

# Autonomous refuelling mission in subarctic conditions

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## Abstract

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## 1 Introduction

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\*Use footnote for providing further information about author (webpage, alternative address). Acknowledgments to funding agencies should go in the **Acknowledgments** section at the end of the paper.

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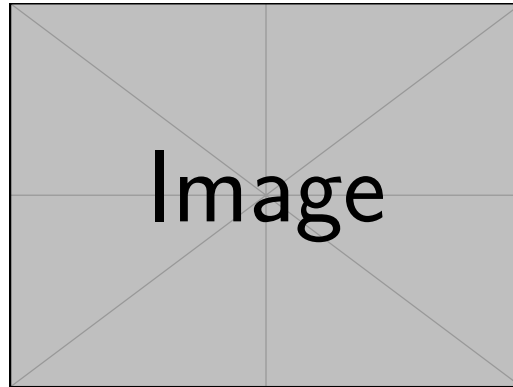


Figure 1: Warthog driving / Aerial shot of the different paths

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## 2 Related work

### 2.1 Robotic deployments in snow

To our knowledge, few robots have been deployed in harsh winter environments. Dante II is a 900 kg tethered legged robot, which conducted a 5-day, 165 m descent into the Mount Spurr Volcano, in Alaska (Bares & Wettergreen, 1999). During this deployment, Dante II reached speeds upwards to 0.011 m/s during the descent. A two-axis lidar was used to create a local elevation map around the robot in order to conduct autonomous navigation.

Nomad is a gasoline-powered 725 kg unmanned ground vehicle (UGV), was deployed at Elephant Moraine, Antarctica for a duration of 4 weeks (Apostolopoulos et al., 2000). The robot reached speeds upwards of 0.5 m/s while using differential-Global Positioning System (GPS) as the primary method of localization. The platform also used stereo cameras and a lidar sensor for obstacle detection, although stereo vision was found to be ineffective on blue ice and snow in Antarctica due to extreme lack of texture (Moorehead, Simmons, Apostolopoulos, & Whittaker, 1999). Roll/pitch/yaw sensors were also added to the robot to make it cognizant to hazardous terrain. Nomad achieved its initial goal to identify meteorites autonomously in Antarctica at a search rate of  $160 \text{ m}^2/\text{h}$ .

MARVIN I and MARVIN II are two diesel-powered Skid-steering mobile robots (SSMRs) weighing 720 kg were deployed in Greenland (Stansbury, Akers, Harmon, & Agah, 2004) and Antarctica (Gifford, Akers, Stansbury, & Agah, 2009) respectively. The goal of these robots was to increase survey safety in remote polar regions and large sensor payloads led to the selection of large vehicles. Both vehicles used Real-time Kinematics (RTK) GPS as primary method, achieving a centimeter-level accuracy. They also used a lidar sensor for obstacle detection and a gyroscope and inclinometer were used to provide the robot's pitch and roll angles. Skid-steer turns often caused MARVIN I to get immobilized in snow and its transmission eventually broke down during operation. MARVIN II thus incorporated design improvements to the hydrostatic drive and track systems to increase its durability.

Sno-mote Mk1 and Mk2 are dual-drive 1:10 scale snowmobiles equipped with a single camera and GPS antenna were deployed on Alaskan glaciers and Wapekoneta, Ohio (Williams & Howard, 2009). These robots were used to conduct manually-driven traverses of about 100 m at a speed of 1 m/s. The data gathered with the Sno-motes was then used to improve visual Simultaneous Localization and Mapping (SLAM) feature extraction methods in snow. Despite improving feature detection methods on snow, it was shown that snow is still feature-sparse (Williams & Howard, 2009). Through this work, improvements were also done on slope estimation (Williams & Howard, 2010) and horizon line estimation (Williams & Howard, 2011).

Yeti is a battery-powered 81 kg UGV in Antarctica and Greenland (Lever et al., 2013). Yeti was used to conduct ground penetrating radar (GPR) surveys in order to detect subsurface crevasses or other voids to increase vehicle travel safety in remote polar environments. Since polar terrain is largely obstacle-free and the effort required to provide reliable obstacle detection on low-contrast snowfields is considerable, Yeti drove "blind", relying only on GPS waypoint following. During surveys, Yeti reached a top speed of 2.2 m/s and managed to acquire data on hundreds of crevasse encounters and even locate a previously undetected buried building in the South Pole.

A Clearpath Robotics Grizzly, a battery- and gasoline-powered SSMR was deployed during winter on the University of Toronto Institute for Aerospace Studies (UTIAS) campus, in Ontario, Canada (Paton, Pomerleau, MacTavish, Ostafew, & Barfoot, 2017). Only stereo cameras were used through a visual SLAM algorithm to localize the robot during autonomous teach-and-repeat runs. Path tracking was accomplished using a Model Predictive Control (MPC) algorithm. A 250 m path was successfully repeated on an light snow cover 3 hours after it was first manually driven. However, deep snow path-following provided unsatisfactory results due to features almost only being observed on the horizon, leading to inaccurate pose estimates, which caused

issues for the path tracker. Furthermore, vehicle tracks that constantly change when driven over lead to an increased pose estimation error.

A full-scale battery-powered Toyota Prius was deployed during winter on roads in Massachusetts, USA (Ort, Gilitschenski, & Rus, 2020). Localization was accomplished using a custom-designed localizing GPR. A prior mapping must be conducted during which the driven is driven by a human operator and the vehicle's sensor data is recorded, the saved map can then allow the vehicle to localize within this area. The GPR location information is then probabilistically fused with wheel odometry and inertial measurement unit (IMU) measurements to provide accurate vehicle localization. Path tracking is accomplished through the use of a Pure Pursuit controller, specifically designed for Ackermann steered autonomous vehicles. The system showed similar performance in localization accuracy (0.34m to 0.39m) and cross-track error (0.26m to 0.29m) between clear weather and snow-covered road. The localizing GPR sensor's measurement range depends on the width of the array, meaning the system cannot be easily miniaturized, which means it was mounted on the rear of the vehicle, at 32 cm above the ground. This sensor size and mounting requirement could lead to decreased performance in deep snow or in off-road environments.

## 2.2 Relative navigation

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## 3 System description

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**3.1 Hardware description**

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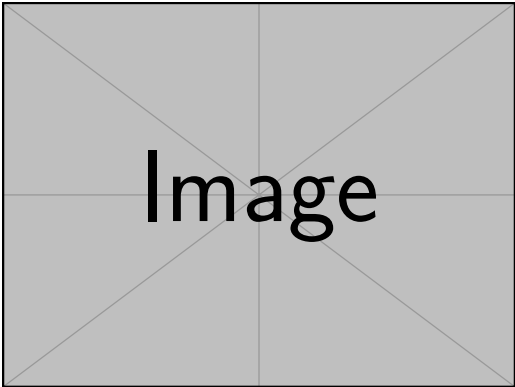


Figure 2: Warthog figure, pointing to every sensor.

**3.2 Lidar teach-and-repeat**

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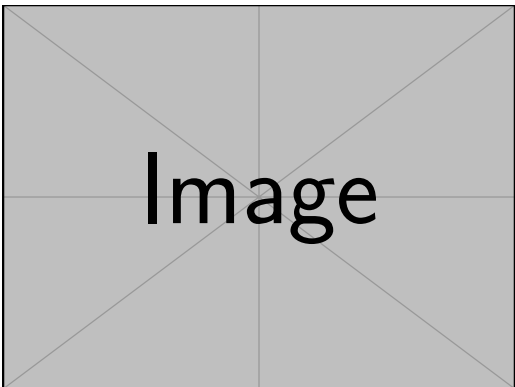


Figure 3: Flowchart for LTR

3.2.1 Iterative closest point

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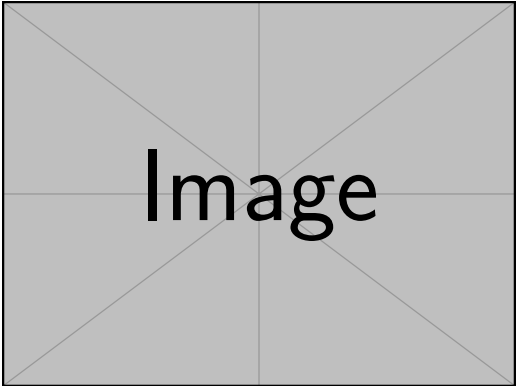


Figure 4: Figure explaining Simon-Pierre’s tiled mapping framework

3.2.2 Path following

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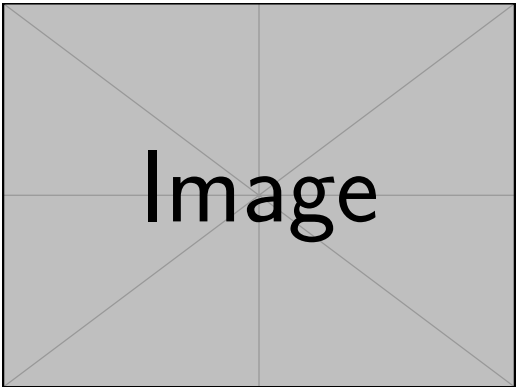


Figure 5: Figure explaining Differential orthogonal-exponential controller

## 4 Environment

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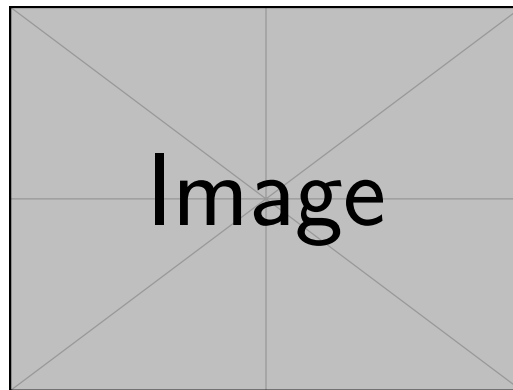


Figure 6: Johann's various runs and meteo figure

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## 5 Results

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Table 1: Teach and repeat runs table

	$k_g$	$k_o$	$c_3$	$c_4$	$c_5$
Careful/Sparse	0.334	0.597	1.101	9.621	8.170
Careful/Dense	3.124	3.195	1.094	5.899	7.318
Aggressive/Sparse	0.840	9.153	2.853	8.274	0.187
Aggressive/Dense	4.838	2.841	0.670	7.952	0.386
Hand-Tuned	0.767	0.060	0.340	2.000	0.250

## 5.1 Localization

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### 5.1.1 Vision-based

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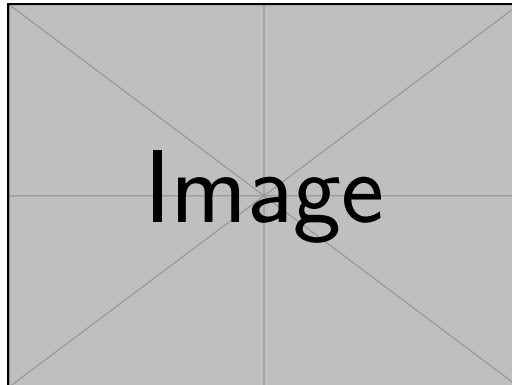


Figure 7: Olivier's over and under exposition figure for cameras



### 5.1.2 GNSS

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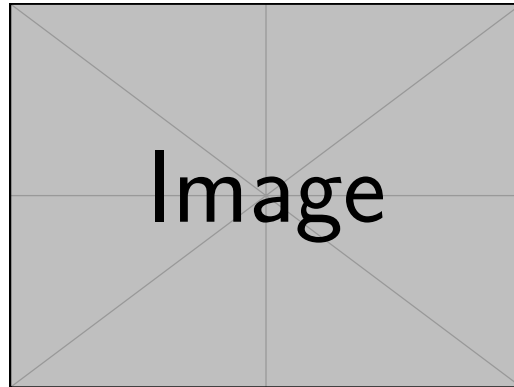


Figure 8: Maxime's GNSS error figure

### 5.1.3 ICP

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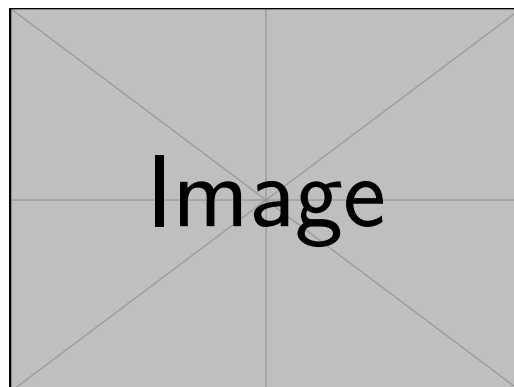


Figure 9: Figure explaining ICP error for every run (correlated with meteo).

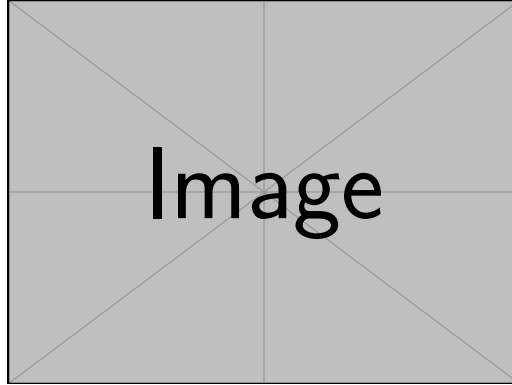


Figure 10: Figure explaining special cases when mapping needed to be enabled.

## 5.2 Motion and control

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### 5.2.1 Path following error

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### 5.2.2 Command error and power consumption

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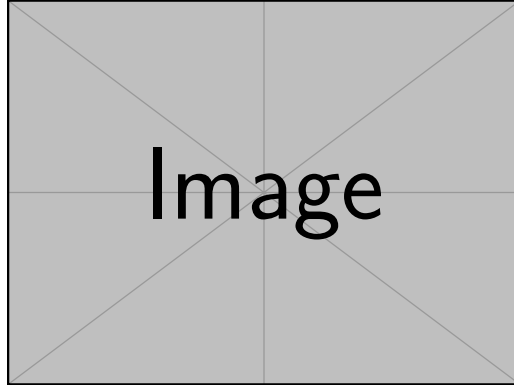


Figure 11: Dominic's path following error figure

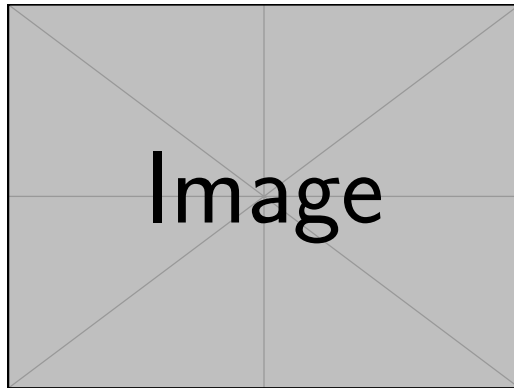


Figure 12: Power consumption / motion efficiency figure.

## 6 Lessons learned

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## 7 Conclusion

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## Acknowledgments

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