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An Unmanned Tracked Vehicle for Snow Research Applications

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ABSTRACT

Lightweight robotic vehicles can be designed for over-snow mobility to carry out a variety of snow and glacier related studies like carrying out ground penetrating radar and global positioning system surveys, collecting snow samples, and carrying out sub-surface experiments on terrain that are dangerous for human movement. Sinkage, resistance to snow compaction, loss of traction and ingestion of snow into the driving system are some of the challenges that an unmanned lightweight tracked vehicle faces in snowbound terrain. In present work, a lightweight and unmanned remotely operated vehicle (ROV) is conceptualized and developed as a technological solution. In this study, design and features of this vehicle, named HimBot, are presented along with the results obtained from tests carried over snow at one of the field research stations of SASE. The outcome of this work will help in developing an optimised design of an ROV for over-snow mobility for a variety of applications.

Keywords: Unmanned tracked vehicle; Sinkage; Compaction; Traction; Remote-controlled

1. INTRODUCTION

Avalanche activity is a common feature in the snow bound regions of Himalayas, causing the loss of many precious lives of troops and civil population as well as property worth millions every year. For evaluation of avalanche danger, real-time snow and meteorological data is required. Therefore, scientists of SASE conduct regular field experiments on the slopes of snow laden mountains in winter season and snow-met parameters are continuously monitored and recorded. At times, these activities become dangerous and impractical due to looming avalanche threats. It seems that a safer way of acquiring experimental data in the field is by using lightweight remote controlled unmanned ground vehicles. These robotic vehicles can be used for conducting GPR surveys of cracks and crevasses over ice crusts that cannot support foot travel, collecting snow samples and carrying out sub-surface experiments with penetrometers, GPS mapping of avalanche debris, assisting in avalanche victim search and rescue operations, etc. without endangering precious human lives.

Snow covered terrain poses many challenges for small and lightweight ground vehicles[1]. Sinking in snow, resisting to compaction of snow, losing traction and snow entering into the driving system are a few to name[1]. The mobility of wheeled vehicles is limited by deep snow where the snow depth is greater than about twice the ground clearance of the vehicle. For mobility of tracked vehicles over deep snow, Mellor[2] suggested that the vehicle should have ground pressure less than about 7 kPa.

A ground vehicle with smaller ground clearance will encounter deep sinkage and will fail to gain support from the underlying snow surface. By designing a vehicle with low track pressure (<1.5 kPa), more support from the underlying snow cover can be obtained[3]. However, with such a design skid-steering becomes very difficult as the outward track tends to loose traction if the vehicle makes a turn. Better solutions to drive lightweight vehicles over deep snow are to use shorter tracks or use articulated chassis.

A small and lightweight unmanned remotely operated vehicle, the HimBot, was conceptualised and designed by Snow and Avalanche Study Establishment (SASE) to overcome the challenges of over-snow mobility. In addition to its capability of over-snow mobility, this vehicle also harbors various payloads. These features make it a unique lightweight remotely operated vehicle which can be used for snow studies. The HimBot may prove helpful in reconnaissance and evaluation of avalanche danger and many other snow study applications. This paper discusses the design of the vehicle as per existing guidelines and brings forth the results from tests carried out at one of SASE's field research station at Solang Nullah, Himachal Pradesh, India.

2. REVIEW OF UNMANNED GROUND VEHICLES

Task-specific designs of unmanned ground vehicles for extreme climate have been developed over the time. Carnegie Mellon University, USA designed a gasoline driven vehicle called NOMAD[4] which was used to find and classify meteorites in Antarctica. It weighed approx. 725 kg and had a speed of about 0.5 m/s.

University of Kansas is developing robotic vehicles under a project called PRISM to utilise them for measurement of

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thickness of ice-sheets and establish bedrock conditions in Greenland and Antarctica[5,6]. An International team of scientists led by Maho[7] at University of Strasbourg, France has developed a small remote controlled wheeled rover to study the behavior of penguins in Antarctica. The rover was fitted with an RFID device to read the heart-rate monitors, already fitted in the penguins.

Cold Regions Research and Engineering Laboratory (CRREL), USA has designed and developed an autonomous solar driven ground vehicle called, Cool Robot[8], for providing assistance during scientific expeditions in Antarctica and Greenland. The 61 kg vehicle was designed with solar panels fitted on its four sides and at top to maximise utilisation of solar power. CRREL has also developed a low cost, GPS guided and battery-powered unmanned ground vehicle with an articulated chassis called Yeti[9]. It was designed to carry out ground penetrating radar surveys in Polar regions.

Two unmanned tracked vehicles, SnoBot and SnoBot-2, have been designed by CRREL for mobility over deep snow. The tracks distribute the vehicle weight over a large surface area[1] which reduces sinkage in snow. Though these vehicles do not have good ability to negotiate step obstructions, but these are the best designs as far as mobility over deep snow is concerned by a lightweight vehicle.

3. MOTION RESISTANCE

Mobility of a tracked vehicle over snow can be analysed by considering various resistive forces acting against it and possible traction forces to overcome them. Most of the theories developed for design of tracked vehicles for mobility over soil are used for snow mobility problems as well. A tracked vehicle experiences resistance to motion due to compaction of snow in vertically downward direction, compaction in the direction of motion, shearing of snow in front of vehicle and resistance component of self-weight opposite to the direction of motion if it is climbing up on a slope. In subsequent sections, these theories have been briefly discussed.

3.1 Compaction Resistance

The sinkage of a tracked vehicle causes power and traction loss due to elastic or plastic snow deformation. Although the elasticity of material does not cause power loss, but real snow has a combined elastic-plastic character. According to Bekker[10], track may be assumed as a rigid rectangular plate and relationship between track pressure and sinkage in homogeneous soil may be characterised as:

$$p_0 = \left(\frac{k_c}{b} + k_\varphi\right) z^n , \tag{1}$$

where p_0 is track contact pressure, b is width of the contact region, z is the track sinkage depth and n, k_c, k_ϕ are pressure-sinkage parameters. A schematic diagram of a simple tracked vehicle is shown in Fig. 1. Where W is the vehicle's weight, L is the track length in contact with the snow, h_t is the track height, h_b is the height of snow in front of the track, z_0 is the track sinkage depth, R_l is lateral drag and R_b is bulldosing force.

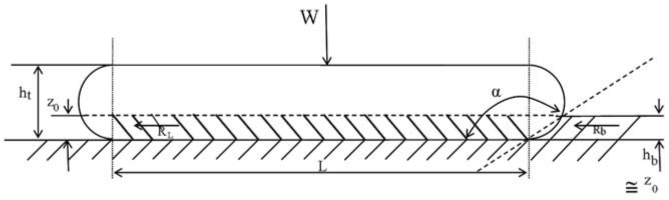

Figure 1. Bulldosing effect.

For a vehicle having enough ground clearance to avoid ploughing of its lower-body, the snow-compaction resistance, R_c, is given by

$$R_c = \frac{z_0}{L} W , \tag{2}$$

3.2 Bulldosing Resistance

When the sinkage z_0 of the vehicle is small compared to the height h_t of the tracks, the frontal area of contact between the snow and the track is small and longitudinal resistance arises mainly from snow compression as the tracks roll over the snow. As z_0 increases relative to the height h_t, there is an increasing drag caused by the bulldosing effect of the frontal portion of the track submerged in the snow to depth h_b.

Bulldosing affects the motion of a tracked vehicle when the vehicle makes a turn, rotating and at the same time moving forward. The rotation requires much more power compared to forward motion, as there is bulldosing along the full length of both tracks. That's why a vehicle with longer track is less manoeuvrable than one with shorter tracks. The deeper the vehicle's sinkage, the bigger the bulldosing force that has to be overcome in the form of lateral resistance.

3.3 Snow Drag

Snow Drag may arise from the drag of the adhering snow mass that penetrates above the track-snow interface. There is shear between the moving and stationary parts of the snow in the area from the snow surface to the depth h_b when the snow is advected by the tracks.

3.4 Rolling Resistance

When the tracked vehicle moves, the tracks and tread elements may deflect and slip at the track-snow interface. The cumulative effect results in rolling resistance.

3.5 Gravitational Resistance

When a tracked vehicle climbs a mountain slope of angle α, the slope adds a resistive component to the vehicle motion proportional to the component of the total weight parallel to the slope. This is called the gravitational resistance R_g and is given as:

$$r_g = W \sin\alpha , \tag{3}$$

Therefore, the total motion resistance that a tracked vehicle may face while moving over snow can be given as the sum of all the above discussed resistive forces.

4. OVER-SNOW MOBILITY PROBLEMS

As a tracked vehicle moves over snow, it has to continuously compact the snow below it to avoid sinkage. If the snow is much deeper than the ground clearance of the vehicle, then it may not be able to compact the snow and sink. If the vehicle sinks to a greater depth, the pressure needed to compact the underlying snow will also increase[11,12]. The lower body of the vehicle will rest over snow and further reduce the vertical force required to develop traction. This will result in the tracks loosing traction while attempting to develop thrust for mobility and the vehicle digging itself deeper into the snow. Even a tracked vehicle having low ground pressure and generating high enough thrust to overcome snow-compaction resistance may result in breaking traction because of shear failure in the snow[1].

Besides mobility problems, snow-covered terrain can also pose other problems for lightweight vehicles. These include performance deterioration of electronic components, batteries and operator as well as ingestion of snow particles into the main controller compartment of the vehicle. Low-temperatures also lead to material failure[13]. Diemand and Lever[14] explain such problems and their solutions.

5. DESIGN DETAILS

5.1 Design Considerations

We have designed the HimBot in accordance to the recommendations given by Lever[1], *et al*., for design of light weight over-snow tracked vehicles. These recommendations are based on the theory of mobility developed by Bekker[10]. The vehicle was designed to be lightweight and have large ground clearance as well as low and uniform ground pressure on the tracks.

Tracked vehicles run over snow in such a way that the frontal part of the tracks are at the snow surface and sinkage increases linearly to a maximum, z_m, at the back. For such case, maximum sinkage is given by

$$z_m = 2\frac{p_0}{k}, \tag{4}$$

where k is pressure-sinkage slope and is equal to 40 kPa/m for relatively uniform and deep seasonal snow. For natural snow variation, an uncertainty of ±30 per cent in this value may be observed.

To satisfy the design guidance that sinkage remains less than the vehicle's ground clearance, it is required that

$$H > 2\frac{p_0}{k}, \tag{5}$$

where H is the ground clearance of the vehicle.

For HimBot the ground clearance comes out to be 15cm considering k as 40 kPa/m. Therefore, the HimBot was designed to have large ground clearance (15 cm) and uniform track pressures below 5 kPa to make sure that sinkage of the vehicle remains less than its ground clearance. Table 1 compares the vehicle parameters of the HimBot with SnoBot and SnoBot-2, developed by CRREL, USA[1]. Weight (W) of the vehicle is taken in Newton (N).

Figure 2 shows a plot of ground clearance of HimBot, SnoBot and SnoBot-2. It can be observed that the HimBot's ground clearance lies on the line with default value of k = 40 kPa/m signifying minimum theoretically permissible ground clearance designed at its weight.

Table 1. Vehicle parameters for the SnoBot, SnoBot-2 and the HimBot

Parameter	SnoBot	SnoBot-2	HimBot
Weight, W (N)	238	144	421
Track width, b (m)	0.127	0.127	0.12
Track length, L (m)	0.616	0.390	0.58
Ground clearance, H (m)	0.154	0.107	0.15
Track gauge, B (m)	0.423	0.425	0.55
Track pressure, p_o (KPa)	1.52	1.45	3.02

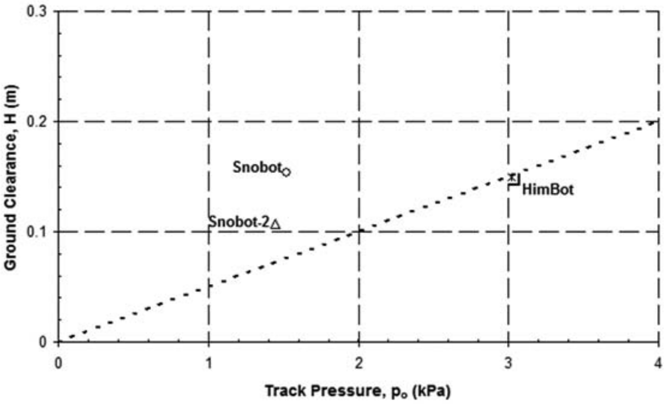

Figure 2. Calculated average sinkage of HimBot, SnoBot and SnoBot-2.

5.2 Construction and Features

The designed robotic vehicle is named HimBot. The vehicle with all the sensors, battery packs and camera weighs approximately 43 kg and measures 67 cm x 67 cm x 24 cm and is 24 cm high with its two tracks which are approximately 67 cm long and 12 cm wide. The chassis and the protective enclosure are made from high grade aluminium alloy. The tracks are made up of special grade rubber that can withstand sub-zero temperatures. The teeth of the tracks protrude out roughly 1.8 cm at 2.5 cm spacing. Each track is supported by three sprocket wheels made of high strength glass filled fibre material. Two motors directly drive the front sprocket wheels on each side of the vehicle.

The HimBot can be controlled remotely within line-of-sight using an all weather custom built analog joystick based remote control unit or by using GUI on a laptop. This feature helps the operator to manoeuvre the vehicle behind small obstacles. The video display on the remote control unit helps in controlling the vehicle behind obstructions. Data communication is done by 2.4 GHz XBee Pro wireless modules at 9600 bps based on ZigBee protocol. The radio, programmable controller and power equipment are all placed inside hermetically sealed compartments in the belly pack of the vehicle.

The vehicle is driven by two 320 W, 130 RPM DC geared motors which are capable of generating approximately 40 Nm torque. Each motor has a position encoder of 0.1 mm resolution. The motors are capable of providing total output power of approximately 0.85 HP. The motors' direction and velocity are controlled by 24 V, 30 Amp motor drivers. All the electronics and locomotion of the vehicle is controlled by one

ATMEGA2560 AVR microcontroller from ATMEL which acts as the main controller.

The vehicle is powered by four lithium polymer battery packs. These batteries are chosen because of their ability to give high discharge current whenever required and improved performance at low temperatures upto - 20 °C. Two separate battery packs are used for locomotion: one for the electronic system and one for the video link, as separate power subsystems improve vehicle's performance and protect its electronic system from the voltage surges generated by the locomotion system. Temperature sensors (LM35) are placed in all the battery packs to observe temperature of the batteries during operation of the vehicle. The vehicle does not activate locomotion and video link if it finds that battery temperature and voltage are below or above critical limits. Main controller continuously monitors the battery voltages through four resistive voltage dividers which send scaled down analog voltages of each battery to the main controller. The main controller gives audio and visual warnings and stalls the operation of the vehicle if any of the battery becomes discharged to critical level.

Table 2. Sensor suite of the HimBot

Sensor	Make and model	Accuracy
Temperature and humidity sensor	Sensiron; SHT75	± 0.4 °C Temp; ± 3 % RH
Atmospheric pressure sensor	Honeywell; NSCDANN015PAUNV	0.25 %
Wheel encoders	EAD Motors	± 3 % non-cumulative
2-axis tiltmeter	Freescale; MMA7361	± 1°
GPS	Locosys GPS MC-1513	< 3 m
Battery temperature sensor	LM35	± 0.25 °C at 25 °C
Video camera	Sony (Pan, Tilt & zoom)	--

The HimBot is equipped with three environmental sensors viz., a temperature sensor, a humidity sensor and an atmospheric pressure sensor. Apart from these sensors, built-in encoders on the wheel motors, a 2-axis tiltmeter, battery voltage & temperature sensors, a GPS receiver and a digital video camera have also been integrated to the main controller as payloads.

The HimBot has a long range wireless colour zoom camera with image stabilization which is mounted on a pan and tilt servo mount and placed over the belly of the vehicle. For video transmission and reception, 900 MHz spread spectrum wireless transceivers are used. The camera enclosure has a microcontroller which maintains the temperature of the enclosure at 10 °C. This enclosure has all necessary electronics for power conditioning, power monitoring and zoom control. The microcontroller cuts the camera power if it detects any fluctuations in the camera's power supply to protect the image sensor. Video from the camera and data from all the sensors can be received wirelessly on a laptop for real time display and recording. Table 2 shows the make and models of the various payloads used in the vehicle with their accuracies.

6. FIELD TESTS

The HimBot was field tested at Solang Nullah, Himachal Pradesh in February 2013. Field testing focussed on validating design guidelines, endurance of the vehicle and ability of the vehicle to negotiate snow-covered terrain. Solang Nullah field research station, operated by Snow & Avalanche Study Establishment, is located west of Manali in Himachal Pradesh at 77° 09' 23″ E, 32° 19' 03″ N and altitude 2450 m.

The tests were conducted over smooth as well as disturbed deep snow representing a typical survey route for 4 consecutive days from 10:00 am IST till 02:00 pm IST on all days. The tests were targeted to determine sinkage when the vehicle was stationary and during motion, turning and negotiating slopes; minimum turning radii and maximum speed achieved over level snow.

The standing snow varied from 110 cm to 107 cm and snow densities ranged from about 200 kg/m^3 near the surface to about 300 kg/m^3 at 20 cm depth during the study period. While snow surface temperature varied from - 0.4 °C to 0.1 °C, the air temperature varied from - 1 °C to + 6.5 °C during this period. A thin 1 cm ice crust was observed on surface in the morning which disappeared after sometime. The weather remained sunny in all days. The tests carried out to assess the vehicle's performance are described in subsequent sections.

6.1 Mobility Test

6.1.1 Smooth Snow Cover Test

The vehicle was run for a distance of 100 m over level snow cover and the depth of ruts made by the vehicle when it was stationary, during free run and 360° turn were recorded. The minimum average turning radii for a 360° turn was found to be approx. 52 cm and the rut depths measured ranged from 2 cm - 4 cm from the snow surface. The maximum speed achieved was approx. 2.95 km/h. The density of snow was measured underneath HimBot's ruts and undisturbed snow near it to determine depth of disturbance caused by the vehicle.

6.1.2 Rough Terrain Test

The following tests were carried out to assess the performance of the vehicle over rough terrain:

6.1.2.1 Disturbed Snow Cover Test

The snow cover was disturbed by walking over it couple of times. Boot sized pits upto 50 cm deep were made on the snow covered track. The vehicle was able to traverse through most of the terrain without getting stuck.

6.1.2.2 Slope Negotiation Test

The vehicle was also driven on snow covered slopes ranging from 15° to 50° to test its ability to climb and negotiate snow laden slopes. The rut depths were also noted while climbing the slopes. The HimBot negotiating a slope during tests is as shown in Fig. 3. Inset shows the remote control unit of the vehicle.

6.2 Load Pulling Test

For the load pulling test, a plastic container weighing 20kg was tethered to the rear end of the vehicle's protective jig and run over level snow as well as slopes as steep as 30°. The vehicle was able to pull the load over the smooth snow cover as well as over the slopes. The rut depths observed for the different mobility tests are as shown in Fig. 4.

Figure 3. The HimBot negotiating a slope.

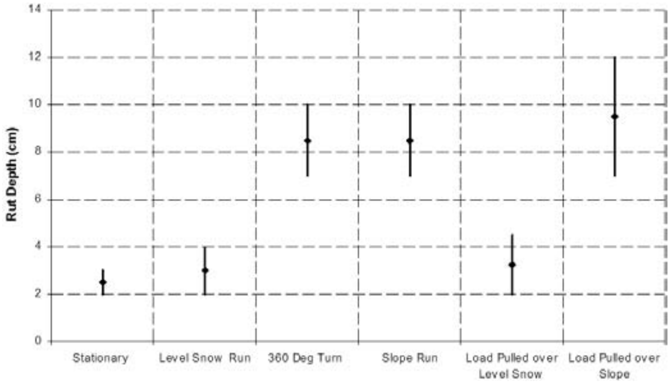

Figure 4. Rut depth ranges observed during field test of HimBot.

6.3 Endurance Test

The vehicle was run continuously over level snow to test the endurance of the batteries. Video transmission was continuously on and data transmission was kept at every 1 minute. The vehicle was run in a circular motion at full speed. The vehicle could run for approx. 95 min when one of the motion control batteries drained out.

7. RESULTS AND DISCUSSION

From the tests carried out in the field, it was observed that except for the cases of slope negotiation, the average sinkage was no more than 4 cm. This shows that at the prevailing snow and terrain conditions during the test period, the vehicle encountered no more than 27 per cent sinkage. From Eqn (4) it is clear that the sinkage parameter, z/H, can be given by

$$\frac{z}{H} = 2\frac{p_0}{kH}, \tag{6}$$

For HimBot, the calculated value of z/H comes out to be 1.00 ± 0.30, considering ± 30 per cent uncertainty in the value of *k*. During the tests HimBot encountered maximum sinkage of 12 cm, which gives the measured value of z/H as 0.80 which is well within its calculated value and signifies its design for most snow conditions.

Similarly, from Eqn (2) the compaction resistance parameter, z/L, can be given by

$$\frac{z}{L} = 2\frac{p_0}{kL}, \tag{7}$$

For HimBot, the calculated value of z/L comes out to be 0.26 ± 0.08. During the tests, the maximum compaction resistance observed was 0.21 which is also within the calculated value.

During the tests when the vehicle was moved over disturbed snow, it got stuck in pits which were about 50 cm deep or more. The vehicle, however, showed excellent recovery in such situations by employing reverse motion drive. It was observed during the slope negotiation tests that the vehicle could very easily climb slopes as steep as 30°. Slopes steeper than this could also be negotiated by driving the vehicle in a zigzag manner and it was observed that the vehicle's performance depended greatly upon the skill of the operator.

The density profiles of snow underneath HimBot's ruts and undisturbed snow were measured. It reveals that the density of the snow compacted by HimBot approached to that of undisturbed snow at about 15 cm - 18 cm below the snow surface which is the approximate depth of disturbance caused by the vehicle's movement. This has significance when using a penetrometer for sub-surface profiling.

Apart from these tests, the vehicle was operated with a laptop also and online data from the sensor suite was recorded. It was observed that the visibility of the display on the remote controller was affected by ambient light making it difficult to manoeuvre the vehicle when it was out of sight of the operator.

8. CONCLUSION

The unmanned tracked vehicle, HimBot, has the ability to support scientific research in snow bound areas by providing reliable operation during scientific surveys and expeditions. It can also be modified to suit military applications like reconnaissance, surveillance, unmanned combats and explosive disposal. This lightweight tracked vehicle, which has been designed to have large ground clearance and low & uniform ground pressure on its tracks, can be adapted to perform a variety of tasks in snow bound regions like GPR and GPS surveys, snow sample collection and deep snow profiling. The results obtained from field tests indicate the robustness and the capability of the vehicle to overcome over-snow mobility problems.

REFERENCES

1. Lever, J.H.; Shoop, S.A. & Bernhard, R.I. Design of lightweight robots for over-snow mobility. *J. Terramechanics*, 2009, **46**, 67–74. doi: 10.1016/j.jterra.2008.11.003
2. Mellor, M. Over snow transport. *In* Cold Regions Science and Engineering, Part III : Cold Regions Research and Engineering Laboratory, Hanover, NH, 1963.
3. Lever, J.H.; Denton, D.; Phetteplace, G.E.; Wood, S.D. & Shoop, S.A. Mobility of a lightweight tracked robot over

deep snow. *J. Terramechanics*, 2006, **43**, 527–551. doi: 10.1016/j.jterra.2005.09.002

4. Apostolopoulos, D.; Wagner, M.D.; Shamah, B.; Pedersen, L.; Shillcutt, K. & Whittaker, W.L. Technology and field demonstration of robotic search for Antarctic meteorites. *Int. J. Robot. Res.*, 2000, **19**(11), 1015–1032. doi: 10.1177/02783640022067940
5. Akers, E.L.; Harmon, H.P.; Stansbury, R.S. & Agah, A. Design, fabrication, and evaluation of a mobile robot for polar environments. *In* Proceedings of IGARSS, 2004, Anchorage, AK, **1**, pp. 109–112. doi: 10.1109/igarss.2004.1368957
6. Polar radar for ice sheet measurements. http://ku-prism.org/ [Accessed on 31 Jan 2014].
7. Maho, Y.L. & Whittington, J.D. Rovers minimize human disturbance in research on wild animals. *Nature Methods*, 2014, **11**(12), 1242-1244. doi: 10.1038/nmeth.3173
8. Laura, E.R.; Lever, J.H.; Streeter, A.D. & Price, A.D. Design and power management of a solar-powered Cool Robot for polar instrument networks. *J. Field Robot*., 2007, **24**(7), 581–599. doi: 10.1002/rob.20163
9. Trautmann, E.; Laura, R. & Lever, J.H. Development of an autonomous robot for ground penetrating radar surveys of polar ice. *In* Proceedings of IEEE/RSJ International conference on intelligent robots and systems, 2009, St. Louis, USA. pp. 1685-1690. doi: 10.1109/iros.2009.5354290
10. Bekker, M.G. Introduction to terrain-vehicle systems. University of Michigan Press, 1969.
11. Harrison, W.L. Vehicle performance over snow: math-model validation study. Technical Report 268, Cold Regions Research and Engineering Laboratory, Hanover, NH. 1975.
12. Lever, J.H. & Shoop, S.A. Over-snow rolling resistance of wheeled vehicles. *In* Proceedings of the Joint North America, Asia-Pacific ISTVS conference and the annual meeting of the Japanese Society for Terramechanics, 2007, Fairbanks, Alaska, pp. 14.
13. Freitag, D.R. & McFadden, T. Introduction to cold regions engineering. ASCE Press, New York, 1997. doi: 10.1061/9780784400067
14. Diemand, D. & Lever, J.H. Cold regions issues for off-road autonomous vehicles. ERDC/CRREL Technical Report TR-04-06, 2004, Cold Regions Research and Engineering Laboratory, Hanover, NH.

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