure 5.26b as per [Actuonix Motion Devices Inc., 2019].

• Pin 1: 5 V for a stable high reference.
• Pin 2: Ground for the actuator.
• Pin 3: 12 V for the actuator.
• Pin 4: Ground for a stable low reference.
• Pin 5: Analog reading from the potentiometer (voltage). The voltage will vary linearly in proportion to the position of the actuator (0 V = 0mm and 5V = 20mm).

The range the quick release actuator must move is between 7,5 and 13,5mm to make sure the drill is released and held in place respectively. For the beacon release the range is the full range of the actuator which is 0 to 20 mm. When it is fully retracted (0mm) the beacon is released. Since the beacon release actuator uses its full range, the potentiometer (pin 5) is not connected.

#### H-bridge

The two actuators are controlled with a single L293 H-bridge. The H-bridge makes is possible to extend and retract the actuators using two digital outputs per actuator. The H-bridge switches pin 2 and 3 in the actuator which changes the direction of the actuator. The pin configuration is as follows as per [Texas Instruments Incorporated, 2019] page 3 and illustrated in 5.27:
• Pin 1: Active high input is provided to enable actuator 1.
• Pin 2 and 7: For actuator 1 digital output from the myRIO decides if it retracts or extends.
• Pin 3 and 6: 12 Actuator 1 is connected to these pins.
• Pin 4, 5, 12 and 13: Ground.
• Pin 8: 12 V is provided to power the actuators.
• Pin 9: Active high input is provided to enable actuator 2.
• Pin 10 and 15: For actuator 2 digital output from the myRIO decides if it retracts or extends.
• Pin 11 and 14: Actuator 2 is connected to these pins.
• Pin 16: 5 V is provided to power internal logic translation.

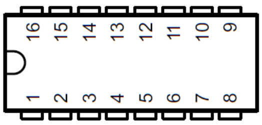



Figure 5.27: Pin configuration for the L293 H-bridge.

### 5.2.11 Gimbal - servo and image processing

#### Servo

To autonomously detect icebergs a gimbal was chosen via the morphology diagram B.3 on page 56 to do the task best. At first a 'FPV 2 axis brushless gimbal' was bought. That gimbal didn't work out because the gimbal had a gyroscope built-in which meant it always tried to level itself. Before control was gained over the gimbal too much current was delivered to the circuit board and it died.

The second solution was a home-made gimbal consisting of to servos to control yaw and roll. Two 'S03N STD' servos were used at first to control the gimbal to test if it would work, but they didn't have any IP-rating and was discarded. In the final solution two ‘SAVOX SW-0231MG’ is used see Figure 5.28. The SAWOX servos have an IP-rating of IP67 and 15 kg·cm torque at 6V which is well above the required torque to move the camera and servos. The servo has a resolution of 12 bit which makes the movement of the camera very smooth. The weight of the servo is 66g. The servo can move in a range of 0-180°. The SubVI made to control the servos uses a position to calculate the PWM signal is based on a servo demo made by NI [National Instruments, 2019b].


Figure 5.28: SAVOX SW-0231MG.

### Camera

The camera used is a ‘Microsoft LifeCam Studio’. It can record with a maximum resolution of 1920x1080 and at a maximum framerate of 30 fps. The camera doesn’t have any IP-rating and would then have to be modified to withstand light rain. At first the plan was a 4K camera, but the ones found wasn’t supported or hadn’t been tested with LabVIEW. One of the 4K cameras looked at was the ‘See3CAM 130’, see [See3CAM, 2019], but e-con Systems who produces and sells the camera module wasn’t sure if it would work with LabVIEW. For that reason, the ‘Microsoft LifeCam Studio’ was used to prove the concept. The final assembly of the gimbal can be seen on Figure 5.29.

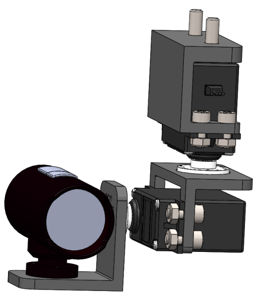


Figure 5.29: Final assembly of the gimbal.

### Image processing

The following section describes the autonomous process for the gimbal to capture the iceberg. The process is also visualized as a flowchart in Figure 5.30. For detecting the iceberg, a 1920x1080 image is received from the camera and then the resolution is lowered to a 640x480 image with only the green channel. This is done to not overload the myRIO’s processor and to make the upcoming image processing faster. For the image processing a threshold is made where it’ll only show the bright objects. The default setting is a range of 240-255 in the RGB-scale. This value would have to be changed to make the iceberg detection work in different light environments and with different colored icebergs. The next step is a basic morphology operation called ‘Close object’

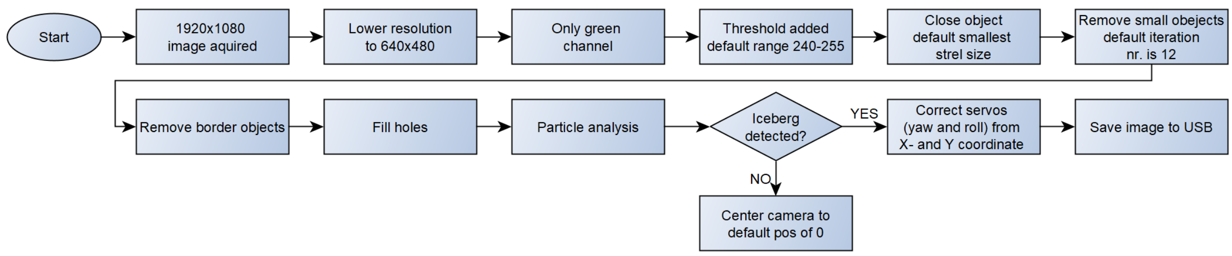



Figure 5.30: Flowchart of the gimbal's autonomous process.

with the smallest structural element (strel) size available. This is done to connect any areas that is separated but should be connected. For the next step an advanced morphology operation called 'Remove small objects' is used with an iteration number of 12. This is done to remove small areas of pixels with a RGB value over 240. This should remove areas smaller than the iceberg. Then an advanced morphology operation called 'Remove border objects' is used. This is done to unwanted icebergs or areas at the edge of the image. Then an advanced morphology operation called 'Fill holes' is used. This makes the area of the iceberg fully filled out. Lastly a particle analysis is made to find the center value in the X and Y direction. The LabVIEW code used for the image processing can be seen in 5.31

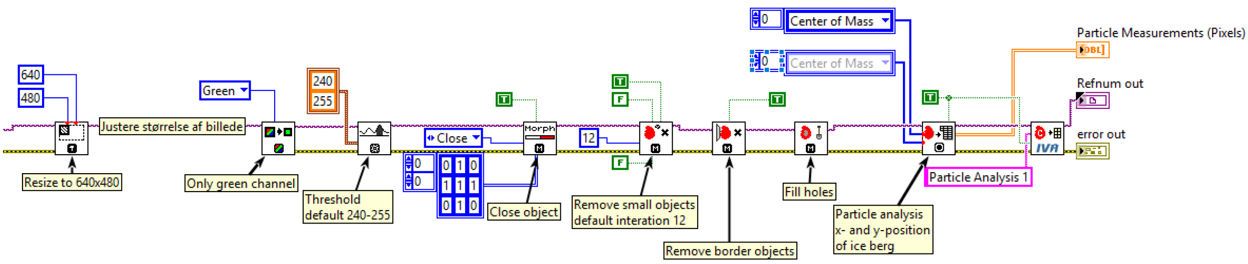



Figure 5.31: Gimbal vision in LabVIEW.

The complete image processing can be seen done on a chair with a blanket on top to simulate an iceberg on Figure H.1 through H.7, appendix H on page 73. To center the iceberg in the image the X and Y direction is used to control the two servos. For that a SubVI has been made to calculate if the servos must make a correction in the X direction (yaw) and/or in the y direction (roll). For that a simple P-regulation is used. A factor is multiplied with the difference between the center of the image and the position of the iceberg in the image. This means the servos will make larger corrections if the iceberg is at the edge of the image and smaller correction if the iceberg is close to the center of the image. If an iceberg isn't detected the servos will try to center the camera in the default position of 0. If an iceberg is detected the image is saved to an USB in the high resolution. This process loops continuously and keeps tracking the iceberg and saves images of the iceberg to an USB.

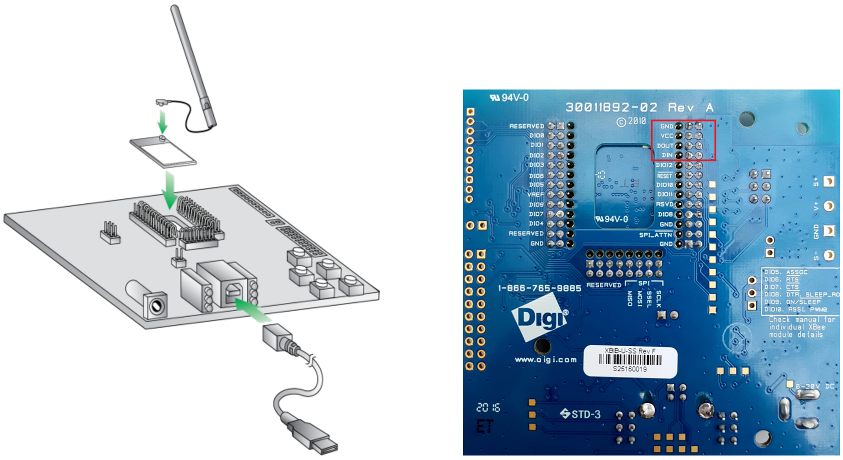
### 5.2.12 Digi XBee SX 868

For wireless communication between the ground station computer and the drone, the transceiver RF-module "Digi XBee SX 868" is to be installed. The RF-module operates in the range

Figure 5.32: XBee SX 868 developer kit.

863 - 870 MHz, [DIGI International Inc., 2019], which does not interfere with the drones 2,4 GHz communication. The primary use of the RF-module is sensor communication, but also transmission of pictures from the gimbal to verify that the gimbal is tracking an iceberg could be relevant, see 5.2.11 on page 35. Because the module is programmable, a developer kit is to be used. This kit includes developer boards that makes it possible to easily set up the 2 transceivers for communication, see Figure 5.32.

The board communicates through UART, but SPI is also possible. UART has been chosen for this project due to the simple setup. Connection of hardware can bee seen on 5.33a.




(a) Hardware connection. (b) Pin connections for serial communication.

Figure 5.33: Connection of XBee SX 868.

The pins to used for UART are the DOUT and DIN on the RF-module. Connection to the myRIO are as follows:

- **XBee**: $\leftrightarrow$ **myRIO**:
- DOUT $\leftrightarrow$ RX.
- DIN $\leftrightarrow$ TX.
- GND $\leftrightarrow$ GND.
- VCC $\leftrightarrow$ 3,3V analog output.

See figure 5.33b and [DIGI International Inc., 2019] for pins on the XBee. Notice that the developer board is being used. This is because of the pin connection which is different from the standard. An adapter can be used instead of the big developer board. Alternatively, the pins can be soldered in order to establish the correct connection. To establish connection between the two modules, the software "XCTU" is used for setup. The XBee's are then connected to the myRIO and used to communication through LabVIEW. Since the modules uses UART, the communication is established by sending a string back and forth between the two transceivers at a specific time rate.

### XBee software

XBee implementation in the main is collecting the items/statusses needed for transfer to the PC Host Main. In this showcase only the implementation of data is shown. The requested items are just concatenated into a known setup string. This is then transferred through UART at a baudrate of 115200, see figure 5.34.

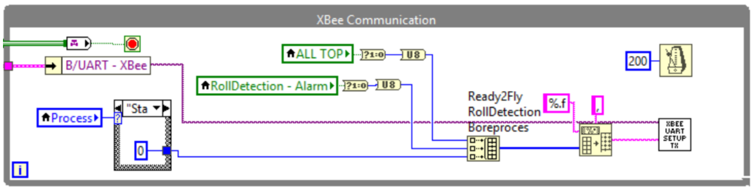



Figure 5.34: Transferred XBee data.

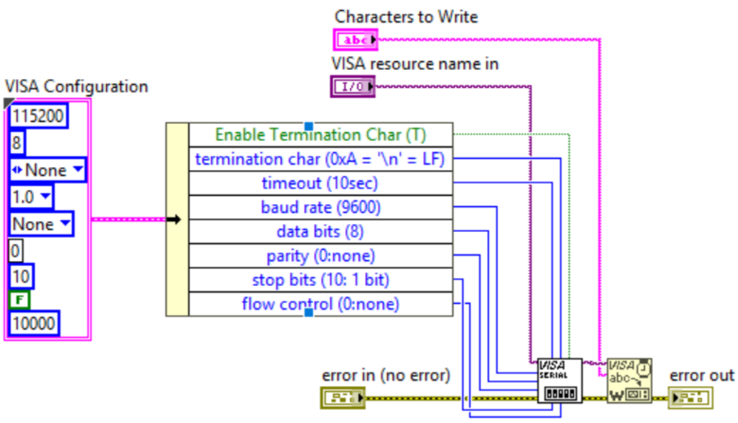



Figure 5.35: XBee setup send data.

In the PC Main the transferred data is then collected the same way it was send and separated the way they were compiled. The important notice to XBee is a sufficiently high loop time in order to transmit the data properly, see figure K.2 on page 79.

## 5.2.13 Circuit diagram & routing

### Circuit diagram

In order to get an overview of the electric components a complete circuit diagram is created in NI-Multisim. The creation of this diagram has been an ongoing task throughout this project. The purpose has been to assist in the creation of the drone. This has helped give an overview of which components were needed to be purchased, were they should be mounted and how they should be connected.

In this circuit diagram, also the myRIO ports are included, this has been a great help in the concurrent design process, meaning that the software and hardware could be wired simultaneously. The complete circuit diagram and belonging color code can be seen on figure I.1 on page 75 and table I.1 in appendix I. The color code will also be applicable in the final product.

The base of this diagram is reused from the previous project, however there has been made quite a few changes along the way. The drill motor and the Stepper drivers, are conected in the same way as earlier. However previously there were only one DC-DC converter (LM2596), to power the rest of the components. Since there has now been added a few more components with different need, there has been added two more to create a 5V line and a 3.3V line in addition to the 12V from previously.

### Routing

Throughout this project, the wiring has been a great concern, from the start it has been a goal to create a product with neat wiring, this helps in troubleshooting, and it is also in important aspect in the design guidelines.

In the following, it will be explained how the group has created a product with mostly internal wiring but still a product which can be disassembled and assembled easily.

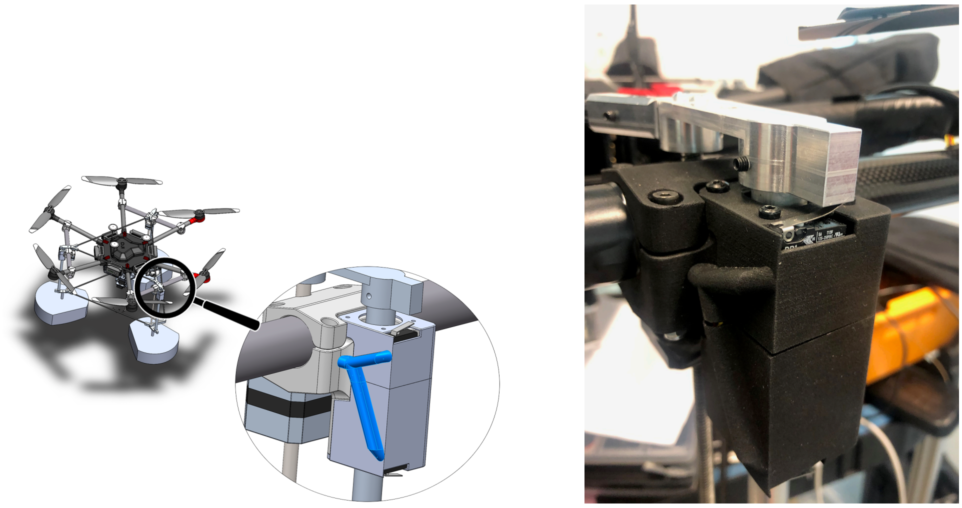
### Micro switches

The micro switches from the previous project has been reused in this project, however, these where not very weather proof, nor were the wiring very neat. The wires were on the outside of the drone and there were a possibility that these could, be caught by the rotors. In figure 5.36 the CAD rendering of the new improved solutions is shown.

Around the micro switches there has been created shields, the purpose of these is to protect the switches from weather, this way the drone is able to operate in light snow/rain. Furthermore the shields include internal routing channels for the micro switches. This means that the cables are removed from the outside of the drone completely, and this way they are also packed away from the drones rotors.

### Landing gear & drone connection

When attempting to route all the cables internally, there are some natural limitations. In this case, it has been decided not to cut holes in the drones arms. Therefore it has been decided to run the cables in a sleeve on the underside of the drones arm. On figure 5.37 it is shown how this is done, It is also shown how the cables are connected with connectors, so the landing gear and drone can be disassembled and assembled, without having to reroute the cables.



(a) Guards around the micro switches, and internal calbe routes marked in blue.

(b) Actual implementation of micro switches and internal routing.

Figure 5.36: Comparison between CAD and reality.

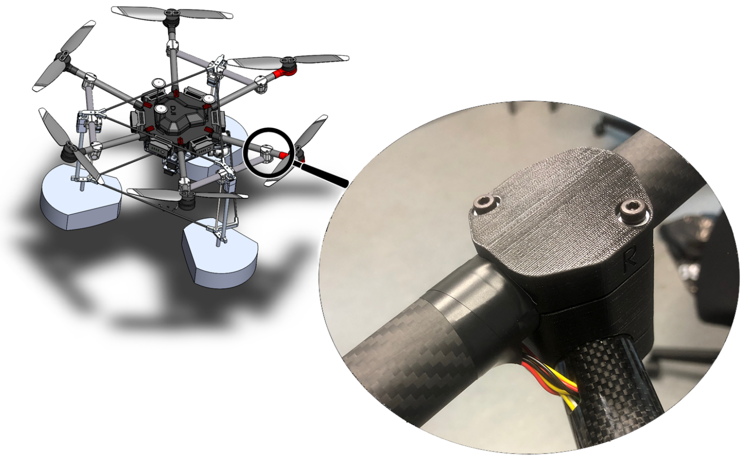


Figure 5.37: Routing between landing gear and the drone.

**Perfboard**

The cables are routed from the connection described in the previous section (5.2.13) along the drones arm, towards the electronics box, in section 5.1.1 on page 18, the layout of this box is described. In this box, a perfboard is placed, this is made from the circuit diagram explained in section 5.2.13. The layout of the perfboard can be seen on figure (J.1) in appendix J on page 76.

All cables routed into the electronics box, are long enough that they can reach the perfboard, even when the electronics box are dismounted and placed on the ground. All cables are labelled, with names that correspond to the names on the perfboard layout shown in figure J.1 in appendix J on page 76.

# 5.3 Software

## 5.3.1 LabVIEW Walkthrough

To briefly summarize the main is composed of several parallel while loops. This is made to simplify the code visually and enhancing the loop time on required elements. The code is split into independent subsystems, which means, that every while loop only consists of the subsystem(s) needed to complete or improve the code. The main consists of the while loops seen on table 5.2.

Table 5.2: While loops in main.

| While loop name | Function |
|---|---|
| Ice drilling process (requirements: needs to be grounded) | Controls the entire process associated with the drilling. It controls the drill, the steppers, end stops, ammeter. Further this while incorporates the controls from the drone controller through the so-called F-Ports on the drone to let the pilot control the process. |
| Gimbal control and Computer Vision | Inputs an image in LabVIEW where it searches for icebergs through Vision Assistant. After it finds the coordinates of the iceberg and then moves the gimbal, through two servos, so that the iceberg is centralized in the image. Further, the gimbal moves to certain positions whether it's grounded or in 'No Search' mode. |
| Transmission of images and data via XBee (switch between data and image when grounded) | The XBee transmit data through UART strings. In the case to send an image, the image is first converted to a byte array before it's converted to a spreadsheet string, which the XBee can transmit. When this is received the spreadsheet string is then converted to a byte array, which is then visualized through an intensity graph which shows the image. With data strings, these are just concatenated before been split back into pieces. |
| Grounded control | Gets an input from the drone controller through the F-port of the A3 controller that the Pilot has set the drone to grounded. Several of the other while loops get the grounded signal to activate a certain process e.g. drilling |
| Beacon Release | Gets an input from the Pilot on the drone controller through the F-Port to release the beacon which gives signal to the linear actuator which then moves |
| Quick Release | Gets an input from the Pilot on the drone controller through the F-Port to release the drill which gives signal to the linear actuator which then moves |
| Roll Detection (requirements: needs to be grounded) | Continuously measures the differences measured by the accelerometer to calculate whether the drone is tipping or not. There's applied a filter to the signal to cancel out the vibration from the drilling process. |
| LiDAR | UART HEX input from the LiDAR which then is converted to U8 byte array before indexing parts to calculate distance. |
| A3 GPS Coordinates | UART HEX input is drawn from the A3 Flight Controller on the drone before the string is separated into the respective parts needed for the position. The A3 GPS Coordinates is written with Little Endian, which means LSB first for the individual byte. |

But it also has an Initialize and Close subVIs for the myRIO Ports and 2 while loops for initialization of the ESC for the drill, see figure K.1 on page 78 in appendix K. Further, there's a second Main on the Host PC. This consists of the receiving while loop from the XBee, see K.2 on page 79 in appendix K.

A flowchart of the drone Main VI can be seen on figure K.3 on page 80 in appendix K.

## 5.3.2 Roll Detection

The making of the roll detection is based on the software from the previous project and adds a new twist to improve the effectiveness. A lowpass-filter has been applied to the myRIO accelerometer, so that it cancels out the vibration of the drilling process. The roll detection basically is set up by taking the measurements of the accelerometer then adding and meaning these values to get a representation of the angle changes - this is done with the 500 latest samples. If the output value is above a certain threshold, an alarm LED will turn on, to alert the pilot that the iceberg might be tipping or rolling. Adding rubber under the myRIO to lower the vibrations from the drilling process was tested but it didn't have a noticeable effect why it wasn't implemented in the final assembly.

### 5.3.3 Drilling Process

The drone has to be grounded in order to move up and down. This is done by the pilot turning a button on the controller. To control the movement / process the control has a 3-step notch to do so. Once the down function is 'ON' the process is automated and the drone drills autonomously, unless the process changes. The entire drilling process operates through a "state machine" principle. The autonomous drilling process is as following:

- Drill spinning at max all the time
- Steppers move down until resistance threshold is met
  - If threshold is met, steppers raise until another threshold is surpassed, then lowers again
- When all bottom end stops are activated, the "Triangle Wobble" process begins
  - Raising one stepper at a time in a circular pattern to snap the ice sample
- When Triangle Wobble is done all steppers raise to top
- When all top end stops are activated the steppers stops and so does the drill

The LabVIEW code can be seen on figure L.1 on page 82 and the flow diagram for the process can be seen on figure L.2 on page 83 in appendix L.

## 5.4 Part conclusion

### 5.4.1 Final prototype

On figure 5.38a the complete drone assembly is shown in real life. In the following, the mounting of the Zenmuse camera, drill and quick release will be shown. Also the actual routing will be shown in this section.

On Figure 5.38b the mounting of the Zenmuse camera can be seen, it is shown how the camera is mounted on vibration dampers to provide a smoother video feed. Also the drill mounting can be seen in this photo. It is also shown (Top left) how the wires from the drone arm are routed in a sleeve into the electronics box.

On figure 5.39a the final assembly of the quick release mechanism can be seen. It is here shown how the wires from the PQ12 actuator are routed into the electronics box, without interfering with the moving parts around the drill or quick release.

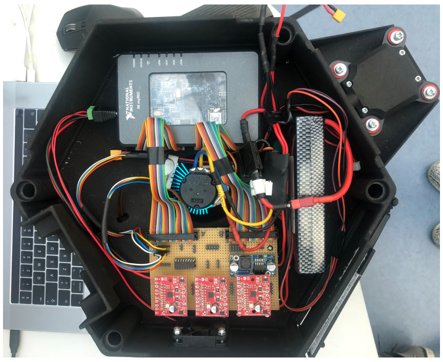
Finally on figure 5.39b the inside of the electronic box is shown, here it is possible to see the layout and how the connection between the myRIO and the perfboard are routed around the drill motor,

(a) The complete prototype.

(b) Mounting of the Zenmuse camera and the drill.

Figure 5.38: The final prototype.

(a) Final assembly of the quick release mechanism.



(b) Final layout inside the electronic box.

Figure 5.39: The final prototype.

which is placed in the center. The battery for this motor held in place with a short velcro strap in front of the small door, this way the drill battery can be changed without dismounting the entire electronics box.

In conclusion the assembly of the final prototype is successful an according to the plans.

# 6 Conclusion

In this project a semi-autonomous ice drilling drone (SAIDD) has been developed.

The objective of this project was to build a drone, which could take ice core samples from high risk areas. The project had its starting point in a previous project from Aarhus University.

Most of the requirements has been accomplished in this project. However some needs further testing on site to verify.

In conclusion, the autonomous parts of the project have been completed satisfactorily. The drilling process is automated, with the addition of an ammeter. Likewise has the process for taking high resolution pictures for 3D scan, been automated using computer vision.

Not everything has been successful, in the specification of requirements 3 on page 3, it is described how a progress bar can show the progress of the drilling. However, due to complications with SPI to UART conversion, it has not been possible to integrate this subsystem in the given time frame.

Many subsystems from the previous project has been redesigned to both add needed functionality, and improve the current functionality, these subsystems include the electronics housing, and the mounting of the drill.

# 7 Design evaluation

## 7.1 Answering specification of requirements

The answering of the specifications can be seen on table 7.1 on the next page through 7.3 on page 49.

## 7.2 Discussion

This has been mostly a successful project, which ended with a functioning prototype. The drone is complete and can operate according to the specification of requirements, however there are still things to improve.

## 7.3 Drill process

On of the main focuses in this project has been to optimize the drilling process time. This has been accomplished, but can still be optimized further. Through this project, the drilling has been made more autonomous, and there has been implemented procedures to release the ice core sample from the iceberg. The drill has been improved to crab the ice core better, this has been accomplished and the success rate of the extraction process has been greatly improved.

## 7.4 Electronic housing

Also the implementation of the electronics has been improved a lot during this process. All components are now shielded from the surrounding, which means it is now safer to fly in the conditions that may be present on a expedition in the Arctic region.

## 7.5 Quick release

Another great focus in this project has been the implementation of a quick release functionality for the drill. This has been a great success and can be used both in emergency situations and for drill changes between missions.

Table 7.1: Answering the specification of requirements.

| Functional requirements | | | |
|---|---|---|---|
| **Description of requirement** | **Note** | **Description of requirement** | **Note** |
| **The drone should be able to be operated from a boat** | The drone can be operated from a boat As long as there is a flat surface to take of and land from 2x2m is requires | **The drone should be able to have a flighttime which is enough to get it safely to and from the iceberg** | The drone is slightly heavier that previously this means the flight time are shorter, however the drilling process is faster. This means that the flight distance is roughly the same (Estimate) |
| **The drone should be able to operate in the arctic environment** | All electronics are shielded from the weather. | **The drone should be able to land and take off from an iceberg** | The drone can land in some amount of snow. However, more snow means a smaller ice sample. |
| **If complications occur, the drone should not be lost** | The drone are able to release the drill, in case of emergency. Also the drone can lift itself off the spikes underneath the landing gear, in case these freezes | **The drone should be able to transport and drop an EXITE GPS beacon onto the iceberg** | All the drones functions can be controlled from the controller - Some information is presented to the operator on a ground station PC |
| **The drone should be able to extract an ice sample of a desired weight and transport it back to the boat** | The drilling process is automated, when the drone is grounded and the drilling process starts, the drones does not need any inputs from the operator | **It should be easy for the operator to assemble the drone and get it ready to fly as well as disassemble the drone and pack it down for transport** | The drone can be setup and packed down by one person, however 2 people will make this process significantly faster |
| **The drone should be able to fly unhindered with the required payload** | The drones recommended take of weight is 15.5 kg, however it is slightly heavier. However it is most likely still possible | **The operator should be able to test all of the drones functions before take off** | It is possible to test all the drones functions. However this is not a fully automated process |
| **The operator should be able to inspect if the tools are working properly when on mission** | The operator can see a video feed from the Zenmuse also the drill current can be monitored on a "ground station PC" | **The drones landing gear should be stable and steady, with no sliding** | The drone does not slip, when landing on an iceberg. However the stability of the landing gear can still be improved. |
| **The drone should be delivered with a user manual** | This requirement has not been accomplished | **The drone should have an alarm that signals if the iceberg is rolling** | The roll detection from the previous project has been improved with a lowpass filter and signals to a ground station PC |
| **The drone should be able to release the drill, if it gets stuck** | This has been accomplished, by the new quick release | **The drone should be able to fly several missions each day of operation** | The drone has multiple battery packs, and according to design guidelines, the Battery changes are made quick and easy |
| **The drone should not be of any hazards to the users or surrounding environment** | This requirements is accomplished based on the FMEA from the bach. project | **The drone should be able to send a videofeed back to the operator** | This is possible through the Zenmuse, mounted on the front of the drone |

Table 7.2: Answering the specification of requirements.

| Functional requirements | | Product requirements | |
|---|---|---|---|
| **Description of requirement** | **Note** | **Description of requirement** | **Note** |
| **The drone should be able to measure the core temperature of the iceberg** | This has not been accomplished | **The equipment should work in arctic temperatures** | The electronics are shielded from the weather, the electronic components make sure, the temperature in the electronics box is above 0°C |
| **The drone should be able to measure the reflection from the iceberg with a light calibrated camera** | This has not been accomplished | **The drone should be able to fly in moderate winds** | The drones flight abilities has not been altered by since this project started |
| **The drone can circle the iceberg and take photos for a 3D scan** | The drone has a gimbal, which autonomously focuses on an iceberg and captures high res pictures for a 3D-scan | **If the drone has to land on water** | The drone is equipped with floaters, which keeps the drone stable and floating on water. |
| **The drone should be able to take an ice sample without contaminating it with iron particles** | This has been accomplished, by using mainly parts of aluminum and titanium | **If the drone looses signal to the radio** | This has not been worked on in this project. The drone follows DJI protocol |
| **The drone should able to be disassembled back to normal working condition** | This is possible, within 1 - 1,5 hours | **Ice sample weight when delivered** | The drone delivers ice sample above 500g |
| **The price of the final device, should not exceed the budget** | The drone has been created for well under the specified amount | **The drone should have a payload that fit the rough estimates of the weight calculations** | The drone around the same weight as the previous bac. project, which was more than the recommended 15.5 kg |
| **Flying the drone must be done by** | The drone can fly by both VLOS and FPV | **The radio transmitter should have a range of at least** | The added XBee radio has a range up to 14.5 km \cite{XBee} |
| **Safe carrying case for the drone and carrying case for the tool/tools** | The drone can be disassembled and fit in the provided carrying case | **Recesses, snow and grooves on the surface of the iceberg may not exceed** | The drone accepts up to 3cm grooves in the iceberg surface |

Table 7.3: Answering specifications of requirements.

| Product requirements | | | |
|---|---|---|---|
| **Description of requirement** | **Note** | **Description of requirement** | **Note** |
| **The drone should be able to carry a EXITE GPS beacon** | This is possible, however due to the weight of the drone, it limits the flight time | **The ice sample should have a depth of** | The drone can sample ice at 20cm depth |
| **Setup/pack down time for the drone** | This is possible for 2 people in less than 1 hour | **Time between missions** | Less than 2 hours, Extra batteries can charge while mission is in progress |
| **The camera angling can be used to monetarize the extraction** | This is possible using the Zenmuse | **Flying capabilities in high relativ humidity (100%RH)** | Requires SAT |
| **The rolling alarm should have a sampling time of 10Hz** | The sampling is above 100Hz | **The drone must have a weight under** | The drone weighs 16.5 kg |
| **The rolling alarm should have a sensitivity of +-1°** | This has not been accomplished | **For the drone to be operated from a boat, it may not exceed** | The drone does not exceed the 2x2m limit |
| **The sampling rate of reflection photos** | This has not been accomplished | **The drone should be able to fly safely even if there is interference from the boat or from the poles** | Requires SAT |
| **The sampling rate of 3D scan photos** | High resolution 5FPS | | |
| **Iron contamination less than** | This has not been tested, however all previous parts containing iron has been made in aluminum or titanium | | |

## 7.6 LiDAR distance sensor

As described in the conclusion, the implementation of LiDAR distance sensor has caused some trouble, this is mainly due to the chosen sensors, which only communicates over UART. In the future, these LiDAR sensor could be changed to a model which can communicate over SPI or I2C. Alternative, the SPI2UART converter could be used, this has not been accomplished in the time frame of this project

## 7.7 Other improvements

In the future, the drilling process can be made faster, and the landing gear stability could also be improved.

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# Brainstorm within each subsystem A

Table A.1: Brainstorm within each subsystem.

| | | |
|---|---|---|
| **Drilling process** | **Extraction Process** | **Quick release** |
| Raise RPM when current raises | Scissor/cutter in bottom | Solenoid pin |
| High constant RPM | Contra valve | Pneumatic |
| Larger center drill | Vacuum (Pneumatics) | Actuator (linear) |
| Better cutting blade/edge | Hooks (for holding the ice) | Weakzone (break<br>- w/ overload) |
| Optimize flutes | Chipmunk drill | C4 explosive |
| | Running water through center | Pin, unplugged with<br>- actuator |
| | Heating element in bottom | |
| | Cone shaped drill | |
| | Expansion drill (chinese finger sock) | |
| **Camera for 3D scan** | **Electrical box** | **Alarm** |
| Gimbal | Round | Tube on drone |
| 360 degree camera | Square | Bicycle light on drone |
| Manuel | Triangle | RGB Light (Drone) |
| Actuator, encoder to control rotation | Dome | LED on operation PC |
| Slow actuator(dc motor) to keep<br>- constant speed | Hexagon | Row of LED<br>- Status bar (Operator) |
| Stereo camera (two cameras) | Pyramid | Buzz sound (Drone) |
| | Ball | Buzz sound (Operator) |
| **Roll detection** | **Landing floaters** | **Vibration dampers** |
| Accelerometer in myRIO to detect shift | One big circular plate | Rubber sticks |
| Use vision to look for horizon | Inflatable pontoons | Air cushioning |
| External accelerometer | Flamingo bricks | Springs |
| Mechanical plate showing direction | Ship circular hull | Rubber bands |
| External compass telling angles | Air canals | Oil damper |
| **Distance and contact sensor** | **Long range communication** | **Beacon release** |
| Laser | WiFi | Solenoid |
| Ultra sonic | LORA | Stepper |
| IR | RF | Servo |
| Microswitches | GSM | Vacuum |
| Radar | 3G Data connection | Brushed DC |
| Sonar | Satellite connection | Linear actuator |
| Lidar | Antenna / Beacon | DC |

# Selection diagrams for morphology B

## B.1 Extraction process

| Extraction process | Price | Complexity | Sample size guarantee | Sample contamination | Delivery time | Security of sample | Extraction time | Sum |
|---|---|---|---|---|---|---|---|---|
| **Weighting** | 1 | 3 | 3 | 3 | 2 | 4 | 4 | |
| Scissor/cutter in bottom | 2 | 2 | 4 | 4 | 3 | 5 | 3 | 70 |
| Contra valve | 3 | 3 | 4 | 5 | 5 | 3 | 4 | 77 |
| Vacuum (Pneumatics) | 3 | 3 | 4 | 5 | 5 | 3 | 4 | 77 |
| Hooks (for holding the ice) | 4 | 4 | 3 | 4 | 4 | 4 | 4 | 77 |
| Chipmunk drill | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 80 |
| Running water through center | 2 | 3 | 3 | 3 | 2 | 2 | 3 | 53 |
| Heating element in bottom | 3 | 3 | 3 | 3 | 4 | 2 | 3 | 58 |
| Cone shaped drill | 4 | 2 | 3 | 3 | 3 | 2 | 4 | 58 |
| Expansion drill (chinese finger sock) | 3 | 2 | 3 | 4 | 2 | 4 | 4 | 66 |

Figure B.1: Extraction Process.

- **Scissor/cutter in bottom** - Custom made parts are fairly expensive and an estimate is hard to make at this point.
- **Contra valve** - Can be made of very simple parts, but this also requires custom made parts (although it is probably cheaper that the option above.
- **Vacuum (pneumatics)** - A complex solution which may require a lot of parts, but pneumatic parts are available in many different specifications (custom parts may not be necessary).
- **Hooks(for holding ice)** - Have already been created in the Bac project, these tests and experiences can be used to quickly create something useful. Custom parts are fairly simple and we should be able to create these quite cheap.
- **Chipmunk drill** - Requires a brand-new drill, however, we will be able to produce this ourselves fairly cheap (I.e. 3d print).
- **Running water through center** - Expensive solution, requires a lot of parts (both commercial and custom), the integration of this solution will require a lot of changes in the design and layout of the drone (which in turn will add extra cost).
- **Heating element in bottom** - Around 600 dkk, however this adds a lot of extra power consumption.
- **Cone shaped drill** - This will just like the chipmunk drill require a brand new drill, however this we will also be able to create ourselves.
- **Expansion drill (chinese finger sock)** - We will most likely be able to create this ourselves, however this requires potentially a lot more parts, which is why it scores lower than the other "self-produced drills".

## B.2 Quick Release

| Quick release | Price | Weight | Complexity | Mounting space required | Execution speed | Weather proof | Reuseability (Boolean 5/0) | Sum |
|---|---|---|---|---|---|---|---|---|
| Weighting | 1 | 3 | 2 | 4 | 3 | 3 | 4 | |
| Solenoid pin | 5 | 4 | 4 | 4 | 5 | 2 | 5 | 82 |
| Pneaumatic | 3 | 4 | 2 | 2 | 3 | 3 | 5 | 65 |
| Actuator (linear) | 4 | 5 | 4 | 4 | 4 | 4 | 5 | 87 |
| Weakzone (break w/ overload) | 2 | 5 | 2 | 5 | 2 | 4 | 0 | 59 |
| C4 | 3 | 4 | 5 | 3 | 5 | 3 | 0 | 61 |
| Pin, unplugged with actuator | 4 | 2 | 3 | 3 | 4 | 4 | 5 | 72 |

Figure B.2: Quick release.

- **Solenoid Pin** - ca 99 dkk.
- **Pneumatic** - ca. 700 dkk.
- **Actuator (linear)** - ca 460 dk.
- **Weakzone** - Custom made shaft, this is most likely very expensive and requires a lot of calculations and testing of prototypes.
- **C4** - ca 150dkk / 500g - however we need quite a bit for testing and prototyping.
- **Pin, unplugged with actuator** - Same as the electric actuator above, however this construction requires extra parts and mounting.

## B.3 Camera for 3D scan

| Camera for 3D scan | Price | Weight | Controllability (autonomous) | DOF | Image quality | Complexity | Post mission editing | Sum |
|---|---|---|---|---|---|---|---|---|
| Weighting | 2 | 3 | 4 | 3 | 4 | 3 | 3 | |
| Gimball | 3 | 5 | 4 | 5 | 4 | 2 | 4 | 86 |
| 360 degree camera | 3 | 5 | 5 | 5 | 2 | 3 | 1 | 76 |
| Manuel | 5 | 3 | 0 | 5 | 4 | 4 | 4 | 74 |
| Actuator, encoder to control rotation | 4 | 3 | 4 | 4 | 4 | 3 | 4 | 82 |
| Slow actuator(dc motor) to keep constant speed | 5 | 4 | 2 | 2 | 3 | 4 | 3 | 69 |
| Stereo camera (two cameras) | 4 | 3 | 3 | 2 | 3 | 3 | 3 | 65 |

Figure B.3: Camera for 3D scan.

- **Gimbal** - ca. 1000 dkk.
- **360 degree camera** - ca. 2500 dkk.
- **Manuel** - Camera can be very cheap however control of rotation (e.g. servos) need to be added which will add a little to the price, but also to the weight.
- **Actuator, encoder to control rotation** - Need 2 actuators to control rotation and angle, this adds weight but it is also fairly cheap.
- **Slow actuator(dc motor)** - A single actuator keeps the camera rotating at a constant speed, cheap and simple, a small 12v dc motor is also very light.
- **Stereo camera** - ca 1700 dkk.

## B.4 Electrical box

| Electrical box | Price | Weight | Complexity | Easy access to components | Weather proof (boolean) | Cooling posibilities | Drag | Drill mounting | Sum |
|---|---|---|---|---|---|---|---|---|---|
| Weighting | 0 | 0 | 3 | 4 | 1 | 2 | 1 | 5 | |
| Round | | | 3 | 3 | 5 | 4 | 4 | 4 | 58 |
| Square | | | 4 | 4 | 5 | 4 | 4 | 4 | 65 |
| Triangle | | | 4 | 4 | 5 | 3 | 4 | 4 | 63 |
| Dome | | | 2 | 2 | 5 | 2 | 3 | 1 | 31 |
| Hexagon | | | 4 | 4 | 5 | 4 | 4 | 4 | 65 |
| Pyramid | | | 2 | 2 | 5 | 2 | 1 | 1 | 29 |
| Ball | | | 1 | 1 | 5 | 2 | 2 | 1 | 23 |

Figure B.4: Electrical box.

- Price and weight notes: In this subsystem price and weight are not added because we are comparing benefits of shape, all these concepts will likely be created in SLS 3dprint (roughly same price and weight regardless which option are chosen).

## B.5 Alarm

| Alarm Visual LED | Price | Weight | Complexity | Clear indication | Graduated scale (boolean) | Placement in sight of operator | Sum |
|---|---|---|---|---|---|---|---|
| Weighting | 1 | 1 | 2 | 4 | 3 | 3 | |
| Tube on drone | 5 | 3 | 5 | 1 | 5 | 1 | 40 |
| Bicycle light on drone | 5 | 3 | 5 | 2 | 1 | 3 | 38 |
| RGB Light (Drone) | 5 | 3 | 5 | 2 | 5 | 3 | 50 |
| LED on operation PC | 5 | 5 | 3 | 4 | 1 | 4 | 47 |
| Row of LED Status bar (Operator) | 5 | 5 | 3 | 5 | 5 | 4 | 63 |
| Buzz sound (Drone) | 5 | 3 | 4 | 1 | 5 | 2 | 41 |
| Buzz sound (Operator) | 5 | 5 | 3 | 4 | 5 | 5 | 62 |

Figure B.5: Alarm.

- All elements in this subsystem are very cheap, compared to other subsystems in this project the price in this subsystem won't have an impact(I.e. All scores 5 points).
- Weight: all these parts are also fairly light, however some of them are not mounted on the drone but by the operator, these will score higher.

## B.6 Roll detection

| Roll detection | Price | Weight | Complexity | Gradient scale (boolean) | Immunity to vibrations | Reliability | Sum |
|---|---|---|---|---|---|---|---|
| Weighting | 1 | 2 | 2 | 1 | 3 | 3 | |
| Accelerometer in MyRio to detect shift | 5 | 5 | 3 | 5 | 3 | 3 | 44 |
| Use vision to look for horizon | 4 | 4 | 2 | 5 | 3 | 2 | 36 |
| External accelerometer | 5 | 5 | 2 | 5 | 2 | 3 | 39 |
| Mechanical plate showing direction | 3 | 2 | 2 | 0 | 1 | 1 | 17 |
| External compass telling angles | 5 | 5 | 4 | 5 | 3 | 4 | 49 |

Figure B.6: Roll detection.

- **Accelerometer in myRIO** - No added cost or weight, since the myRIO need to be on the drone regardless.
- **Vision, look for horizon** - A small and fairly cheap solution which keeps looking for the horizon. This will add a little cost and a little weight.
- **External accelerometer** - Can be added at almost no cost (99dkk). This will also add nearly no weight.
- **Mechanical plate** - Custom made parts, which require change in the layout of the drone. This is both heavy and expensive.
- **External compass telling angles** - Just like the external accelerometer this adds almost no weight or cost (ca. 70dkk).

## B.7 Landing floaters

| Landing floaters | Price | Weight | Complexity | Size | Stability | Interference with camera visability (Boolean) | Reuseability (Boolean) | Sum |
|---|---|---|---|---|---|---|---|---|
| **Weighting** | | | 2 | 1 | 4 | 2 | 3 | |
| One big circular plate | | | 4 | 1 | 4 | 1 | 5 | 42 |
| Inflatable pontoons | | | 2 | 3 | 3 | 5 | 1 | 32 |
| Flamingo bricks | | | 4 | 3 | 3 | 5 | 5 | 48 |
| Ship circular holl | | | 3 | 4 | 1 | 1 | 5 | 31 |
| Air canals | | | 4 | 4 | 2 | 1 | 5 | 37 |

Figure B.7: Landing floaters.

Price: All elements in this subsystem are very cheap, compared to other subsystems in this project the price in this subsystem won't have an impact(I.e. All scores 5 points).

Weight: all these parts are also fairly light, however some of them are not mounted on the drone but by the operator, these will score higher.

- **Big circular plate** - This solution might be heavy and would most likely interfere, with other subsystems like distance sensors.
- **inflatable pontoons** - requires onboard compressed air to inflate. will most likely add extra weight and complexity
- **flamingo bricks** - This is the current solution, this is an easy option, since the current floaters could easily be modified.
- **ship circular hull** - As with the big circular plate, this solution might also interfere with other subsystems.
- **Air canals** - This solution requires, on board compressed air, which adds both weight and complexity to the drone.

## B.8 Vibration dampers - camera

| Vibrationdampers | Price | Weight | Complexity | Damping effect | Size | Sum |
|---|---|---|---|---|---|---|
| **Weighting** | 1 | 2 | 4 | 3 | 3 | |
| Rubber sticks | 5 | 5 | 5 | 4 | 5 | 62 |
| Air cushoning | 2 | 3 | 2 | 4 | 4 | 40 |
| Springs | 4 | 4 | 4 | 2 | 4 | 46 |
| Rubber bands | 5 | 5 | 4 | 2 | 3 | 46 |
| Oildamper | 3 | 3 | 3 | 3 | 3 | 39 |

Figure B.8: Vibration dampers.

- **Rubber sticks** - These will not add extra cost (Claus has some) and they are also very light.
- **Air cushioning** - The complexity of this option requires a lot of parts and it may be very expensive. The added parts might add quite a lot of weight.
- **Springs** - Springs are fairly inexpensive and lightweight.
- **Rubber bands** - Cheap but doesn't give a lot of damping.
- **Oil damper** - These can be a little expensive, and also requires a lot of mounting space which in turn means a new layout of the components on the drone (this could very well turn out to be expensive).

## B.9 Distance and contact sensors

| Distance and contact sensor | Price | Complexity | Immunity of interference from drone | Graduated lift detection (Boolean) | Interference from surface | Check landing surface (Boolean) | Sum |
|---|---|---|---|---|---|---|---|
| **Weighting** | 1 | 3 | 4 | 2 | 3 | 1 | |
| Laser | 4 | 4 | 5 | 5 | 3 | 5 | 60 |
| Ultra sonic | 3 | 5 | 1 | 5 | 5 | 5 | 52 |
| IR | 4 | 5 | 5 | 5 | 3 | 5 | 63 |
| Microswitches | 5 | 5 | 5 | 1 | 5 | 1 | 58 |
| Radar | 1 | 1 | 4 | 5 | 4 | 1 | 43 |
| Sonar | 1 | 1 | 4 | 5 | 4 | 1 | 43 |
| Lidar | 5 | 4 | 5 | 5 | 3 | 5 | 61 |

Figure B.9: Distance and contact sensors.

- **Laser** - From around 50 dkk. Might give wrong measurements from surfaces like ice and snow.
- **Ultra sonic** - Around 200 dkk. Noise from the drone will affect the measurements.
- **IR** - Around 10 dkk. Might give wrong measurements from surfaces like ice and snow.
- **Microswitches** - around 5 dkk each (3 is needed for the drone). Only gives readings from end stops.
- **Radar** - Above 1000 dkk. Complex setup and expensive.
- **Sonar** - Same as above.
- **Lidar** - Around 300 dkk. Might give wrong measurements from surfaces like ice and snow. Could be a bit complex to setup.

## B.10 Long range communication

| Long range communication | Price | Complexity | Data rate | Range | Size | Interferance from drone | Sum |
|---|---|---|---|---|---|---|---|
| **Weighting** | | 3 | 5 | 5 | 2 | 5 | |
| WiFi | | 5 | 5 | 2 | 4 | 1 | 63 |
| LORA | | 3 | 2 | 0 | 0 | 0 | 19 |
| RF | | 3 | 2 | 3 | 5 | 5 | 69 |
| GSM | | 1 | 1 | 0 | 0 | 0 | 8 |
| 3G Data connection | | 1 | 4 | 0 | 0 | 0 | 23 |
| Satellite connection | | 1 | 2 | 5 | 4 | 5 | 71 |
| Antenna / Beacon | | 1 | 2 | 2 | 0 | 0 | 23 |

Figure B.10: Long range communication.

For the long range communication the weighting criteria's are as follows

- Complexity (1: 20h - 5 :1h).
- Data range (1: 100kbps - 5: 1Mbps).
- Range (1: 100m - 5: 500m).
- Size (1: 100x100mm - 5: 20x20mm).
- Interference from drone (1: Yes - 5: No).

After the morphology process, it has been decided i agreement with Claus Melvad and the other mechatronic groups to go with a Digi XBee SX868, this way the groups can help each other with getting the best possible result.

## B.11 Beacon release

| Beacon release | Price | Complexity | Size (mounting possibilities) | Sum |
|---|---|---|---|---|
| **Weighting** | | 1 | 3 | |
| Solenoid | | 5 | 5 | 20 |
| Stepper | | 5 | 4 | 17 |
| Servo | | 5 | 4 | 17 |
| Vacuum | | 2 | 3 | 11 |
| Brushed DC | | 5 | 4 | 17 |
| Linear actuator | | 5 | 5 | 20 |
| DC | | 5 | 4 | 17 |

Figure B.11: Beacon release.

- **solenoid** - This is the current solution, easy to implement in the new design, however it is in a large housing and quite heavy
- **Stepper** - Easy to control, however it requires quite some space
- **Servo** - Easy to control, however it requires quite some space
- **Vacuum** - Quite a complex solution, which requires some way to create a vacuum, this might be heavy
- **Brushed DC** - Requires some space, easy to run, however other solutions are simpler
- **linear actuator** - Simple, and light weight
- **DC** - Requires some space, easy to run, however other solutions are simpler

# C FEM on electronics box

## C.1 Introduction

To ensure the electronics box has the needed strength to not break during drilling, a FEM study has been made.

The box is made from PA 2200 that has been laser sintered (3D-printed). The PA 2200 has the following material properties, [3D HUBS B.V., 2019]:

- **Tensile strength:** 48 MPa
- **Modulus of elasticity:** 1650 MPa
- **Density:** 0,93 $g/cm^3$
- **Poisson's ratio:** 0,28

## C.2 Purpose

The purpose of the analysis is to determine whether or not the electronics box is able to withstand the torque from the DC motor during drilling, see section 5.2.2 on page 27. The study will be static.

## C.3 Lineup

The geometry of the box can be seen on figure C.1. Notice that the small door is not included in the analysis, because of the increased calculation time and the negligible effect on the stability of the geometry.

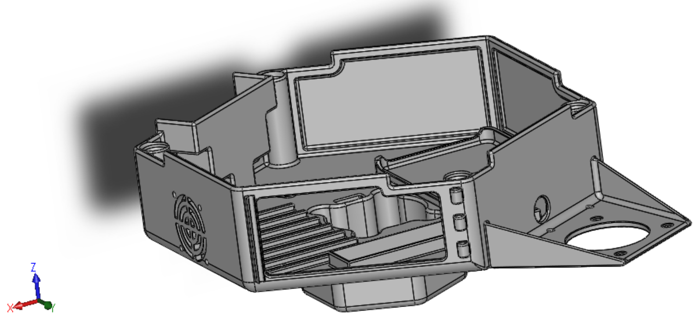


Figure C.1: The electronics box.

The box is connected to the drone via 4xM3 screws going through the 4 connector holes, seen on figure C.2

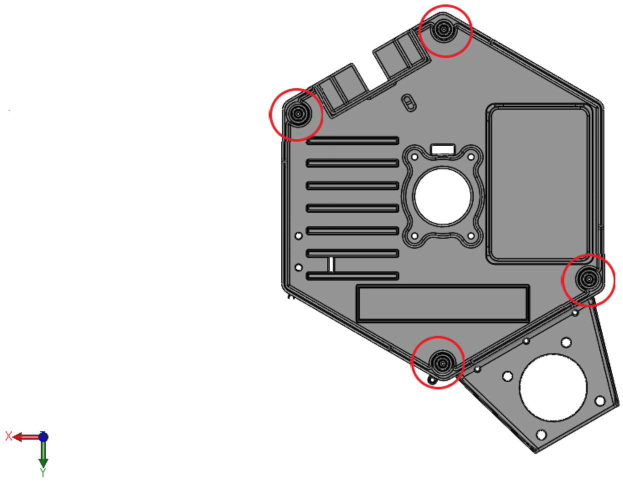


Figure C.2: Holes for the screws that are tightened from the bottom of the box.

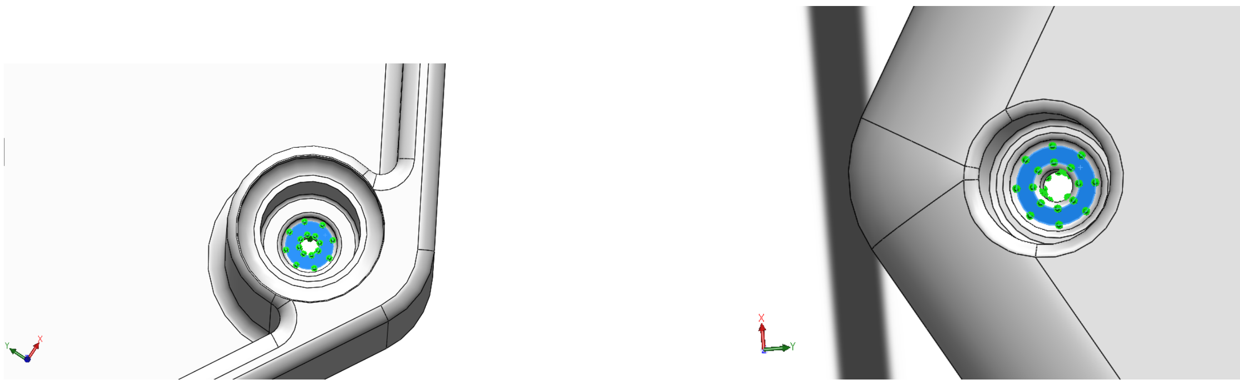
The DC-motor and the drill suspension is connected through the big hole in the middle and the 4 bolt holes surrounding it.

The 4 holes for connecting the box to the drone will be locked by the screw head in the bottom, the drone on the other side. For this reason, these surfaces cannot move up and down and a "roller/slider" fixture is applied, see figure C.3a and C.3b.

The hole going through will be locked by the screw and will not be able to move in any direction and a "fixed geometry" fixture is applied to this face, see figure C.4 on the facing page.

## C.4 Loads

The drill suspension and DC-motor is connected by the 4 bolt holes marked on figure C.5. These are the holes experiencing the torque of the motor. However, due to the complexity of applying torque to the holes the torque is applied to the big hole, see figure C.6. The result is still valid with



(a) Connection from top.

(b) Connection from bottom.

Figure C.3: Faces where the roller/slider fixture is applied.

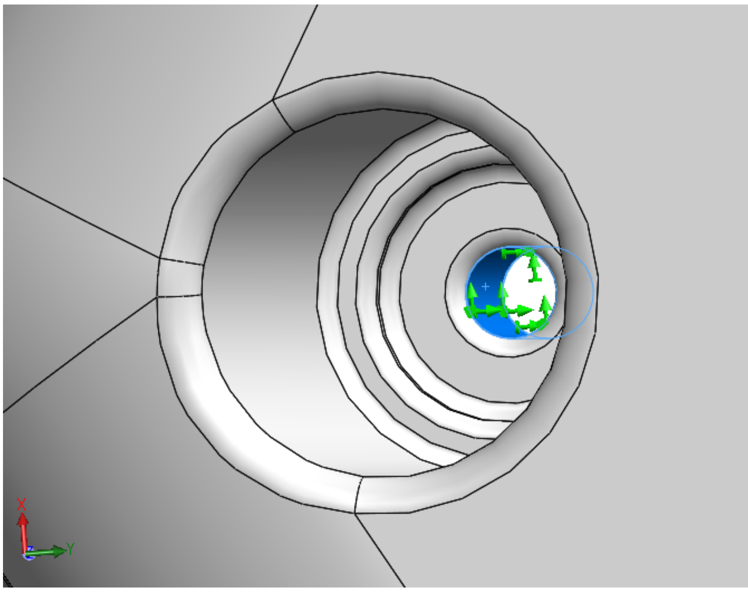


Figure C.4: Holes for the screws where the fixed geometry fixture is applied.

small deviations for the overall geometry and it is assumed that it is very unlikely that the holes would suffer from the torque because of the high concentration of material at the holes. A torque of 6,4Nm is applied to the face seen on figure C.6. The size of the torque comes from section 5.2.2.

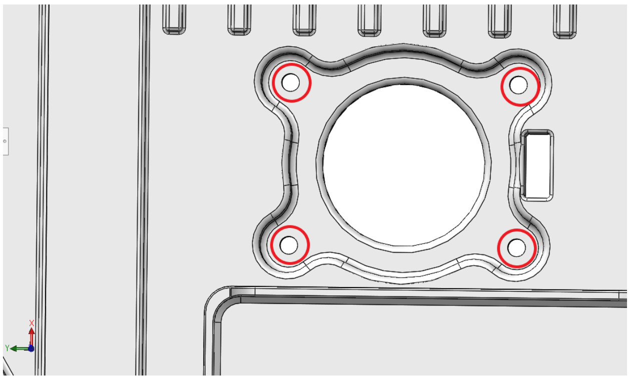


Figure C.5: The holes for connecting the drill suspension and DC-motor.

## C.5 Mesh

The box is meshed with "Blended curvature-based mesh" with the minimum element size is 0,1mm and the maximal element size is 8mm. Because of the size of the box, CST-elements are being used. This makes the simulation go faster but with slightly bad mesh resolution.

### C.5.1 Results

The results of the analysis can be seen on figure C.7 on the next page.

As expected the highest stress concentration is located on the smaller polygon where the drill suspension and DC-motor is connected to the box. However, it should be noticed that the stress values are very low with a max of 0,917 MPa.

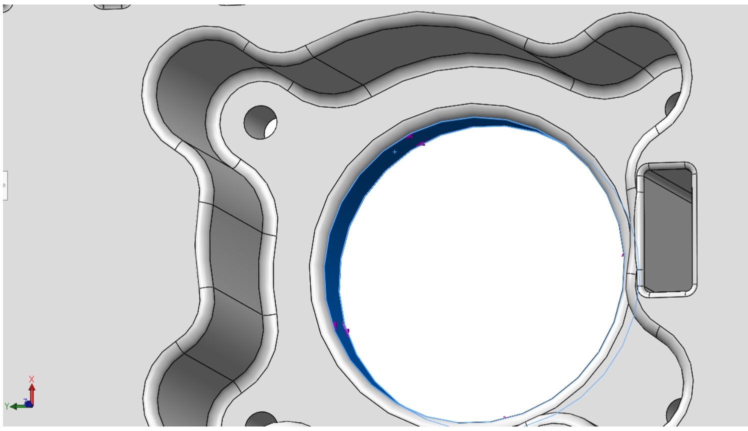


Figure C.6: The big hole where the torque is placed.

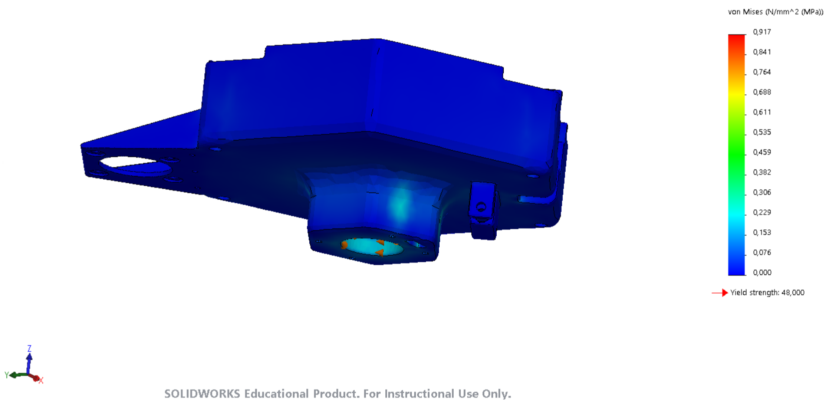



Figure C.7: Stress distribution on the box.

## C.6 Discussion and sources of error

Due to the complexity and size of the electronics box a few compromises have been made to run the simulation. For example, the use of CST-elements and the placement of the torque. However, the CST-elements should provide a valid result but not high resolution. The placement of the torque is close to the 4 holes where the torque is experienced by the box in reality and since the highest stress occurs in the smaller polygon at the transition between the bigger and the smaller polygon where it is expected, the results are acceptable.

Because the box is from made from a thermoplastic it must be taken into account that even small stress over a period of time may deform the geometry. However, the time of the drill process which is less than 20 minutes, is not expected to have this consequence.

## C.7 Conclusion

The analysis shows that the box can withstand the torque of 6,4Nm delivered from the drilling process.

# Calculations on floats D

**Floats calculations**

A safety factor of 1,5 is used. The density of water and the weight of the drone is shown below.

$n_{safety} := 1.5 \qquad g := 9.82\ \frac{m}{s^2} \qquad \rho_{water} := 1000 \cdot \frac{kg}{m^3}$

$m_{drone} := n_{safety} \cdot 18\ kg = 27\ kg$

Lift required produced by floats in Newtons using mass and gravitational acceleration.

$F_{lift} := m_{drone} \cdot g = 265.1\ N$

Volume required to lift the current drone using Archimedes' principle.

$F_{lift} = \rho_{water} \cdot V \cdot g$

$V_{teototal} := \frac{F_{lift}}{\rho_{water} \cdot g} = \left(2.7 \cdot 10^7\right)\ mm^3$

Theoretical volume of new floats.

$V_{floatsteo} := \frac{V_{teototal}}{3} = \left(9 \cdot 10^6\right)\ mm^3$

Current floats (from CAD model in SolidWorks).

$V_{oldfloats} := 15158241\ mm^3$

$V_{oldfloatstotal} := V_{oldfloats} \cdot 3 = \left(4.547 \cdot 10^7\right)\ mm^3$

Ratio between volume of float required and floats currently on model.

$\frac{V_{oldfloatstotal}}{V_{teototal}} = 1.68$

If the height is changed from 200 mm to 120 mm the new volume of the floats is the following.

$V_{floatnew} := 8987287\ mm^3$

$V_{floatnewtotal} := V_{floatnew} \cdot 3$

The lift from the new floats using Archimedes' principle is.

$$F_{liftnew} := \rho_{water} \cdot V_{floatnewtotal} \cdot g = 264.8\ \boldsymbol{N}$$

$$m_{dronenew} := \frac{F_{liftnew}}{g} = 27\ \boldsymbol{kg}$$

The new floats is able to carry around 27 kg which is the same as the required $m_{drone} = 27\ \boldsymbol{kg}$ .

# Quick release - Throw tolerance E

As described in the main report, the drill is mounted in a quick release system, see section 5.1.4 on page 20. It is also described how the drill shaft runs in two bearings, the QR mechanism works in between these two.

On figure E.1 these bearings are marked in blue.

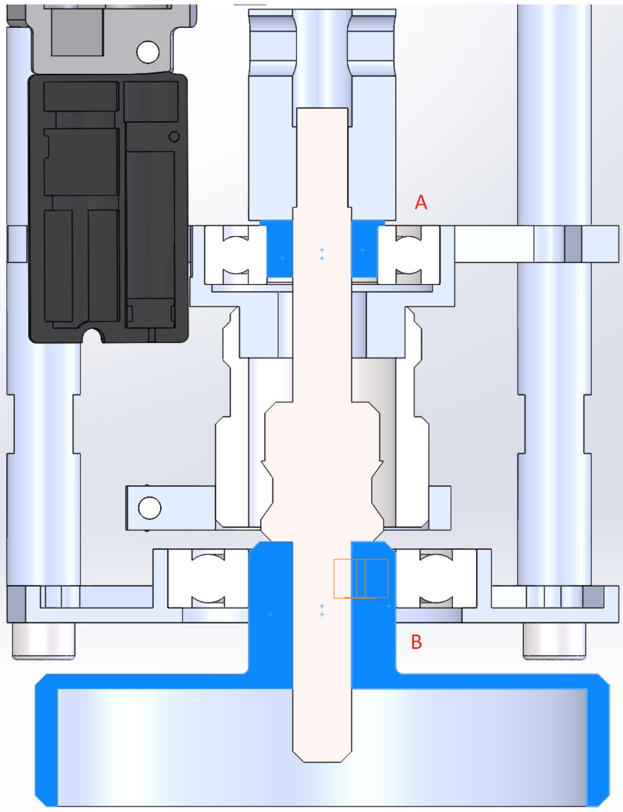



Figure E.1: QR cross section.

In the top bearing, marked with A runs a bushing. This is a press fit into the bearing. The part of the shaft which fits in this bushing is made with a H8/d9 tolerance, which give a maximum clearance of $TopCL = \frac{0,098mm}{2}$ The drill shaft is fixed and centered in the drill connector, above the bearing, which is why we only has half of the clearance.

At the bottom of the bearing, marked with B on figure E.1. The top of the drill is made with a H9 tolerance, this gives a maximum clearance of $BotCL = 0.052mm$ This adds up to a total clearance of $TOTCl = TopCL + BotCL = 0.101mm$

From this it is a simple trigonometric calculation to compute the maximum throw at the drill tip.

The distance between bearings: $Dist = 54.86mm$

The length of the drill $L = 334,65mm$

$\alpha = atan(\frac{TOTCL}{Dist}) = 0.105deg$ $totalThrow = sin(\alpha) \cdot L = 0.616mm$

# F Material changes for drill construction

Table F.1: Material changes in V3 vs V4.

| Part | V3 | V4 | Reasoning |
|---|---|---|---|
| Drill Head | FDM printed PLA | SLS printed Nylon 22 | SLS printed material porosity offers better wax coating retention. Nylon 22 offers improved E-modulus under sub-zero conditions. |
| Fluted Body | FDM printed PLA | SLS printed Nylon 22 | SLS printed material porosity offers better wax coating retention. Nylon 22 offers improved E-modulus under sub-zero conditions. |
| Cutting teeth | Machined, Coated and Hardened High Carbon Steel | DMLS printed Titanium | Increased wear resistance of Titanium. Removal of iron from part. Printing allows for otherwise impossible geometry. |
| Center bit | Standard Wood Drill bit | DMLS printed Titanium (tip) Machined Aluminium (body) | from the aluminium body. Increased wear resistance of Titanium. Removal of iron from part. Printing allows for otherwise impossible geometry. |
| Chipmunk teeth | 8.8 grade zinc-coated steel screws (static) | DMLS printed Titanium | Increased wear resistance of Titanium. Removal of iron from part. Printing allows for otherwise impossible geometry. |
| Drive axle | Machined and coated steel | Alloy Steel | Does not need to be iron-free since on outside of drill. |
| Screws and springs | 8.8 grade zinc-coated steel hardware | Machined and rolled Titanium hardware | Increased wear resistance of Titanium. Removal of iron from part. |

# Command code SPI to 4x UART G

## G.1 Command code

The command table for the SPI-UART converter is as follows:

Table G.1: Command code for SPI to 4x UART.

| Command Code | Parameters 1 | Parameters 2 | Returns | Description |
|---|---|---|---|---|
| (C = UART Channel) | (Command sent after CC) | (Command sent after P1) | (Bytes read after CC, P1 & P2) | |
| 0x1C | N/A | N/A | Num Bytes (0-255) | Reads the number of bytes in the channel receive buffer. |
| 0x3C | N/A | N/A | Num Bytes (0-255) | Reads the number of bytes in the channel transmit buffer. |
| 0x2C | Num Bytes (0-255) | N/A | Data Bytes (0-255) | Reads data byte(s) from the channel receive buffer. |
| 0x4C | Num Bytes (0-255) | Data Bytes (0-255) | N/A | Puts data byte(s) into the channel transmit buffer. |
| 0x8C | Baud (0-7) | N/A | N/A | Sets the channel baud rate. |

## G.2 Command usage

An example of the command code's use is:

1. to read the number of bytes in UART channel two receive buffer send the following command code and then perform a read:

- Drive CS pin Low to prompt SPI conversation
- Send SPI command: 0x12

- Read the commanded bytes on the SPI line
- Drive CS pin High to end SPI conversation

2. To transmit five bytes to UART channel number two send the following command code, the number of bytes and then perform enough writes to send out the data:

- Drive CS pin Low to prompt SPI conversation
- Send SPI command: 0x42
- Send SPI command: 0x05
- Transmit the commanded bytes on the SPI line in rapid succession.
- Drive CS pin High to end SPI conversation

# Appendix H: Morphology on imitated iceberg

Figure H.1: Raw image.

Figure H.2: Green channel.

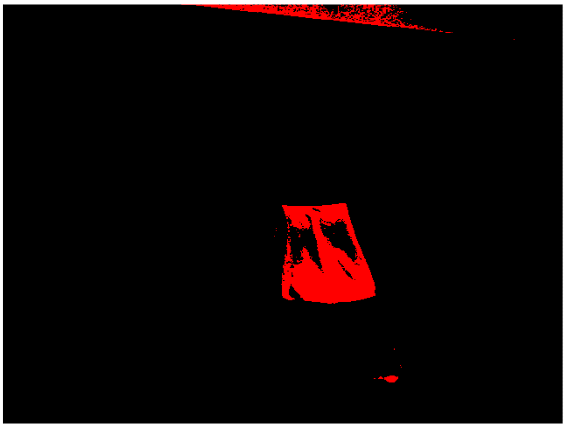


Figure H.3: Threshold 240-255.

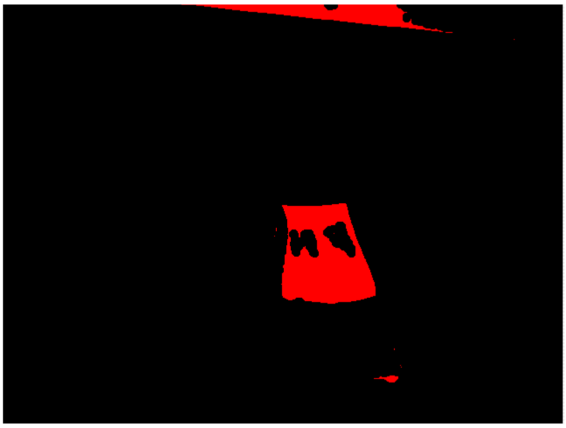


Figure H.4: Close object.

Figure H.5: Remove small objects.

Figure H.6: Remove border objects.

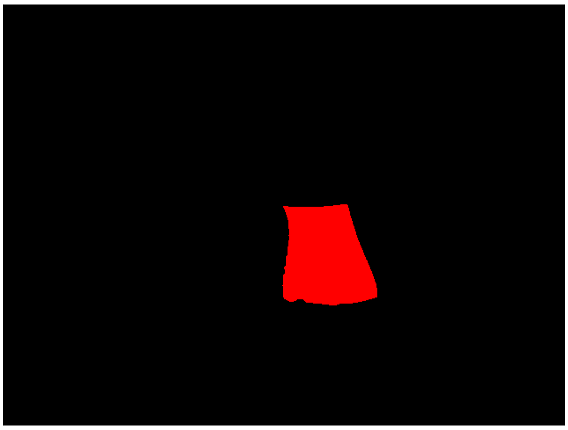


Figure H.7: Fill holes.

# I Circuit diagram from NI Multisim

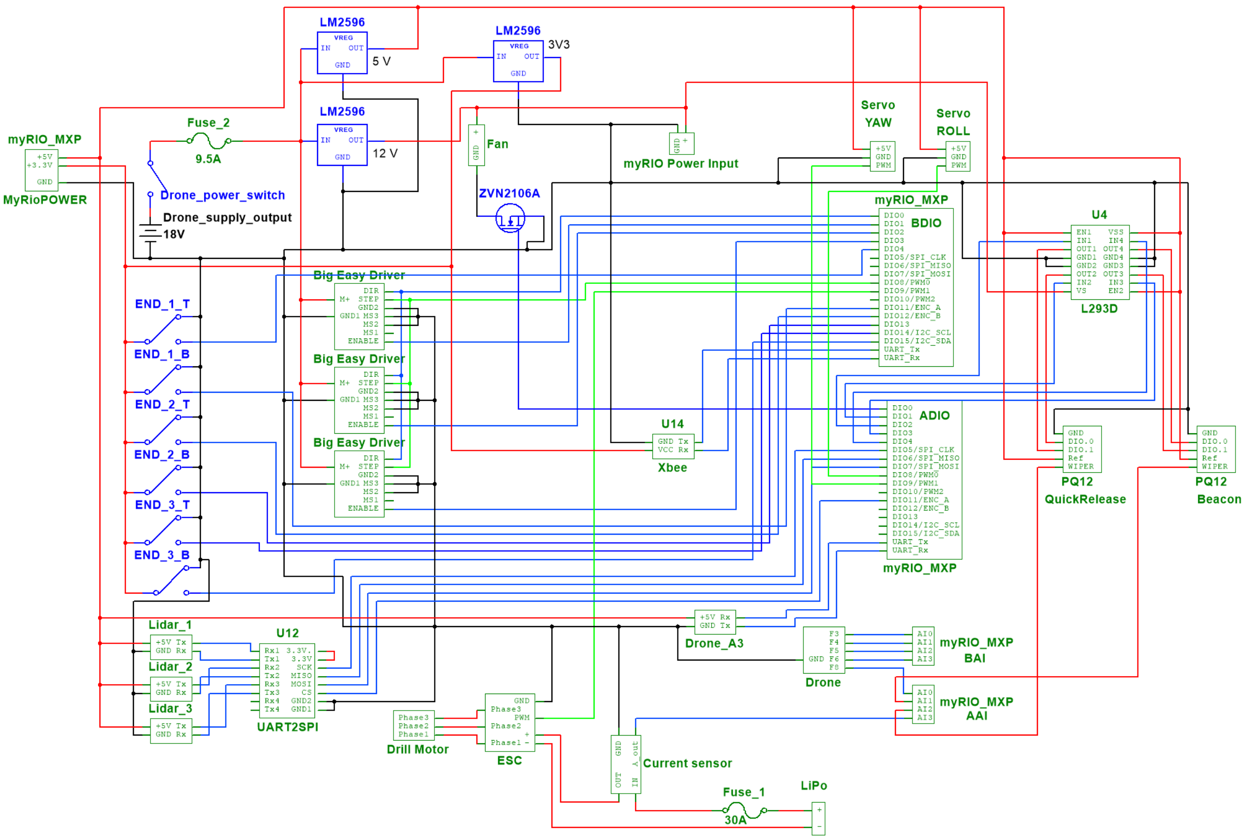



Figure I.1: Complete circuit diagram.

| Color Code | Use |
|---|---|
| Black | GND |
| Red | Power |
| Blue | Signal |
| Green | PWM |

Table I.1: Color code for circuit diagram.

# Perfboard layout J

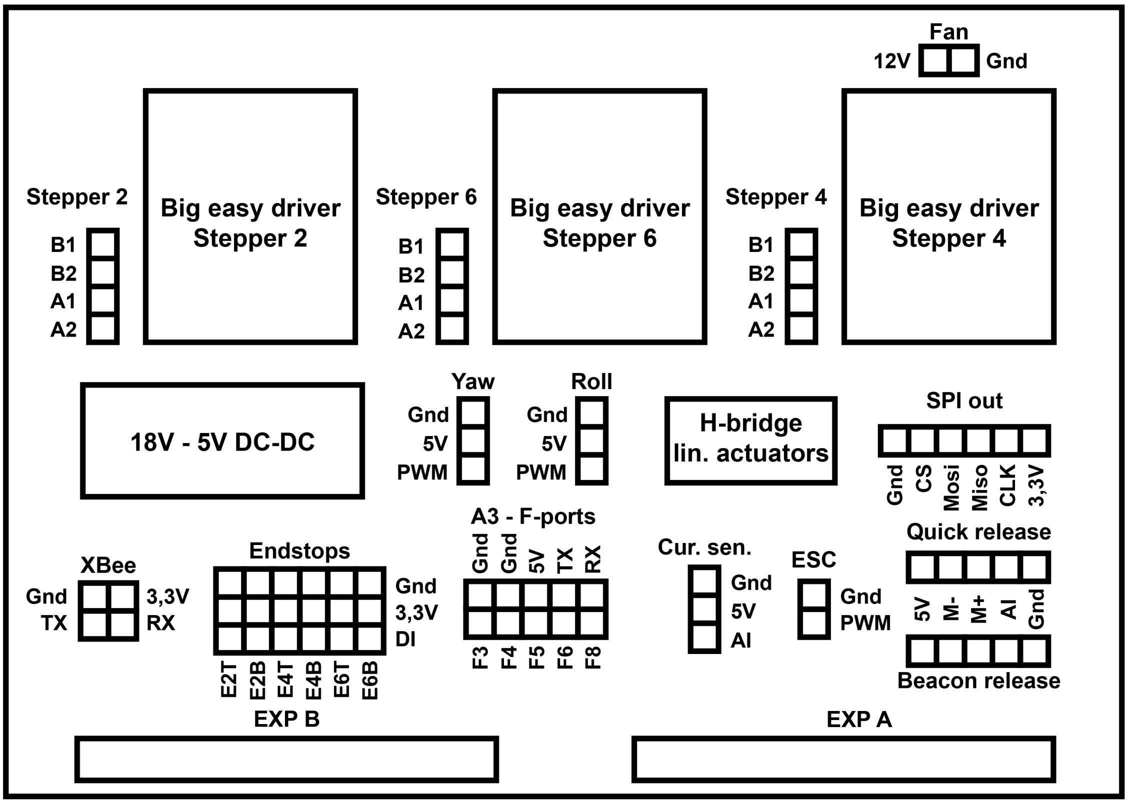



Figure J.1: Layout of the perfboard.

# Main VI and PC VI K

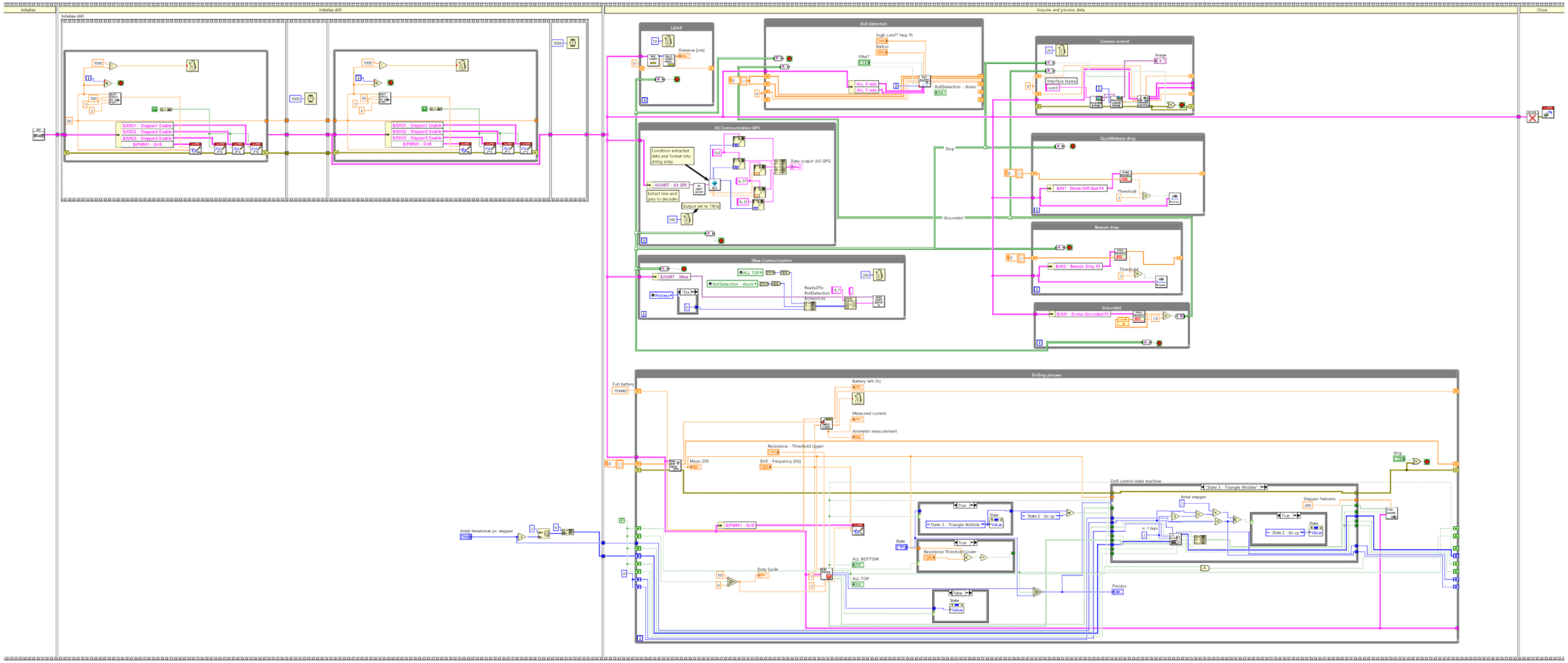


Figure K.1: Drone Main VI.

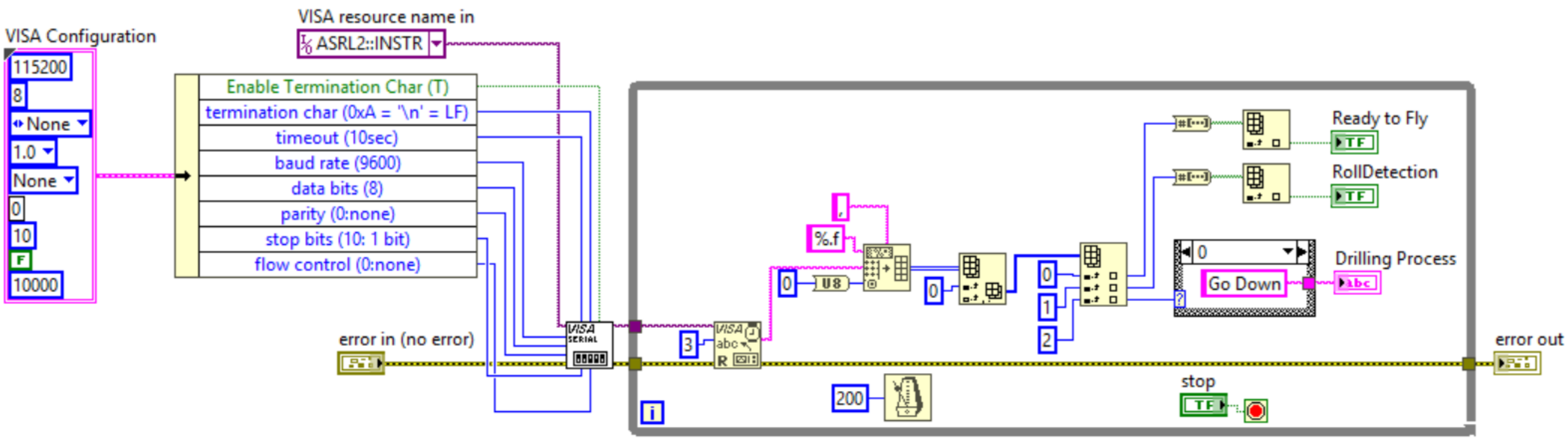



Figure K.2: PC Host Main VI.

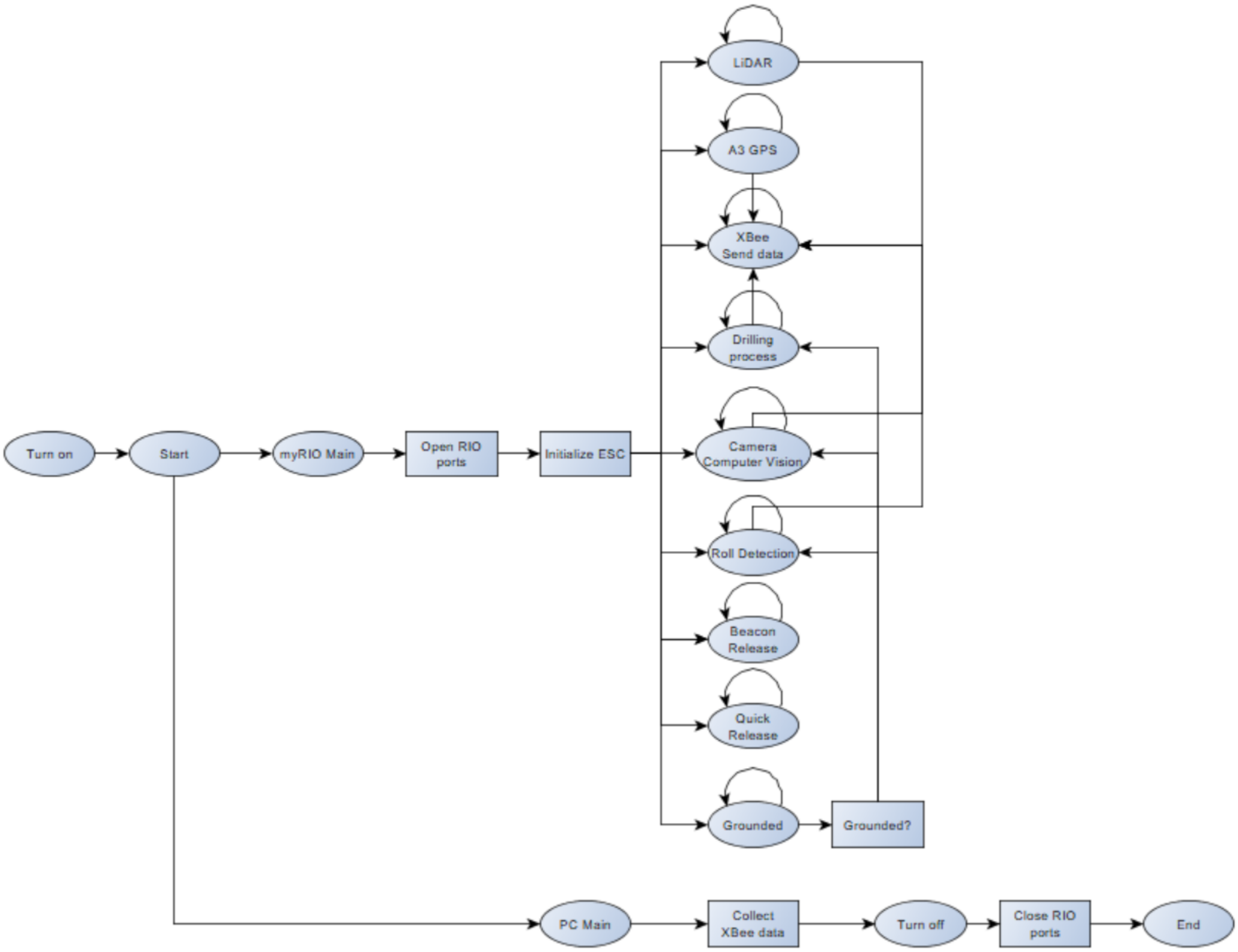



Figure K.3: Flowchart of Main VI.

# Drill process VI L

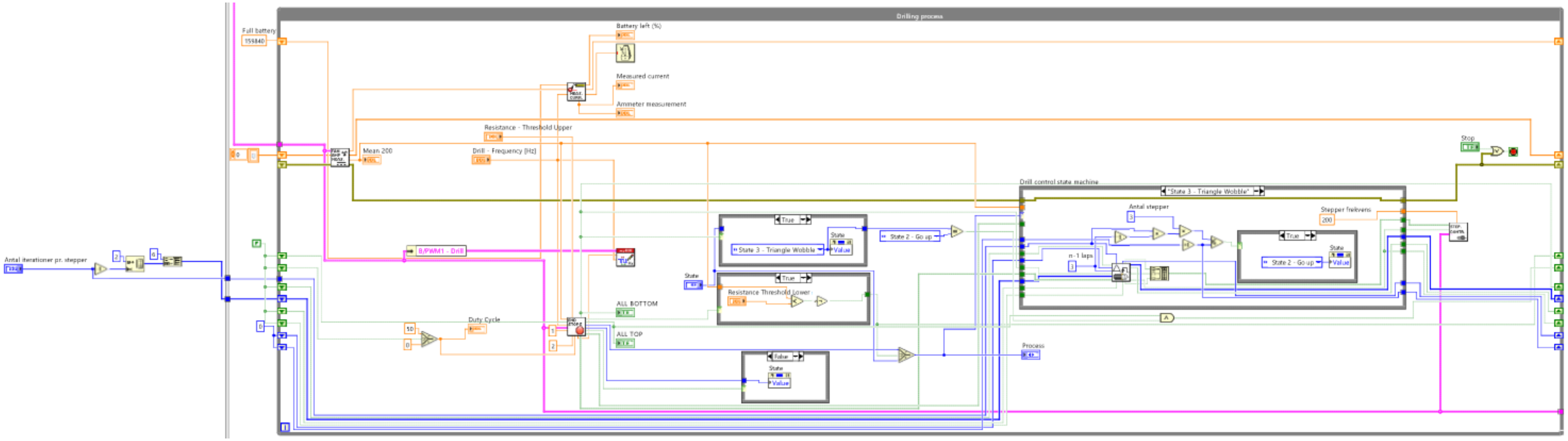



Figure L.1: Drilling Process while loop.

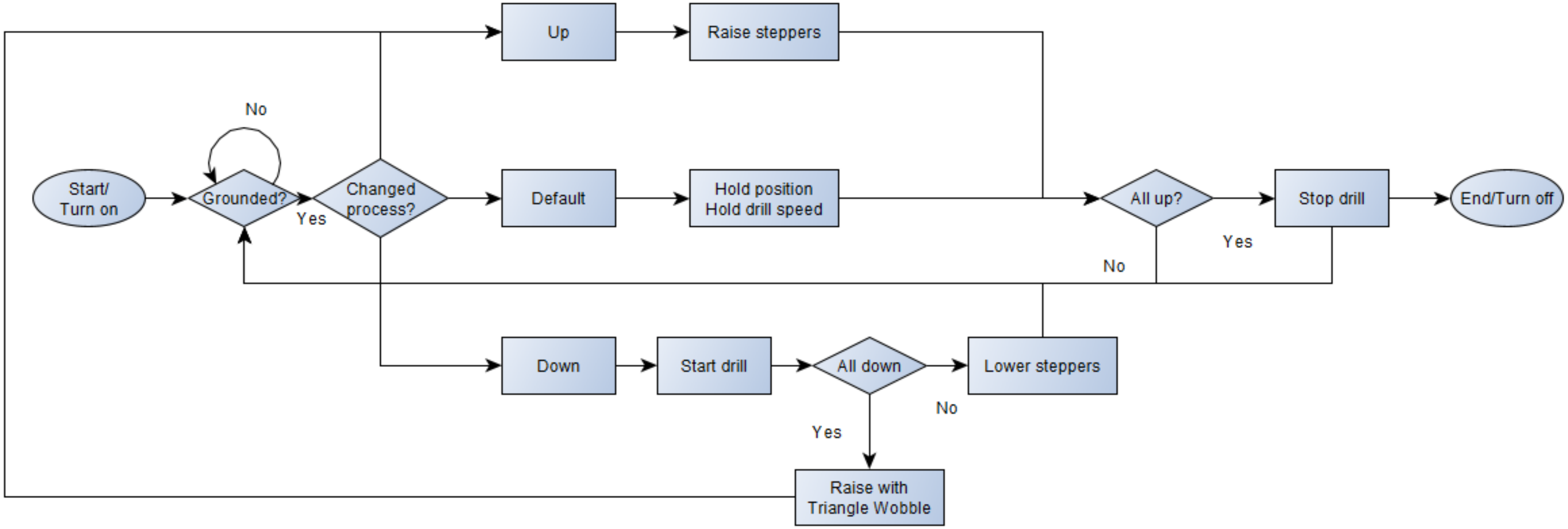
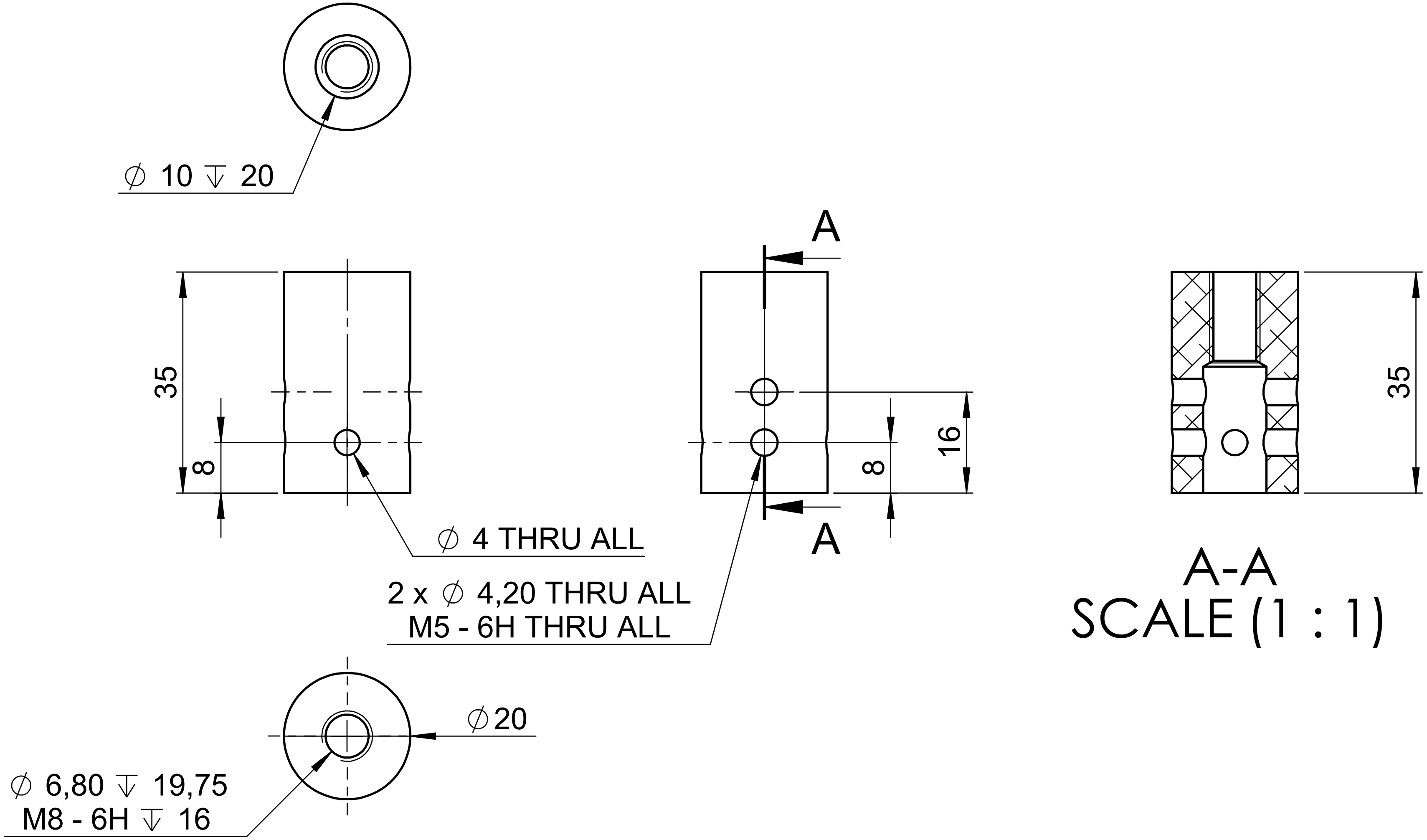


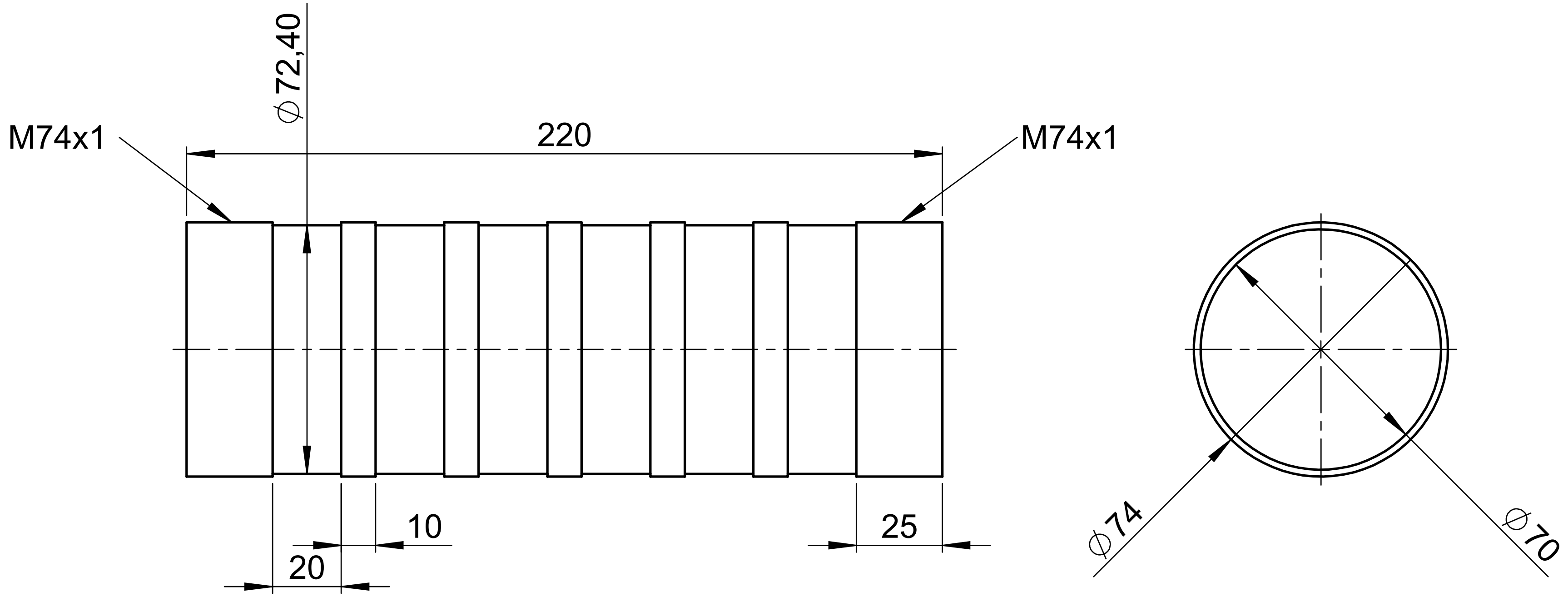

Figure L.2: Flowchart of the drilling process.

# Technical drawings M




| 1 | - | - | - | Aluminium |
|---|---|---|---|---|
| **Qty.** | **Item** | **Item no.** | **Drawing no.** | **Material / Model no.** |

| | | | |
|---|---|---|---|
| **AARHUS UNIVERSITY**<br>SCHOOL OF ENGINEERING<br>Department of Mechanical Engineering | **Scale:**<br>2:1 | **Group ID:** MECH CH 4<br>**Student ID:** 201511622 | **Date:** 22/04/2019<br>**Initial:** STT |
| **Description:**<br>Ice Core Drill adapter | **Drawing no.:**<br>SAIDD_DA_M_007 | | |




| 1 | 74OD x 2 x 240 Aluminium tube | - | - | - |
|---|---|---|---|---|
| **Qty.** | **Item** | **Item no.** | **Drawing no.** | **Material / Model no.** |

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Department of Mechanical Engineering

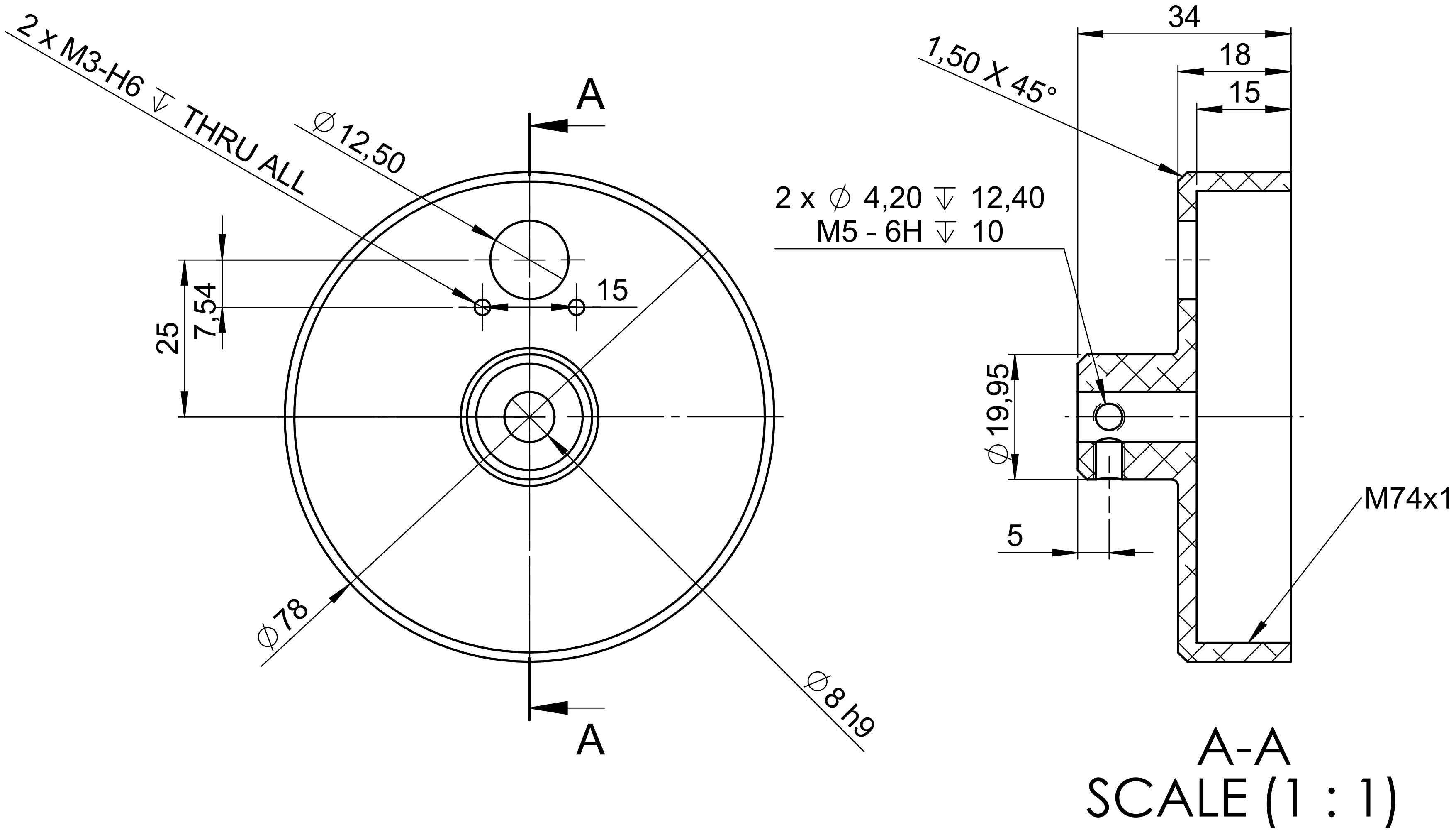
| **Scale:** | **Group ID:** | **Date:** |
|---|---|---|
| 1:2 | MECH CH 4 | 22/04/2019 |
| | **Student ID:** | **Initial:** |
| | 201511622 | STT |

**Description:**

Ice Core Drill center tube

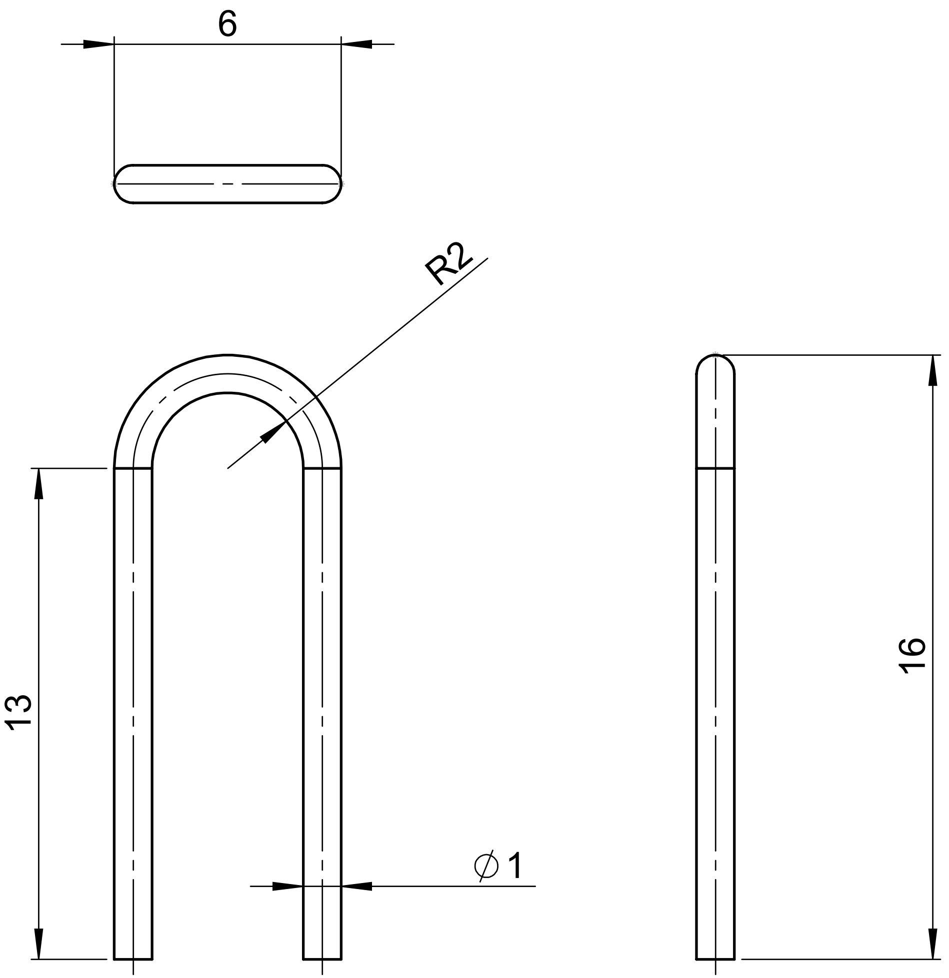
**Drawing no.:**

SAIDD_DA_M_009




| 1 | - | - | - | Aluminium |
|---|---|---|---|---|
| Qty. | Item | Item no. | Drawing no. | Material / Model no. |

| | | | |
|---|---|---|---|
| **AARHUS UNIVERSITY**<br>SCHOOL OF ENGINEERING<br>Department of Mechanical Engineering | Scale:<br>1:1 | Group ID: MECH CH 4<br>Student ID: 201511622 | Date: 25/04/2019<br>Initial: STT |
| Description:<br>Ice Core Drill Top | Drawing no.:<br>SAIDD_DA_M_011 | | |




| | | | | |
|---|---|---|---|---|
| 1 | - | - | - | 1.0mm Titanium Rod |
| **Qty.** | **Item** | **Item no.** | **Drawing no.** | **Material / Model no.** |

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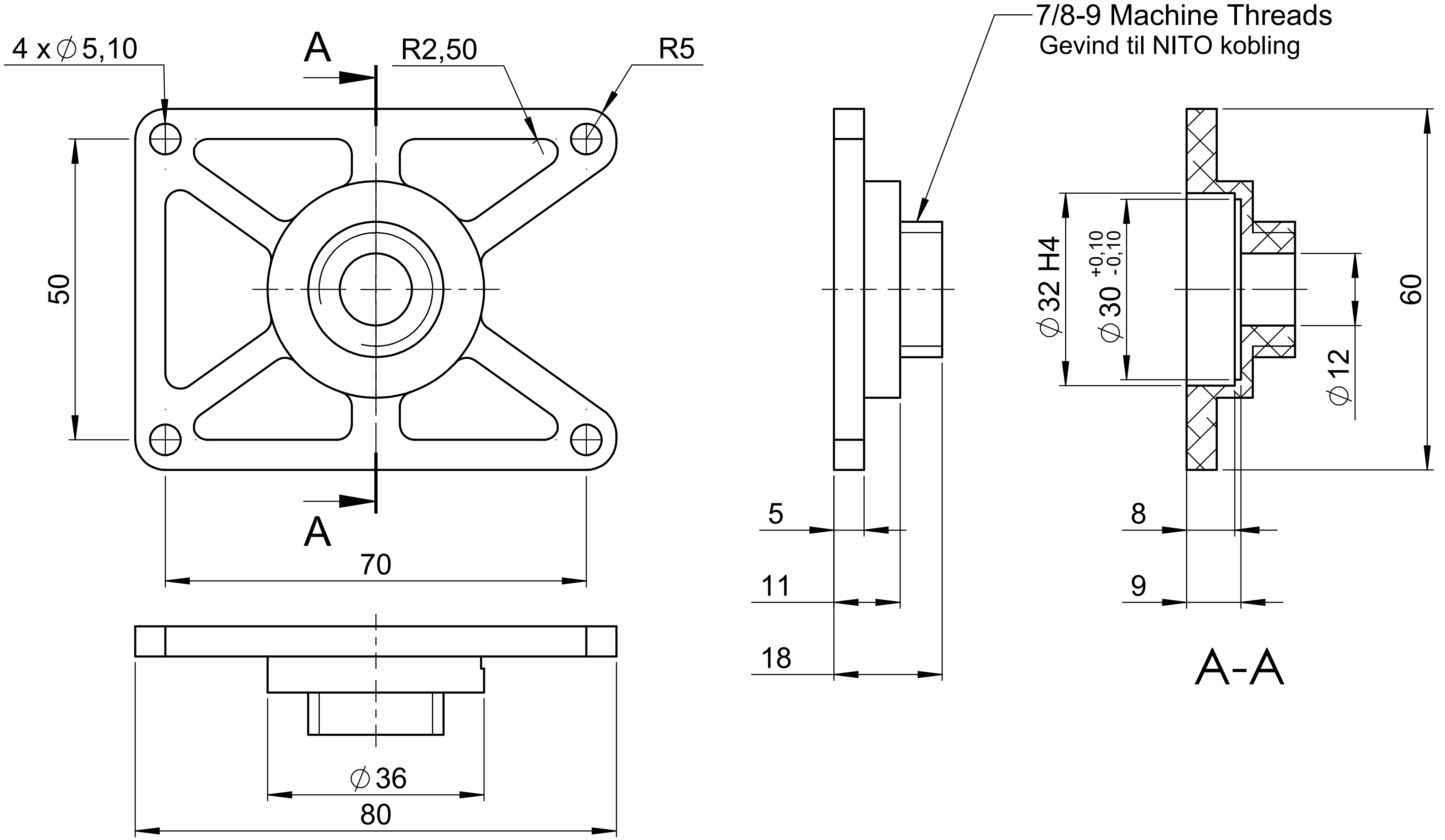
| | | |
|---|---|---|
| **Scale:** 5:1 | **Group ID:** MECH CH 4 | **Date:** 25/04/2019 |
| | **Student ID:** 201511622 | **Initial:** STT |

**Description:** Core Dog Spring

**Drawing no.:** SAIDD_DA_M_016




| 1 | | | | Aluminium |
|---|---|---|---|---|
| **Qty.** | **Item** | **Item no.** | **Drawing no.** | **Material / Model no.** |

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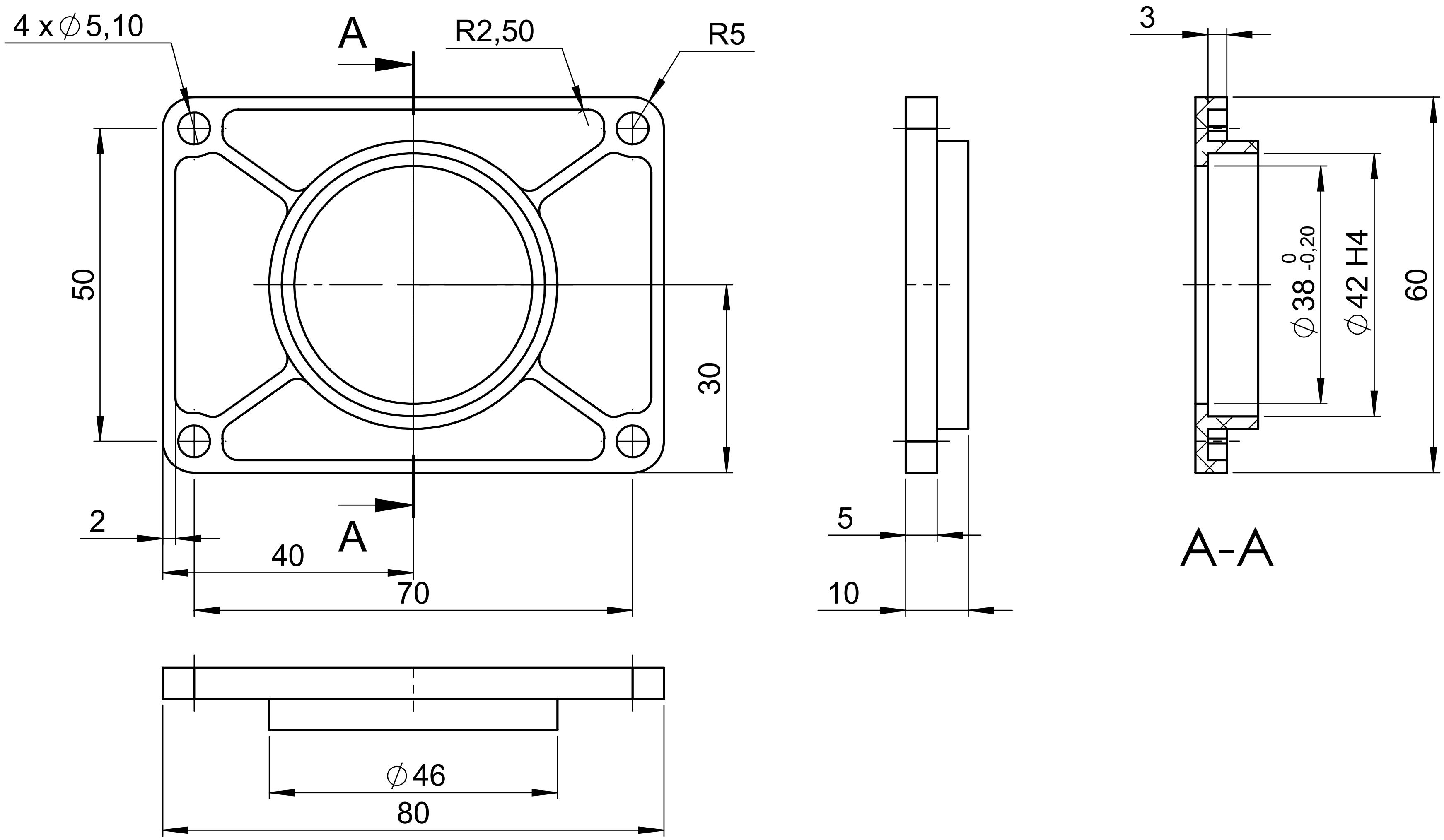
| **Scale:** | **Group ID:** | **Date:** |
|---|---|---|
| 1:1 | Mech. Ch. 4 | 23/04/2019 |
| | **Student ID:** | **Initial:** |

**Description:**
Quick Release Mounting Plate

**Drawing no.:**
SAIDD_QRA_001




| Qty. | Item | Item no. | Drawing no. | Material / Model no. |
|---|---|---|---|---|
| 1 | | | | Aluminium |

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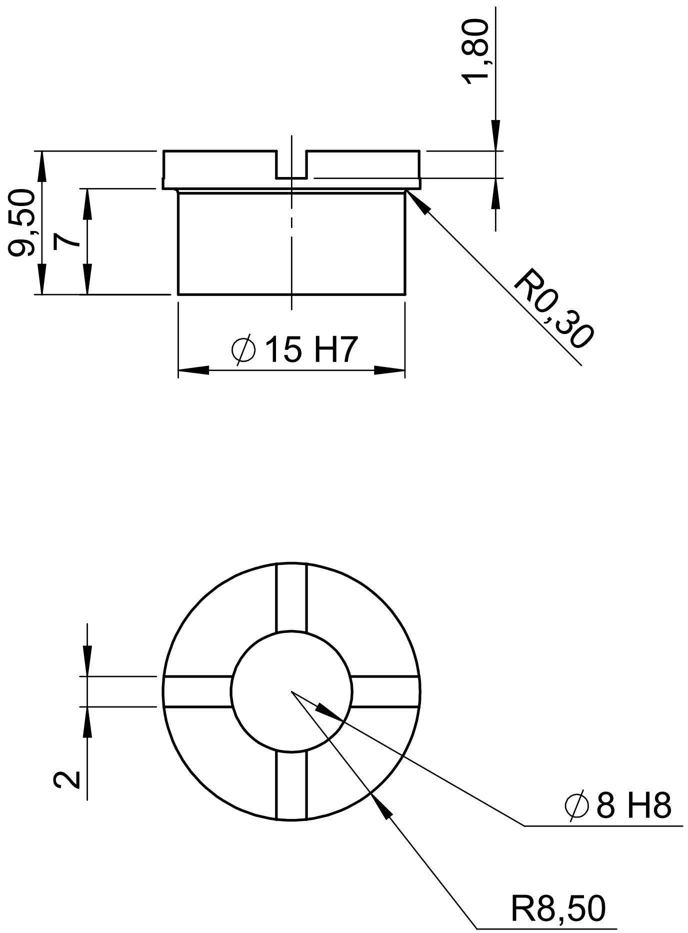
Department of Mechanical Engineering

| Scale: | Group ID: | Date: |
|---|---|---|
| 1:1 | Mech. Ch. 4 | 23/04/2019 |
| | Student ID: | Initial: |

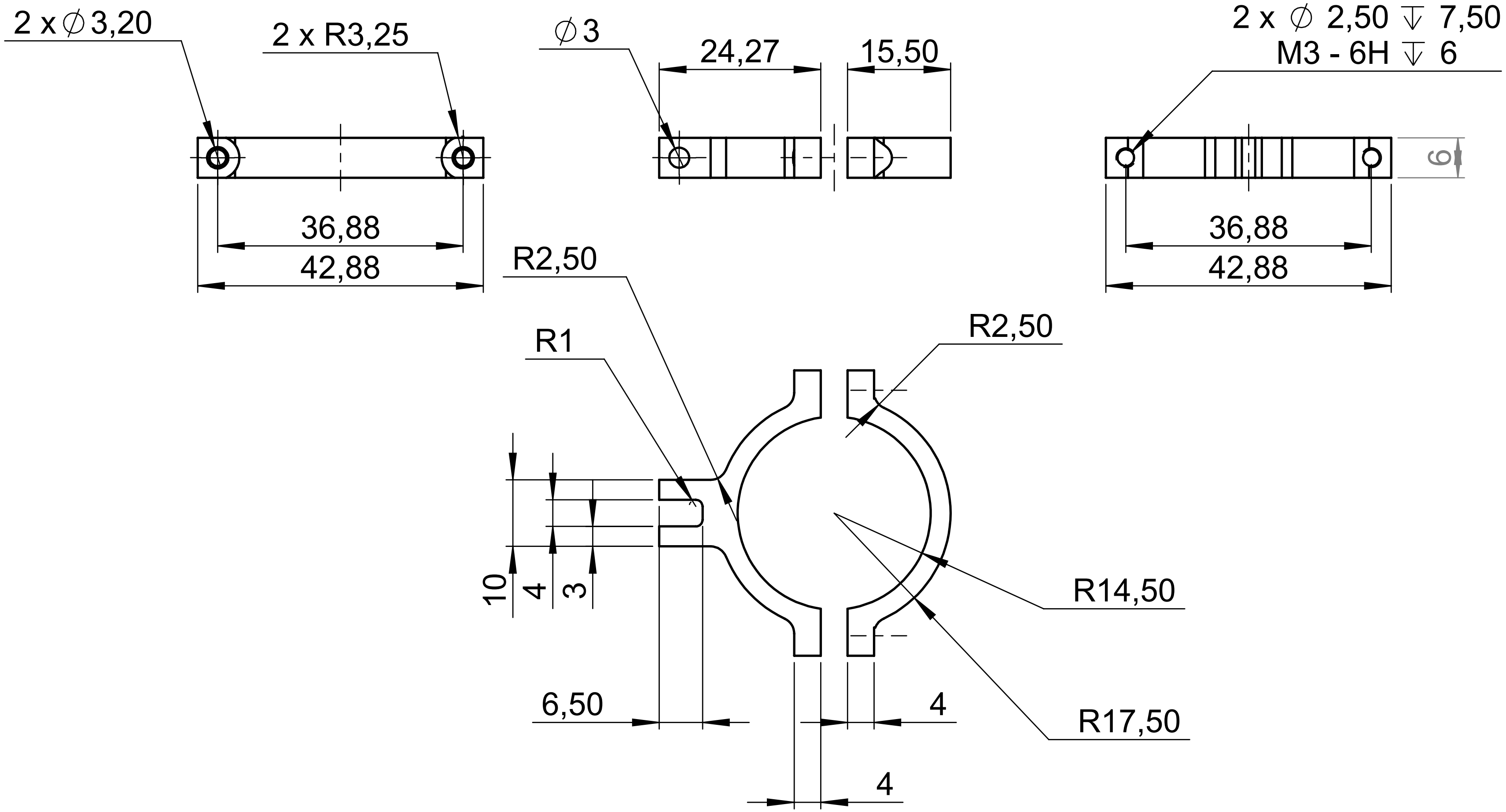
Description:
Quick Release Support Plate

Drawing no.:
SAIDD_QRA_M_002




| | | | | |
|---|---|---|---|---|
| 1 | | | | Aluminium |
| Qty. | Item | Item no. | Drawing no. | Material / Model no. |

| | | | |
|---|---|---|---|
| **AARHUS UNIVERSITY**<br>SCHOOL OF ENGINEERING<br>Department of Mechanical Engineering | Scale: 2:1 | Group ID: Mech. Ch. 4 | Date: 22/04/2019 |
| | | Student ID: | Initial: |
| Description: Quck Release Shaft Spacer | Drawing no.: SAIDD_QRA_M_003 | | |




| 1 | | | | Aluminium |
|---|---|---|---|---|
| **Qty.** | **Item** | **Item no.** | **Drawing no.** | **Material / Model no.** |

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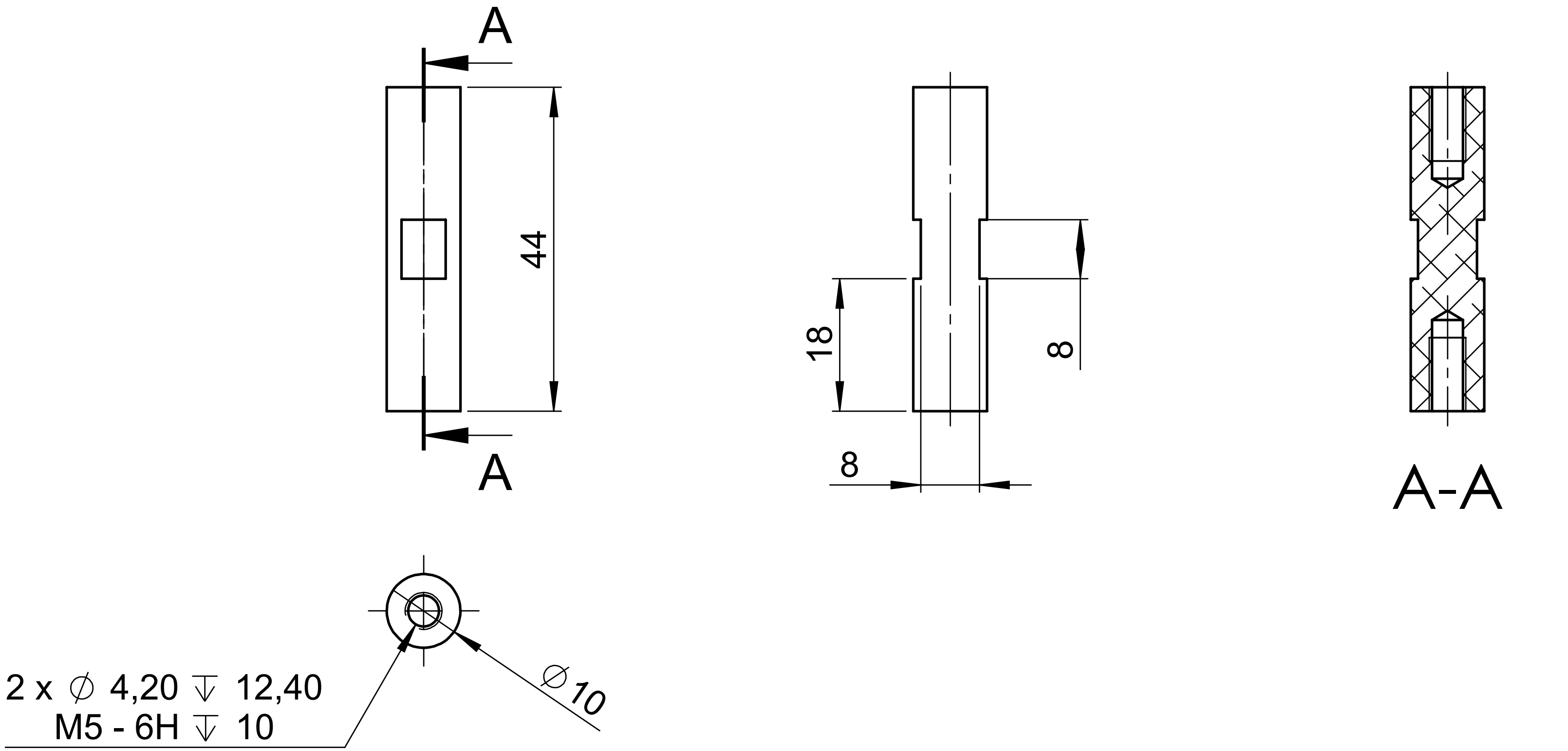
| **Scale:** | **Group ID:** | **Date:** |
|---|---|---|
| 1:1 | Mech. Ch. 4 | 22/04/2019 |
| | **Student ID:** | **Initial:** |

**Description:** Quick Release Clamp

**Drawing no.:** SAIDD_QRA_M_004




| | | | | |
|---|---|---|---|---|
| 1 | | | | Aluminium |
| Qty. | Item | Item no. | Drawing no. | Material / Model no. |

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Scale: 1:1
Group ID: Mech. Ch. 4
Date: 22/04/2019
Student ID:
Initial:

Description:
Quick Release Plate Spacer

Drawing no.:
SAIDD_QRA_M_005


| Qty. | Item | Item no. | Drawing no. | Material / Model no. |
| --- | --- | --- | --- | --- |
| 1 | | | | Aluminium |

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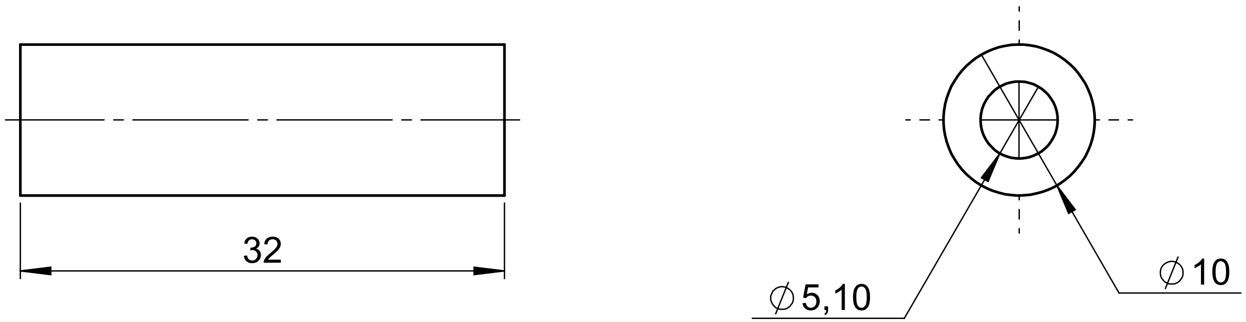
| Scale: | Group ID: | Date: |
| --- | --- | --- |
| 2:1 | Mech. Ch. 4 | 22/04/2019 |
| | Student ID: | Initial: |

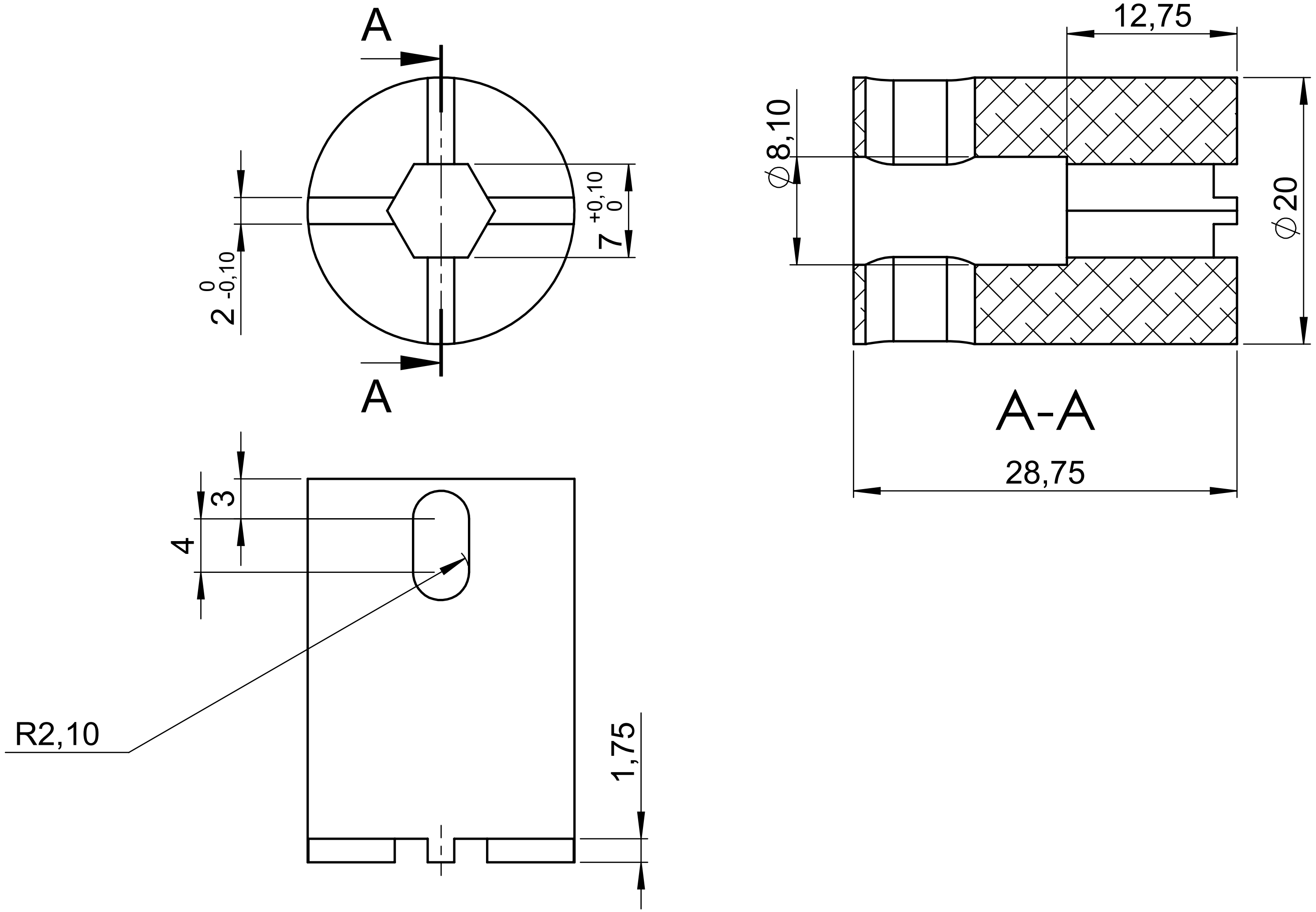
**Description:** Quick Release Spacer 1

**Drawing no.:** SAIDD_QRA_M_006




| | | | | |
|---|---|---|---|---|
| 1 | | | | Aluminium |
| **Qty.** | **Item** | **Item no.** | **Drawing no.** | **Material / Model no.** |

| | | | |
|---|---|---|---|
| **AARHUS UNIVERSITY**<br>SCHOOL OF ENGINEERING<br>Department of Mechanical Engineering | **Scale:**<br>2:1 | **Group ID:** Mech. Ch. 4<br>**Student ID:** | **Date:** 22/04/2019<br>**Initial:** |
| **Description:**<br>Quick Release Spacer 2 | **Drawing no.:**<br>SAIDD_QRA_M_007 | | |




| | | | | |
|---|---|---|---|---|
| 1 | | | | Aluminium |
| Qty. | Item | Item no. | Drawing no. | Material / Model no. |

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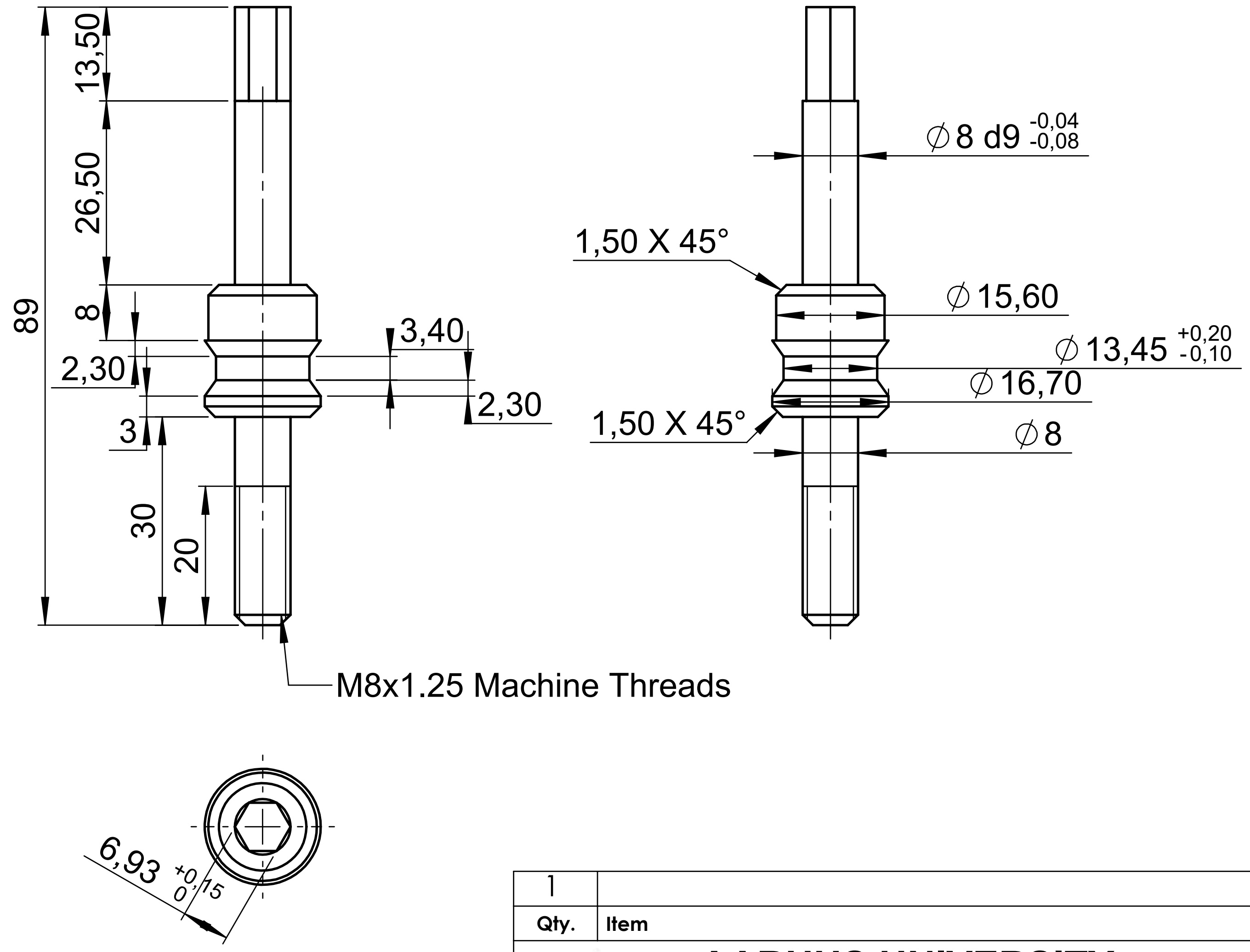
| Scale: | Group ID: | Date: |
|---|---|---|
| 2:1 | Mech. Ch. 4 | 09/05/2019 |
| | Student ID: | Initial: |

Description:
Quick Release Drill Connector

Drawing no.:
SAIDD_QRA_M_008




| 1 | | | | Aluminium |
|---|---|---|---|---|
| **Qty.** | **Item** | **Item no.** | **Drawing no.** | **Material / Model no.** |

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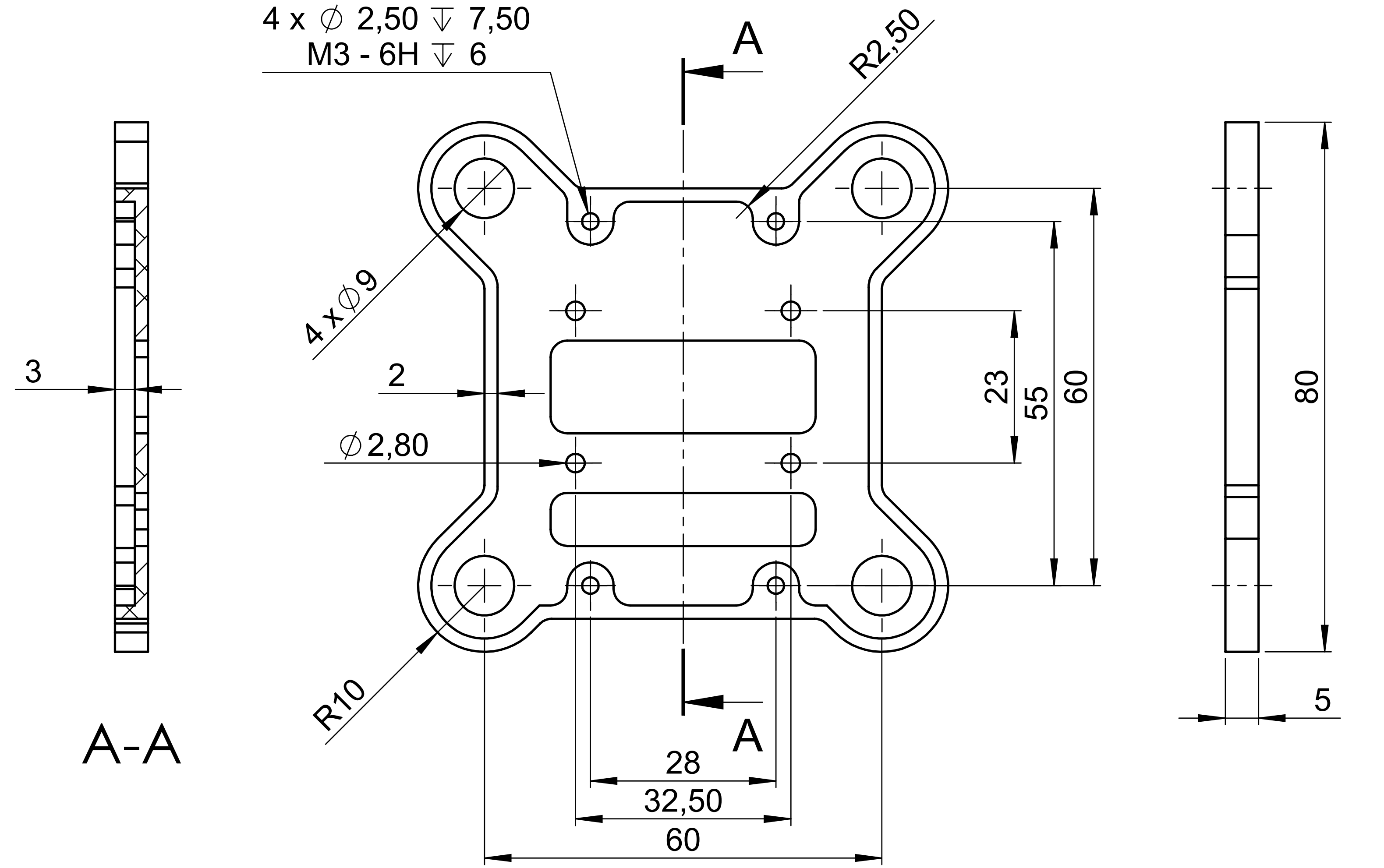
Department of Mechanical Engineering

| **Scale:** | **Group ID:** | **Date:** |
|---|---|---|
| 1:1 | Mech. Ch. 4 | 23/04/2019 |
| | **Student ID:** | **Initial:** |

**Description:**
Quick release/drill shaft

**Drawing no.:**
SAIDD_QRA_M_009




| 1 | | | | Aluminium |
|---|---|---|---|---|
| Qty. | Item | Item no. | Drawing no. | Material / Model no. |

| AARHUS UNIVERSITY<br>SCHOOL OF ENGINEERING<br>Department of Mechanical Engineering | Scale: 1:1 | Group ID: Mech. Ch. 4 | Date: 22/04/2019 |
|---|---|---|---|
| | | Student ID: 201511622 | Initial: STT |
| Description: Zenmuse Vibration Dampening Mount | Drawing no.: SAIDD_ZCA_M_002 | | |