2020 Automated Snowplow Competition

<u>Team Caribou</u>

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Executive Summary

- Team Caribou has conceived and designed an affordable automated snow plow platform for the masses. It consists of four electric DC brushless motors, a steel frame, two 24V DC marine batteries and Jetson Nano for processing the sensor information and sending control commands.

- The Jetson Nano sends control signals to the ESP32, which are connected to four IBT2 motor drivers, each of which can handle up to 40 amps of current. Two sensors will be used for path planning, localization, obstacle detection, and avoidance.

- The snowplow is to be covered with an acrylic body that will cover and protect the electronics from rain, snow, etc.

- The acrylic body will also have a housing that will hold the manual e-stop in a visible way. In addition to the manual e-stop, there will be a remote and a software e-stop, which works as described in the safety section.

- The team consists of 8 members, which have mechanical engineering, mechanical and computing technology, or computer engineering background. The team roles are roughly divided into mechanical, electrical, software, and communications. However, many of the team members have mechatronics experience and play multiple roles.

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Units

Quantity	**Symbol**
Current	A
Voltage	V
Battery Capacity	Ah
Length	Inches, cm, m
Frequency	Hz

1 Safety Systems

1.1 Software e-stop

In order to demonstrate geo-fencing, the snowplow would do a demonstration to attempt to move past the geofenced area. As a result, the software e-stop will be triggered, as the GPS boundary has been exceeded, or the red edge boundary is detected. A front-facing camera paired to the NVIDIA Jetson Nano will use Canny Edge Detection to detect the arena edges. Geo-fencing will be implemented using RTK-GPS. A live classifier will show that the Jetson Nano determines its current boundary status (Green, Yellow, or Red). The classifier will fuse both camera and GPS information to make the best prediction (based on a weighting of individual predictions). This geo-fencing safety on, the snowplow may only move if it is in the Green or Yellow boundary. If it is in Yellow, it will attempt to return to Green. Otherwise, the snowplow will be disabled.

1.2 Manual E-stop and Remote E-stop

The team will also demonstrate its remote shut-off (in the case of manual activation or lost signal from the remote disable), along with manual shut-off. Top speed will be electronically limited to 10km/h, so that in the case that one needs to use the manual shut-off, it is possible to reach it. The team will demonstrate that the vehicle has been disabled, and the main power relay has been broken (shown by the buck converter light indicator, and additional signals as needed). This will all be performed within 2 seconds. Figure 1 below represents the manual snowplow e-stop is to be placed on the rear acrylic panel and will have a 20 cm diameter red circle surrounding it.

Figure 1: The manual snowplow e-stop to be placed on the rear acrylic panel

The remote snowplow e-stop the team is planning to purchase is the Vehicle Safety Controller (VSC) unit from FORT Robotics. The VSC unit has the ability to operate at an ambient temperature range of -40 degrees to 70 degrees celsius. Also, using a 2.4GHz radio frequency, the vehicle can be controlled at as far as 500m within the line-of-sight. Since the remote e-stop system is the only component of the vehicle that uses radiofrequency, there will be no interference with any other command or control link. The remote e-stop will be integrated as part of the electronic and software system. The controller for snowplow wireless e-stop will be purchased from FORT robotics and implemented into the hardware and software system of the snowplow. An image illustrating the manual controller for the remote e-stop is shown in Figure 2.

Figure 2: The controller for snowplow wireless e-stop from FORT robotics

2 Propulsion Systems

2.1 Mechanical

Click here for a full breakdown of the mechanical materials used.

Figure 3 below shows the snowplow without the acrylic box as of December 2019

Figure 3: The snowplow without the acrylic box

The team was tasked with assembling the drive train. It was required that this was done in a way that was mechanically sound (straight wheels, parallel axles) and easily serviceable (chain could be easily replaced, wheels could be removed). The team decided to go with a four-wheel-drive system, with four independent motors. This was done for the following reasons:

- Firstly, all-wheel drive was a must to deliver as much force as possible to the ground. This is done by maximizing friction force which is proportional to the normal force on the powered wheels. If only the front two or the two rear wheels were powered, there would be less force on the ground to push snow.

- Secondly, the team also wanted an independent left and right drive, a steering system with twisting wheels similar to what a car has was not required instead, tank-style turning mechanism was utilized as the left and right wheels turn in opposite directions to turn. Only four independent motors can accomplish these goals unless the team decides in the future to use tracks instead of tires.

- Lastly, sprockets were mounted on the motor and wheel shaft. The sprockets were welded onto hubs, and then the tires were mounted on a set of plates, which could accommodate a hub. The original intention was to weld sprockets to these hubs as well, then bolt the plates to the sprocket. However, the welds the team produced did not satisfy the requirement that the wheels were straight, the sprockets were crooked. Rather than attempting to do the welds again, the team opted to machine custom aluminum hub adapters. These allowed for easier removal of the wheels and were a lower-cost solution to purchasing more hubs and sprockets.

In conclusion, the implemented drive system achieves its goals, the wheels are straight and concentric, the chain and wheels can be serviced with ease, while effectively and efficiently delivering power. Figure 4 below shows the team assembling the drivetrain during the fall 2019 semester at uOttawa Brunsfield Centre

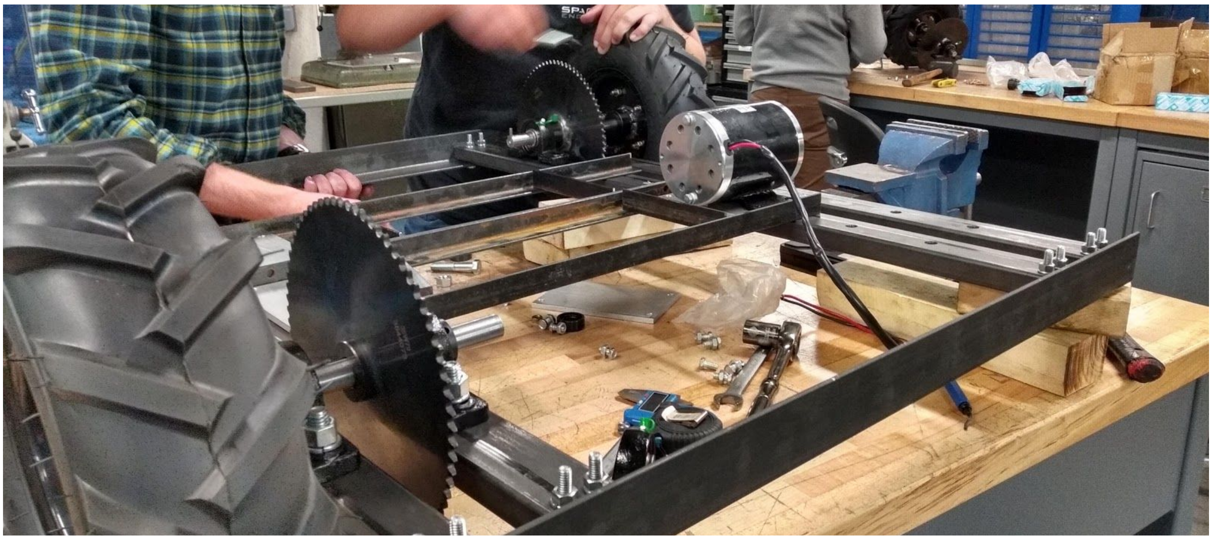

Figure 4: The team assembling the drivetrain

The motors would be connected to the wheels with a chain. Alternatively, belts or gears could have been utilized. However, gears can be challenging to work with as they have to be lubricated and placed with adequate spacing. Additionally, they generate thrust forces. Chains were chosen over belts due to the following reasons:

- They were readily available from a local hardware store;
- They are more flexible in design than belts since the chains can be shortened or lengthened easily.

To provide tension for the chains, the bearings used were mounted in pillow blocks. The pillow blocks had slots that allowed for some adjustment. Furthermore, the motors were mounted on plates in such a way that they could be translated to ensure the chains attached are straight and have proper tension. The plates which the motors reside on were machined with slots cut so that the motors could slide approximately 0.125” along each slows, allowing for 0.25” of total adjustment length on the attached 0.5” length chain links, the pillow blocks provided the rest needed to accommodate one link.

2.2 Electrical and Motor Control

The snowplow is powered by two 12 V 120 Ah Deep cycle marine batteries. They were chosen for the following reasons:

- Considering no weight limitation, these batteries are an ideal cost-effective option

● Wired in series, the batteries deliver 24 V, which is optimal for powering the 500 W 24 V brushed DC motors.

All four motor drivers were wired individually in series with both batteries, thereby supplying 24 V to each driver. Each of the four positive cables first passed through its own 25 A fuse and relay before connection to a driver. The team chose 25 A fuses since this current at 24 V yields a power of 600 W, which the motors were assumed to be capable of for a short period. The four relays were wired in a simple series circuit, consisting of the master switch and an emergency stop with power being supplied by one of the batteries. When both of the switches are closed, 12 V is supplied to each of the four relays, thereby switching them on and allowing power to each of the motor drivers. When either the emergency stop or master switch is open, all of the relays are off, and power to the drivers is cut off.

Each of the motor drivers was also wired to a respective motor. Each motor driver receives 24 V from the batteries and may use that power to drive a motor forward, backward, and at different speeds as determined by the software. Each of the motor drivers is controlled by signals from the ESP32. The ESP32 is powered by 5 V, which was achieved using a 5 V step-down converter wired to one of the 12 V batteries. The circuit powering the ESP32 is also wired in series with the master switch so that the ESP32 is off when the master switch is open. Figure 5 below shows the rear end of the snowplow chassis, showing the current placement of the e-stop (to be moved to the acrylic box, with a 20cm diameter circle before further testing).

Figure 5: The rear end of the snowplow chassis

Problems encountered while building the electrical system were minimal compared to the problems involved with making the mechanical components. The built-in voltmeter stops working early into testing the electrical system, but this component was not necessary as the team was able to test voltage using a voltmeter on hand. The most major issue was that some of the motor drivers which were installed were faulty, but this was addressed with some troubleshooting and replacement of the bad drivers.

The next steps for the electrical system are primarily to streamline and add protection to all of the cables. In its current state, the snowplow uses an excessive amount of cables and which have been set up in an unorganized fashion. The multiple jumper cables connecting the batteries in series can be swapped for a single suitable jumper cable and all connectors can be soldered to ensure a reliable connection. The numerous jumpers attached to the batteries can also be swapped with single high gauge jumpers, and block connectors can be used to split these into smaller cables at the points where power needs to be distributed. Any bundled wires can be wrapped with a sleeve to ensure longevity. The individual motor drivers can also be rewired to the ESP32 directly, rather than through an intermediate board.

3 Communication Systems

3.1 Robotics Framework

The following Tools/Software are used for tracking:

- Dual Frequency (or Multi-Band) RTK from NavSpark NS-HP-GN2
- 2 Heltec Lora 32 (Long Range) 915Mhz version
- NMEA and RTCM software

The NS-HP-GN2 is compatible with GPS L1/L2C, Beidou B1I/B2I, Galileo E1/E5b, GLONASS L1/L2, thus giving more accuracy and more tolerance for signal blockage. The RTK receiver can send an error correction signal up to 10Hz. The Heltec Lora 32 is used to communicate the error correction sent from the RTK receiver on the snowplow and the GPS receiver located at the base station. Also, the Heltic Lora32 has two-way communication between Wifi and LoRaWAN software which can be used to track objects in the area of operation
Also, the model used for tracking is both economical and easy to use.

3.2 Hardware Communication

The communication between hardware can be summarized in the following diagram. Both a GPS module and a Lidar module are connected to an NVIDIA Jetson Nano to provide both the location and distance to other objects of the snowplow. The Jetson Nano then communicates with the ESP32 microcontroller. The ESP32 communicates with 4 separate H-Bridges to send input to the 4 individual DC brushed motors. The entire setup is powered by 2 120Ah marine deep cycle batteries. Figure 6 below shows an overview of the mechatronics system used for the snowplow.

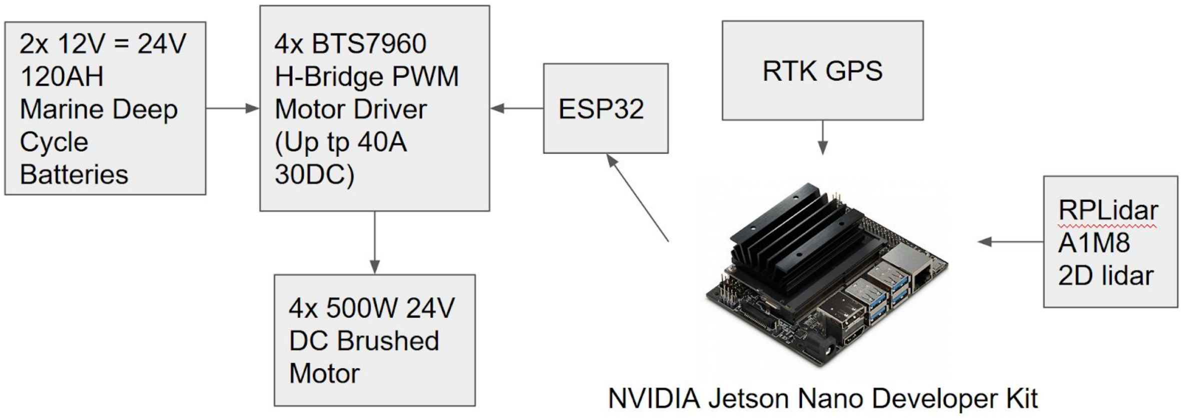

Figure 6: An overview of the mechatronics system used for the snowplow

3.3 Localization and Path Plan

Figure 7 below shows an overview of the snowplow path navigation during competition.

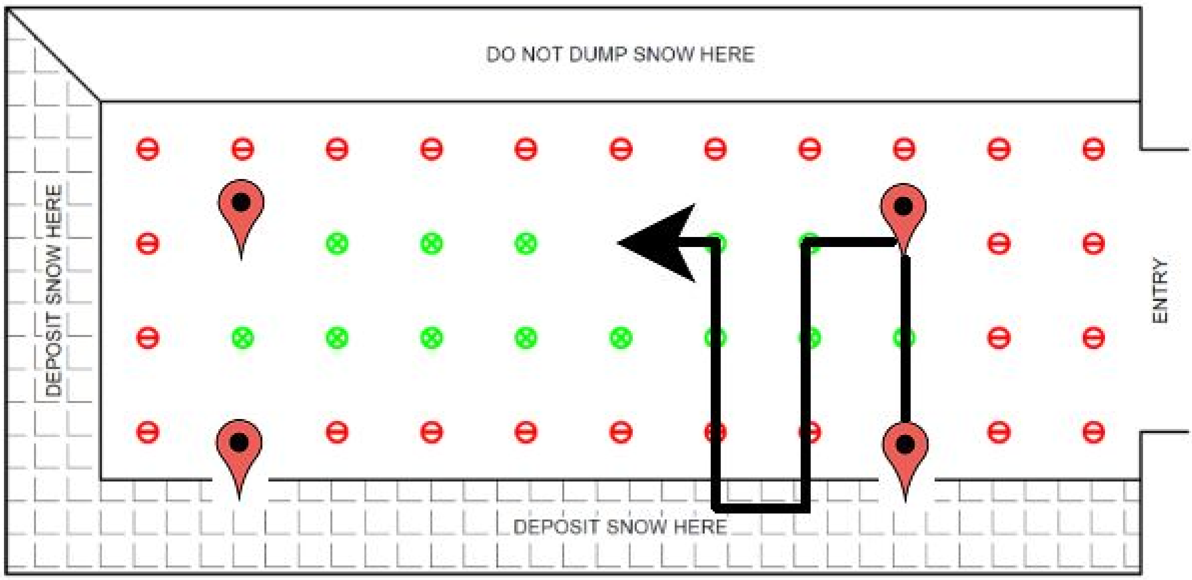

Figure 7: Overview of the snowplow path navigation during competition

The 4 points designated above represent the geofence which will be used during the mission. The snow will be deposited in the indicated area by using an algorithm-generated within the geofence. For each cycle (generated by the algorithm), the snowplow will collect the snow when traveling northbound and will keep the snow contained while turning, where it will deposit the snow in the designated area after traveling southbound. This will repeat the entire path generated by the algorithm that has been traveled, in turn, depositing all of the snow in the designated area.

4 Vehicle Design and Dimension

Even though no cost constraints are enforced by the competition committee, the monetary resources from the sponsors are finite. Thus the vehicle design needs to be cost-efficient but without making sacrifices on key parts of the design. Note that the verbal estimation given to the sponsors for the vehicle design was between $2000-$3000 CAD.

4.1 Main Body Design

Based on the principle of keeping it simple, the chassis of the vehicle was mainly constructed with durable and easy to construct materials.

First, the main supporting frame of the base was built with two aluminum square extrusions and two Steel angle irons with approximately 1 x 2 x 27 inch dimensions, combined with two other Steel angle irons with approximately 1 x 1 x 24 inch dimensions. Together they form a rectangular skeleton in order for other features to be mounted. The aluminum extrusions and steel irons with 27 inch length were placed in the length direction, while the other 24 inch length steel irons run in the width direction.

In general, for the main supporting frame, metal was always selected as the preferred material due to its durability, strength, and weight. It is always good to add more weight to the vehicle as it helps to increase traction, which is essential for snow vehicles. In addition, the weight constraint was set to be 400kg, a quite generous amount.

For the initial design, two 24 x 3.5 inch aluminum shovels were combined and attached to the front steel iron, as these will be used as the snow shovels for the vehicle. In the middle section along the length direction, eight 2 x 2 x 4 inch steel angle irons were used to form two square slots in order to mount the two marine batteries. The selection of the mounting area for the battery helps to provide accessibility for all four wheels mounted on the side of the vehicle, while also helping to keep the center of weight more towards the middle section of the vehicle, increasing the stability.

In the front section of the battery region, an 20 x 9 inch rectangular acrylic plate was mounted to form the platform for attaching the Nvidia Jetson Nano controller and the Raspberry Pi camera system to form the position control system. In the section behind the battery region, another 20 x 9 inch rectangular acrylic plate was affixed to provide a platform for installing H-bridges and the controller unit for the motors, as well as the manual emergency E-stop button. The system in the back region was raised up to a height to make the E-stop more accessible and ergonomic for the users, which is necessary as mentioned in the safety constraint. A preliminary CAD model of the vehicle is shown below in Figure 8.

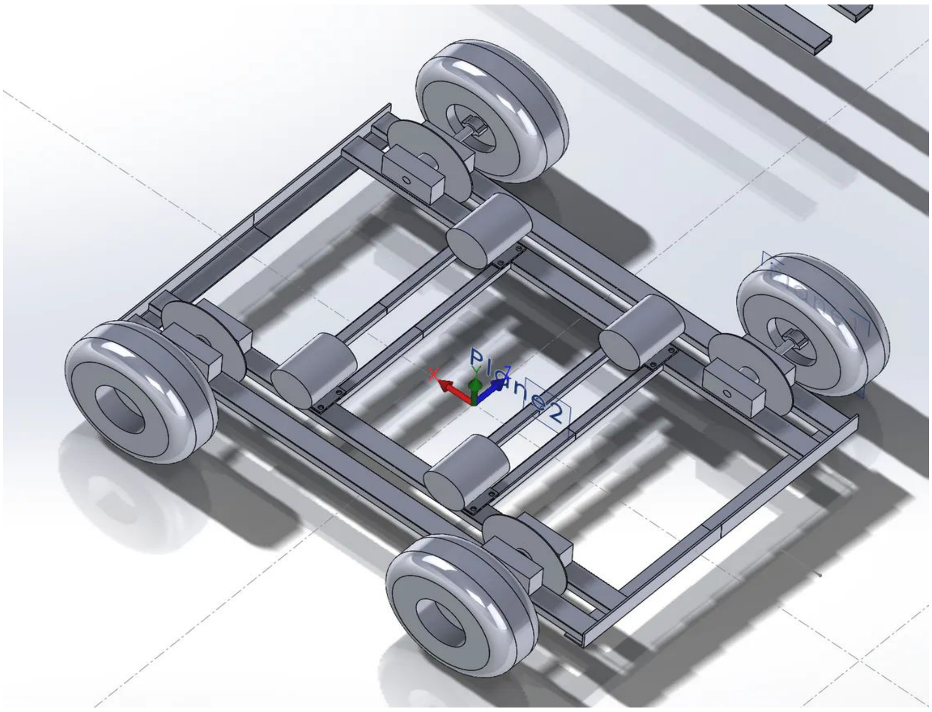

Figure 8: Preliminary CAD model showing the outlining structure of the snowplow

4.2 Weather Resistance System

Due to the possible wide range of outdoor conditions, such as wind and rain, the vehicle must be able to withstand, a robust weather resisting system will be implemented onto the vehicle in the future.

The simple solution the team came up for the system is to install acrylic boards all around the frame, forming a box that encloses all the hardware and software systems onboard of the vehicle. Gaps near the edges and fasteners will be closed off using silicone caulking.

The team decided to use acrylic boards because they are low cost, easy to assemble and easy to obtain from local sources. Acrylic boards can be transparent, which is necessary for the Raspberry Pi Camera system in the front section of the vehicle. As a material, acrylic is often used for outdoor projects such as panels for shed windows and greenhouses. Amongst all other general-purpose plastics, acrylic is one of the best in terms of weather resistance as it can withstand high levels of UV light exposures, it is resistant to corrosion caused by regular contact of saltwater, and it doesn't become more fragile in a cold climate. All of the factors make acrylic a great material for the weather resisting protection for the vehicle.

In addition, the acrylic boards installed on the vehicle provides plenty of space to clearly display the team name and sponsors' names. The vehicle's mainframe will also be painted with bright colours to help distinguish the vehicle in the course of the competition.

4.3 Maximum Vehicle Dimensions

With the majority of the components assembled, the maximum dimension for the vehicle in the length direction includes snow shovel combined with the mainframe, and it was measured to be approximately 30.5 inch (0.775m). The maximum dimension in the width direction includes the mainframe combined with the width of the wheels (two wheels on each side of the vehicle), and it was measured to be approximately 33.0 inch (0.838m). Height wise, the maximum point will be the acrylic board roof which covers all the components aboard the vehicle and has a height of approximately 20.0 inch (0.508m) from the ground. Evidently, all three dimensions (0.775m x 0.838m x 0.508m) are well within the bounds of the maximum constraint of vehicle dimensions listed by the CONOPS (1.5m x 2m x 1.5m).

5 Roles and Responsibilities

Nicholas Schmidt is the team lead and is responsible for overseeing all activities taken by team members as well as coordinating and delegating tasks. Nicholas also takes charge of managing the team's budget and primary source of income.

Christopher Kuehl is responsible for mechanical design as well as the initial circuitry setup. His secondary tasks include professional photography of major events and milestones throughout the project's development.

Benjamin Mclean is responsible for the electrical design (drawings and diagrams) and mechanical design of the frame, gear assemblies, and hub manufacturing. He is also assisting in propulsion system installment.

Thomas Alkhoury and Samarth Saxena are responsible for electrical circuit configuration and software development for object detection and clearing the snow on the track. They are also leading in software implementation and programming of the ESP32.

Gary Li Is responsible for assisting in the development of the propulsion system and in assisting in mechanical design and plow design.

Joshua Sweig is responsible for assisting in mechanical design as well as in managing the secondary sources of income and sponsorship by reaching out to local companies for support.

Zohaib Ali is responsible for assisting in the mechanical design of the chassis and in assisting in organizing weekly meetings to take meeting minutes.

6 Safety Aspects of the vehicle

As for safety measures, the team wanted to ensure that there were three mechanisms in place to shut off the snowplow in case of emergency (as described in detail in section 1):

- Mechanical shut-off via the e-stop button
- Remote shut-off for a person monitoring the system
- Software shut-off if the system detects a situation where this is needed

The full-scale snowplow made use of a car fuse box, which would require an e-stop to be disengaged in order for all the relays to switch on and allow current to run from the batteries, and through to the motor drivers and motors (depending on the control signal).

7 Used Frequencies

The only radio frequencies required for the vehicle arises from the wireless e-stop which will be implemented in the future. The wireless e-stop controller will use a 2.4GHz radio frequency to control the shut-off system.

Conclusion

In conclusion, the team has a simple and cost-effective solution for a snowplow that automates the snow removal process. There are three safety mechanisms in place: a manual e-stop, a remote e-stop, and a software e-stop. The snowplow uses a steel frame with many parts that can be found locally in Ottawa. Four electric motors drive the wheels and help provide traction. An RTK-GPS and camera are the primary sensors used for object detection, localization, and navigation. An NVIDIA Jetson Nano handles all the sensor processing and sends drive signals to the ESP32, which drives the motors. The motors draw current from two deep cycle marine batteries, which supply 24V together in series. An acrylic box body will cover the chassis. Currently, a small team of 8 members is responsible for the project. Figure 9 below shows the testing of the snowplow during January 2020.

Figure 9: Testing session with the snowplow in without the acrylic body