AUTONOMOUS ROVER FOR POLAR SCIENCE SUPPORT AND REMOTE SENSING

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ABSTRACT

This paper reports outcomes of recent field deployments of the solar-powered *Cool Robot*, which was developed as an autonomous platform for towing or carrying scientific instruments in Greenland and Antarctica. This simple 70-kg four-wheel drive, solar-electric vehicle executes autonomous surveys via GPS waypoint following, while towing or carrying payloads of over 40 kg. *Cool Robot* conducted over 175 km of autonomous surveys to study atmospheric chemistry at the snow-air interface in the vicinity of Summit camp. The robot also conducted local grid surveys of the Summit ice layer in order to evaluate the potential of using ground penetrating radar to estimate the density of melt channels in the ice layer. Our key objectives were to demonstrate the operational value of a rover to locate subsurface features and the use of autonomous rovers in collecting scientific data from long-duration surveys. The *Cool Robot* operated reliably at −30 C, and demonstrated good oversnow mobility and adequate GPS accuracy for waypoint-following on a 5-10 meter grid. The deployment results demonstrate that autonomous vehicles have great potential to improve the efficiency of polar science.

Index Terms**—** Remote sensing, autonomous polar robots

1. INTRODUCTION

The *Cool Robot* is an autonomous solar-powered mobile robot designed to serve as a roving platform for measuring spatial-temporal phenomena in polar regions. Its original design, development, and performance are described in [1-3]. In this project, we extended the performance and improved human factors in operation of the power, control, and communications systems for reliable, long-duration summertime deployment over polar snowfields, and we integrated scientific instrument payloads. Instrument payloads were developed to measure snow-surface characteristics, and to sample near-surface atmospheric pollutants, with the payload towed on a sled behind the robot (See Figure 1). We also developed a physical and user interface between instruments and the robot, such that the robot stops at established waypoints, or at specified time or distance intervals to sample and log data, and/or to communicate data to a base station when requested. We conducted validation tests demonstrating over-snow performance and cost-effective expansion of range and duration of Polar science campaigns.

2. ROBOT DESIGN FEATURES

The *Cool Robot* is comprised of a rigid, lightweight four-wheel drive chassis with power provided by a solar-panel box with panels on four sides and the top. Its operating speed is approximately 3 km/h and it is programmed to be operated either manually, through a radio link, or

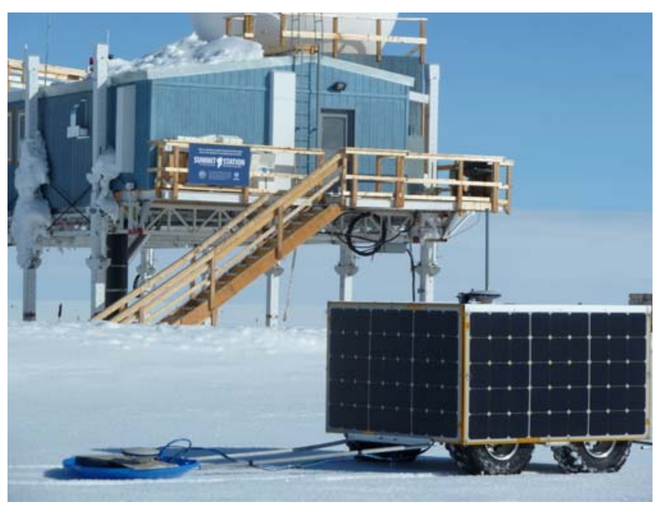

Fig. 1. *Cool Robot* towing ground-penetrating radar near Big House at Summit Station, Greenland, in June 2013. (Photo courtesy of Tom Holford)

autonomously through GPS waypoint following. The original solar panel box, described in [1-3] provided a peak power of ~300 W for diffuse-sky radiation, r = 0 on May 21 or July 21 at 80 degrees North latitude. The solar panel box was redesigned to increase peak power and reduce robot height, increasing the wind tip-over speed. The revised solar power design and analysis, detailed in [4], shows that the solar power system can meet the power demands of the robot continually at 80 degrees north or south latitude from one month before to one month after solstice, with excess power available. Figure 2 shows the Diurnal variation of solar-power for *Cool Robot* in Greenland using the new solar panel box for diffuse-sky radiation, r = 1, .5, and 0. The power required to travel at half of its maximum speed is ~120 W, and its full-speed power is just over 200 W. The new solar panel box has a peak power of 455W, and excess power over that required is available for at least half of each day at the edges of the field season – May 21 and July 21 in order to charge batteries while the robot remains in motion. The revised design streamlines the solar panel box providing a 33% reduction in mass and a wind tip-over speed of 30 m/s, well over the maximum recorded summer wind speed at Summit of 22 m/s.

The solar panel box is a unique feature of the *Cool Robot* and without it, long duration, zero emissions, autonomous science campaigns are not feasible. The original box was difficult to assemble and attach to the chassis, and once attached, the user was not able to access the electronics or payload inside the robot chassis or panel box. The new solar panel box is designed the user can access the interior of the robot and collect data when needed. It has two hinged side panels that attach to the neighboring side panels with quick release pins from outside the box and allow access to both sides once mounted. Additional instrument payload space exists between the chassis and solar panel box. Figure 3 shows the panel box with a side panel hinged for access to

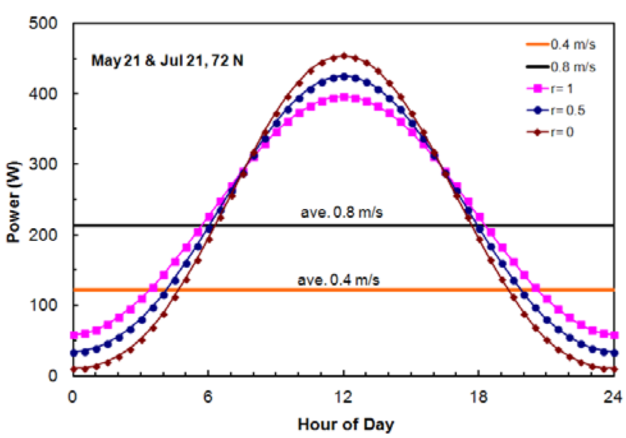

Figure 2 Diurnal variation of solar-power for *Cool Robot* in Greenland using the new solar panel box for diffuse-sky radiation, r = 1, .5, and 0, correspond to no diffusion, half diffuse, and all diffuse.

Figure 3 Access to interior of solar box by hinged mechanism.

the instruments mounted on top of the chassis.

3. INSTRUMENTATION

An aerosol instrument package was developed by the Univ. of New Hampshire and includes an optical particle counter and an aethalometer integrated into an environmental enclosure with GPS, data logger, and battery pack. The interface to the package is comprised of a laptop that is programmed through a GUI to specify sampling protocols for the payload. It allows a user to select stopping intervals for sampling by time, distance, or specified waypoints, or the user can specify continuous sampling. While the robot also can provide up to 20 W of 12 V power to instruments, the nature of some instruments within the aerosol package is that the manufacturer provides only a self-contained instrument, with its own flash memory for data storage and its own power. The optical particle counter and GPS location of each measurement are recorded to the data logger, while the aethalometer, owing to the nature of this OEM instrument, has its own data storage device and power.

Two ground penetrating radar (GPR) units – a 900 MHz GSSI SIR 3000 and a 0.5-5 GHz experimental radar from the Univ. of Kansas CRESIS were deployed to measure firn features in the top layer (approx. one meter) in the vicinity of the camp. These instruments were used to survey melt channels discovered in 2012 in order to sample their distribution and density.

4. 2013 FIELD DEPLOYMENT

The *Cool Robot* executed over 200 km of autonomous driving (programmed survey patterns plus autonomous staging/recovery) over natural snow at air temperatures ranging -11ºC to -26ºC during a three week deployment in June 2013. Typical rut depths were 5 ± 2 cm, and only four immobilizations occurred (a struck, partially buried bamboo pole and three sharp turns attempted at slow speed during low-power mode). Otherwise, robot operation was extremely reliable throughout the tests. Figure 4 shows the combined tracks of all deployments conducted during the three-week deployment data. The “fan” surveys were conducted to follow the direction of the station plume while towing the aerosol instrument package. The four smaller spots are local grid surveys conducted while towing the 900 MHz ground penetrating radar. Remaining tracks are from “box” surveys while towing the aerosol package.

The rover completed five autonomous grid surveys (typically 100-m x 100-m) while towing the 900 MHz SIR 3000 ground-penetrating radar (GPR) to study the physics of melt water percolation through snow and firn in dry snow zones due to 2012 melt-freeze events at Summit. During three of these surveys, we followed the rover with a snowmobile towing a large 0.5 – 5 GHz CRESIS radar to compare the capabilities of the two radars. We dug two snowpits to ground-truth the radar data. Figures 5 – 7 show a sample of a survey grid, along with a sample radar image and ground-truth photograph of a flow channel from one of the two snowpits.

The *Cool Robot* autonomously executed seven lengthy air-sampling surveys (four box surveys north of the skiway and three triangular/fan surveys along the direction of the station’s emissions plume ranging in distance from 12.3 - 42.7 km and in time from 4.3 – 22.4 hours). The towed instruments included samplers for particulates and carbon black described above. All data from the GPR and air-sampling payloads are geo-referenced using synchronized

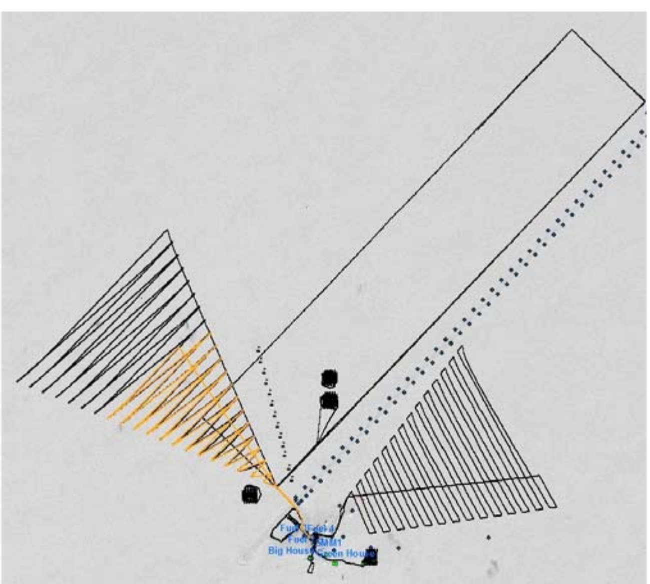

Figure 4. GPS tracks of all *Cool Robot* deployments at Summit Station during June 2013. The dense black grids were 100-m x 100-m GPR surveys; the larger box (4.8 km x 0.9 km) and triangular patterns were air-sampling surveys, often extending overnight.

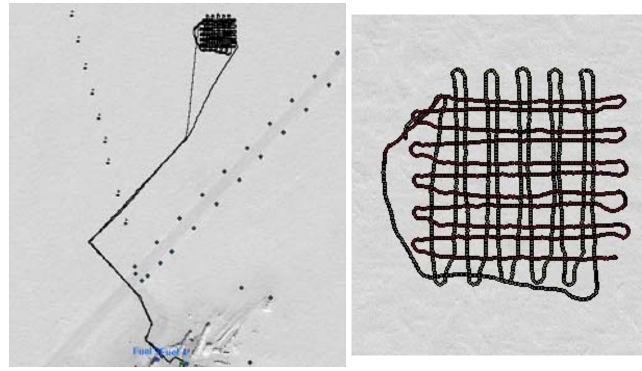

Figure 5. 100 m x 100 m GPR Grid3 (10-m line spacing) executed autonomously on 20 Jun 13, including autonomous staging and return to camp (upper). Total distance was 5.5 km and no immobilizations occurred. Close-up of robot’s GPS track shows reasonable grid geometry despite relatively small extent of survey. HDOP was 0.6 – 0.7 m on 18 – 21 satellites.

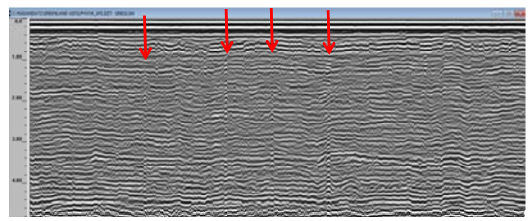

Figure 6. Segment of 900 MHz GPR record from Grid3 revealing possible signatures from 2012 horizontal snowmelt layer and underlying vertical drainage channels (arrows). Geo-referencing of the drainage channels will allow mapping of their spatial distribution.

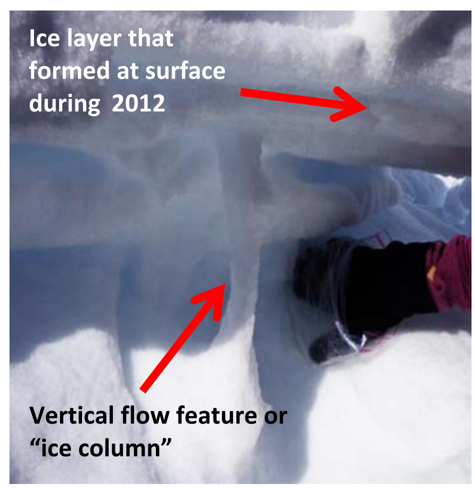

Figure 7. Snowpit-1 in undisturbed snow reveals 2012 melt layer at ~ 0.6-m depth and refrozen drainage tubes below it (the one here measured ~ 5 – 9 cm dia). Subsequent gridded GPR surveys attempted to map the distribution of the 2012 drainage channels.

GPS track files. Figure 8 shows sample processed data from a 24 hour survey June 24-25, 2013. The robot was stationary and nominally under the station's plume from 22:18 – 09:30 WGDT (00:18 – 11:30 GMT). The station was initially operating on its backup generator then switched to its primary generator at ~ 9:00 WGDT (11:00 GMT). The pulse counts changed abruptly at that time.

Solar power was sufficient to meet the rover's mobility and housekeeping requirements (~ 225 W) during all but a few hours around midnight. The rover autonomously slowed down or stopped during low-solar periods and resumed when solar input increased. A planned battery upgrade and simple algorithm changes (turn rate scaled with forward speed) are expected to eliminate the minor problems encountered and extend reliable autonomous operations to full 24 hours during most Polar summer conditions. Although towed science payloads were light (max 41 lb) the rover was able to tow the CRESIS radar (~ 300 lb) near camp. It should have little trouble towing up to 100 lb of science instruments over snow conditions similar to those encountered at Summit. *Cool Robot* is ready to conduct ever more ambitious autonomous surveys to support Polar science campaigns.

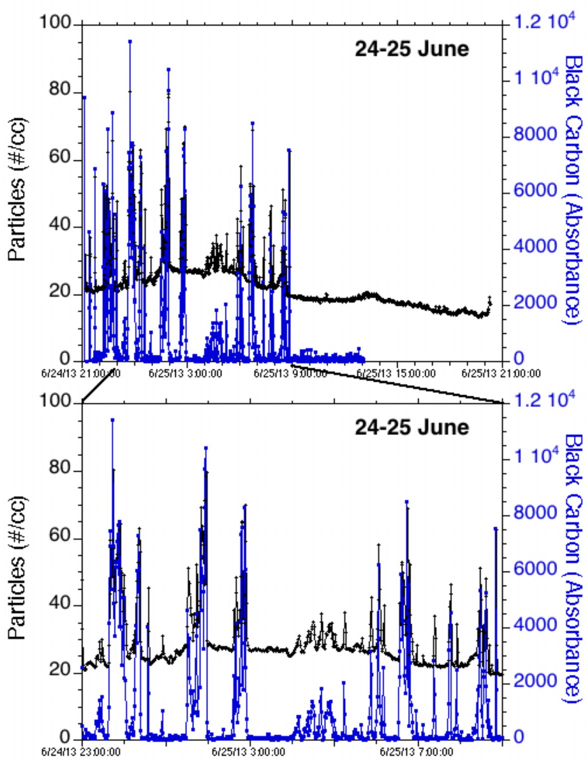

Figure 8 Sample of processed data showing particle count per cc and black carbon absorbance for a nearly 24-hour overnight run from 19:34 to 17:50 WGDT (21:34 to 19:50 GMT) 24-25 June 2013.

5. CONCLUSION

The *Cool Robot* supports long duration, autonomous science campaigns in polar regions through a unique low-profile solar-powered design coupled with simple navigation software and a user interface that allows flexible selection of sampling protocols. The robot successfully completed a 200-km, three week field campaign near Summit Greenland in June 2013 and is available for use by other science teams.

ACKNOWLEDGEMENT

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