# MOBILITY, AUTONOMY, AND SENSING FOR MOBILE RADARS IN POLAR ENVIRONMENTS


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## ABSTRACT


This report focuses on mobility, autonomy, and sensing aspects of mobile radars for polar environments. The radar is provided with mobility using a robotic platform. This report is organized into five sections: snowmobile versus CMU Nomad, sensors, laser range finder, automation of the rover, and distributed and fault-tolerant control.



## KEYWORDS

Mobile robots for harsh polar environments.

# 1. SNOWMOBILE VERSUS CMU NOMAD

The purpose of this section is to run through a quick comparison of the capabilities of the CMU NOMAD robot and a heavy-duty snowmobile. It is necessary to determine feasibility of the snowmobile as a mobile robotics platform, and to expose any unseen benefits and/or drawbacks of using either of these machines for the upcoming Antarctic expedition.

## 1.1 NOMAD

### 1.1.1 Physical Characteristics

One of the most important details about NOMAD is its size – NOMAD, when fully unfolded and functioning, is 2.4 x 2.4 meters square. This is roughly the length and width of a small car. It's height is also 2.4 meters, but this is relatively unimportant for our considerations as NOMAD has already been proven to function in Antarctic climates, so we know it will not blow over because of high speed winds.

Nomad is also relatively heavy, at 725 kgs NOMAD requires a relatively high amount of wattage to power its 4 internal motors. Expedition notes revealed that when the generator failed, they needed at least 1000 watts of power to be supplied externally just to get NOMAD moving, and this power level wasn't sufficient for climbing hills or obstacles. Furthermore, because of the weight of NOMAD and limitations on power, NOMAD is meant to operate at speeds of .15 - .5 m/s, and due to its size, the best non-skid turning radius it can achieve is roughly 2.5 meters.

Winterization of NOMAD is achieved by the use of internal electrical heaters that are run by the gas-powered generator. The generator is started by hand and after approximately one half hour the electronic systems are warmed up sufficiently to be started. Steel wheels with metal studs are used for traction on the slick ice and packed snow.

### 1.1.2 Sensing and Computing

Nomad is also equipped with a modular science unit, which allows sensors and other devices a relatively easy interface into the robot so it can be set up to run different experiments. Nomad already has a built in Laser Range Finder, Differential GPS, and Stereo Cameras for navigation and data collection.

Nomad's computing platform, using the most recent published data, consists of a Motorola 68060 VME computer for real-time navigation and low-level functions such as controlling the motors and servos for steering. Nomad also has a Pentium 133Mhz computer running RedHat Linux 5.2 that handles path planning and long-term navigation goals. A third computer, a Pentium Pro 200, runs Windows NT and is used for add-on science modules and the cameras.

It can be safely assumed that some of the software and hardware has been upgraded since the last publication of data, however there are some devices that may not be easily changed. The use of Redhat 5.2 may still be a necessity due to changes in linux hardware interfaces through different revisions. In other words, there is a possibility that any planning and navigation algorithms would have to be designed to run under RedHat 5.2.

## 1.2 Snowmobile

### 1.2.1 Physical Characteristics

Snowmobiles can vary a great deal in size and weight. Due to the equipment payload for the expedition, the Skidoo Skandic snowmobile was chosen for all comparisons as it is a heavy duty snowmobile capable of carrying our payload, and has a proven track record of use in Antarctica.

The Skandic snowmobile is a heavy-duty snowmobile designed for hauling cargo over rough and cold terrain. Depending on the specific model, the length will vary somewhat, but for the WT 600 model, the overall length (from ski tip at front to track at back) is 3.15 meters, the width is 1.1 meters and the height is 1.2 meters. The dry weight of the sled is 275 kgs and has a 10.6 gallon fuel tank. The sled runs on standard unleaded gasoline, with a special oil mixture that can be used under extreme cold conditions.

The Skandic is capable of travelling at a maximum speed of 30 mph, and can achieve fuel efficiency of 70-80 mpg when unloaded. With a sled attachment the Skandic is capable of hauling up 800-1000 lbs. of weight. This of course reduces fuel efficiency, but is still quite good overall.

Obviously snowmobiles are not autonomous, so efforts would have to be made to automate the vehicle. Heavy-duty servos can be used to automate the steering and much of the throttle and other features are electrical in nature, so they can be directly routed into a control computer with relative ease.

Fortunately, snowmobiles are meant for cold weather, so nothing would have to be done to winterize the actual vehicle. On the other hand it will be necessary to winterize the computer equipment the possibly the servos used for steering.

Information on turning radius and actual handling isn't available, most likely due to the fact measuring the turning radius of a vehicle on snow isn't going to be a consistent operation (snow tends to slip). However, seeing as how this snowmobile is about 3 meters in length, it can safely be assumed that without skidding the turning radius would need to be at least 3 meters, but would most likely be around 4-5.

### 1.2.2 Sensing and Computing

Obviously, snowmobiles don't have sensors except for engine characteristics such as oil temp, fuel level, and speed. All other sensors would have to be added, and a portable generator would need to be used to power some of the sensors and all of the computing equipment.

## 1.3 Conclusions

Either vehicle has a share of problems. While NOMAD has been proven to work in this environment, it isn't any better suited for dragging an antenna than a snowmobile. In actuality it may be worse as there was no available data as to the amount of weight it could haul. The inclusion of sensors in NOMAD is a nice feature because it lifts the burden of doing this ourselves. On the other hand NOMAD requires a small army of graduate students to maintain, and developing our software and programs to run on it may be extremely difficult due to its physical location and our inexperience with their hardware.

The snowmobile is basically a blank slate, but it would allow us a great deal of freedom and flexibility in how we developed our tools and where we place them physically with respect to the platform. The snowmobile also requires lower maintenance than NOMAD and is significantly cheaper.

# 2. SENSORS

## 2.1 Laser Range Finders

There are three basic ways of measuring distances.

- Pulsed
- Phase measurement
- Triangulation

### 2.1.1 Pulsed

- Measures the time for the beam to be reflected to determine distances.
- Most reliable in tough environments.
- Can work up to several hundred meters. Less accurate than phase measuring devices.
- Sampling rates are not as fast as triangulation or phase measurement systems.

### 2.1.2 Phase Measurement

- Measures the phase shift of the laser beam to determine distances.
- Phase shift increase linearly with distance.
- Systems generally work up to 100 meters.
- The reflective surface must be a mirror.
- Accuracy is quite high (2mm or so)

### 2.1.3 Triangulation

- Systems use a CCD array such as those in cameras to measure distances.
- Systems are good at short ranges
- Can be highly accurate at short distances
- Sampling rates are fast (up to 500khz)

### 2.1.4 SICK LMS 221 (pulsed)

- 180 degree coverage
- Compact design
- Contact free measurement
- High resolution - 10 mm
- Integrated heating and fog correction
- Outdoor laser measurement
- Transmission of measurement data in realtime
- Windows setup software
- The LMS 221 is an outdoor system, with rapid scanning times so the target objects can move at high speeds.
- The target objects require no illumination, reflectors or markings.
- The measurement data is available in real time and can be used for further processing or control tasks.
- Has fog correction which should help with environmental effects.
- This device offers an accurate scanning method over a 180 degree field of view. Within this field, the LMS may be programmed to monitor up to multiple zones. Each zone can then be assigned one of three solid state outputs on the device. Other data may be read via an RS-232 or RS-422 line.

## 2.2 Nomad Application

Nomad used all of its sensors to make goodness maps of its surroundings. The laser range finder would scan areas and determine the slope of areas based on differences per reading. It scanned in 1 degree increments at all times. The software then used this data to determine which direction was the best. An obstacle such as a cliff would veto a path. Real time navigation could be achieved via this method. Nomad uses an LMS-220 unit which is nearly identical to the LMS-221. Both are designed for outdoor use. Both interface in the same way. The LMS-221 has fog correction and the LMS-220 does not.

## 2.3 Sonar

Sonar offers several advantages and disadvantages over Laser Range Finders

- Inexpensive and simple design
- Not dependent on light reflectivity
- Short range and less accurate
- Relatively slow
- Less of a dependence on environmental effects

## 2.4 Accelerometers

- Used for measuring physical shock to a system such as bumps or large accelerations
- Undesirable movement may be detected and remedied before becoming serious.
- Chip based solutions are available and are preferred for low temperatures.
- IMI chip based approach: IMI developed a digital chip based solution that drastically reduced the need for many components.

## 2.5 Inclinometers and Gyroscopes

- Two basic solutions:
- Non chip-based solution: long rod containing matter of some type. Glycol is often used because it is very viscous and reduces overshooting (the principle is similar to a carpenters leveler)
- Chip based solution: microchip containing a gyroscope

### 2.5.1 Non chip-based Inclinometers

- 0.0001 sine angle accuracy
- Must remain above 14 degrees
- Harder to interface

### 2.5.2 Chip-Based Inclinometers

- Slightly less accurate
- More features including magnetic positioning information
- Ideal for computer interfacing
- Can withstand low temperatures easily
- Example: TCM2-50, Features: 3 axis magnetometer, 2 axis inclinometer, thermometer, detects magnetic anomalies, throws various error flags, sophisticated configuration, choice of scientific units, and electronically gimbaled. Specifications: 1-30 Hz sampling rate, RS232 interface, -20 to 70 degree operating range, magnetic accuracy: 0.2 ut, heading accuracy: 0.1 degrees, tilt accuracy: 0.3 degrees

## 2.6 Other Sensors

- Shaft encoders
- Wind sensors
- Internal humidity sensors

### 2.6.1 Shaft encoders

Shaft encoders are inexpensive sensors. Most shaft encoders use either optical or magnetic encoders. Optical encoders are usually infrared and sometimes laser based. Encoders simply count the number of times that the beam is broken. Encoders are designed for various RPMs and accuracies. Things to look for: operates at TTL levels, high frequency, high precision, has ball bearings, and works at low temperatures.

One example is the US Digital S4:

- Tracks from 0 to 30,000 cycles/sec
- Ball bearing option tracks up to 7,000 or 15,000 RPM
- -10 to +85°C operating temperature
- 100 to 360 cycles per revolution (CPR)

- 400 to 1440 pulses per revolution (PPR)
- 2 channel quadrature TTL squarewave outputs
- Low power strobe option available

# 3. LASER RANGE FINDER

## 3.1 Models

The two most common laser range finders produced by the Sick Optic Electronic company are the LMS 200, and the LMS 220, which are essentially the indoor and outdoor versions (respectively) of the same unit. The ActivMedia PeopleBot, which is owned by the University of Kansas, is equipped with the LMS 200. There are also several other models in Sick's laser measurement product line (LMS 211/221/291), which are essentially the same as the 200 or 220 except they have faster scanning rates so that target objects can move at a higher speed. Because the LMS 200/220 are the main units distributed by Sick, and the other models are basically just variations of one of these, this report will focus on the 200/220 models. Unless stated otherwise, the following specifications apply to both models. Information on additional Sick Optic Electronic products can be found at www.sickoptic.com.

## 3.2 General

The laser range finder (LRF) works by emitting a pulsed class 1 laser. This laser is directed at an internal rotating mirror, which deflects the pulses out from the unit in a fan shape. Measurements are based on the time of flight technique—that is, the distance between an object and the LRF is determined by the amount of time it takes a laser pulse to travel from the LRF to the object, and then back again. The contour of a target object is determined by the sequence of impulses that are received. The LMS 200/220 models can scan at rates up to 75 Hz. All scans are limited to a two-dimensional plane that extends outward from the LRF at the level at which the laser pulses are emitted. Also, the scans require no reflectors or positional markers to be placed on the target objects or surrounding environment.

The data obtained while the LRF is scanning is available for real time evaluation via serial interface. A special serial cable interface that is properly configured to connect directly to the LMS unit can be obtained from Sick.

There are a number of practical applications for the Sick LMS, including (but not limited to):

- Measuring objects: such as boxes and other packages being shipped or received, or automobile parts on an assembly line.
- Determining position: useful with robots that must navigate hallways, or with industrial robots that must position themselves correctly to perform a task.
- Monitoring areas: for safety purposes such as making sure no one enters a hazardous area while dangerous machinery is in operation, or for security reasons such as monitoring an entryway to a museum or bank vault.

## 3.3 Measurement Specifications

The maximum possible range for the LRF is 150 meters. However, this is only accomplished if supplementary reflectors or reflecting surfaces are placed on the target objects or environment being scanned. For the more common case in which supplementary reflectors are not used, the effective range is reduced to approximately 30 meters. If the LRF is being used to scan areas with minimum reflectivity (approximately 1.8%), then the range is reduced further to 4 meters.

The resolution of the laser measurements is 10 mm with the statistical error of +/- 15 mm.

There are several different settings for the angular resolution of the measurements, which are selected using the LMS software. For a scanning field of 100º, measurements can be taken at 0.25º, 0.5º, or 1.0º increments. For a scanning field of 180º, measurements can be taken at 0.5º and 1.0º increments. (note: 180º is the max scanning angle for the LMS)

The response time of the LRF will vary depending on the angular resolution. For scanning increments of 0.25º, 0.5º, and 1.0º, the response times will be 52, 26, and 13 ms, respectively.

## 3.4 Connections

The interface between the LRF and the controlling system is a switchable serial RS-232 or RS-422. The measurement data is binary and is transferred in real time at 9.6, 19.2, 38.4, or 500

Kbaud. The transfer rate can be selected as desired using the controlling software. The LRF requires an electronic voltage supply of 24 VDC (+/- 15%).

## 3.5 Physical Specifications

There are several significant physical differences between the indoor (LMS 200) and outdoor (LMS 220) models. These differenced are due primarily to the fact that the outdoor model is better insulated and has a built in unit that is used to heat the LMS internally. Because of these differences, the specs for each model will be given separately.

The LMS 200 is 15.5 cm wide by 18.5 cm high by 15.6 cm deep and weighs 4.5 kg. Its ambient operating temperature is between 0 and 50º C. Recommended storage temperature for the LMS 200 is between –30 and 70º C. When in operation, this unit will consume 17.5 Watts of power.

The LMS 220 is 35.2 cm wide by 26.6 cm high by 19.45 cm deep and weighs 9 kg. The ambient operating temperature is between –30 and 50º C, and the recommended storage temperature range is from –30 to 70º C. When in normal operation, the power consumption for the LMS 220 is 17.5 Watts. However, when the on-board heating unit is used, the power consumption jumps to 150 Watts.

## 3.6 Relevant Applications

LMS technologies have been used by many designers in the robotics industry to provide navigational support, assist with docking or handling procedures, and help with collision prevention.

Researchers from Carnegie Mellon University and NASA's Ames Research Center have used the LMS 220 technology on a Nomad all terrain rover designed to navigate the Antarctic terrain in search of meteorites and other rocks. The project is also aimed to develop the ability for the rover to navigate autonomously or with minimal human guidance.

Also, several organizations have used specially mounted LMS units along with their own software to create 3D scanning systems.

# 4. AUTOMATION OF THE ROVER

## 4.1 Problem Overview

- How do we automate a vehicle designed to be operated by a human?
- Mechanical considerations
- Sensory devices
- Computer control and integration

## 4.2 Example - NAVLAB

- Project created at Carnegie-Mellon headed by Chuck Thorpe
- Currently Working on NAVLAB 11
- Added servos and cameras to cars
- Using Neural Networks for navigation, cars can drive themselves
- Main goal of the project is for automated highway driving

## 4.3 Questions We Have to Address

- Gas/Electric Vehicle?
- Mechanical/Power Steering?
- Hydraulic/Electric Throttle (Pedal)?
- Brakes
- Do we need manual and computer control?

## 4.4 Gas or Electric Vehicle?

- Electric Vehicle already has electromechanical or computer control
- Gas Vehicle - Fuel injected (Usually Electronic)
- Gas Vehicle - Mechanical/Hydraulic Pump

- Electric Conversion

## 4.5 Power or Mechanical Steering

- Power Steering - Uses Hydraulics
- Mechanical Steering - Electric Servo
- Sensors to indicate manual control override

## 4.6 Hydraulic/Electric Throttle/Pedal

- Hydraulic Pedal - Need to use solenoid or actuator - some cruise control units already have a means of doing this
- Electric Pedal - Tap in directly/already solved

## 4.7 Brakes

- Exactly like the throttle pedal

## 4.8 Integration

- In some cases we may have mixed electric/hydraulic system
- Physical movement of pedal (throttle/brake) may or may not be necessary
- Electric conversion brings weight/balance issues, steering may or may not be changed.

## 4.9 Components Required

- Electric Systems - Microcontroller, Servos, Possibly solenoids
- Mechanical Systems - Same as electrical plus hydraulic pumps

## 4.10 Details

- Types, Sizes, and Strength of Servos, Pumps, and Solenoids won’t be known until actual vehicle is tested for resistance in steering, throttle, and brakes.

# 5. DISTRIBUTED AND FAULT-TOLERANT CONTROL

This section presents the related work regarding distributed control and the use of fault-tolerant robotics. When searching for distributed control of robotics three ideas keep resurfacing: (1) the use of distributed control with multiple robots, (2) parallel processing, and (3) neural networks.

The use of a distributed brain in robotics seems to be currently limited to the concept of a multiagent system where multiple robots are used to perform a task. Under this scenario there are many different variations of control and hierarchy, but the key is that there are multiple robots. There are currently hundreds of ongoing research projects in this area; approximately twenty such projects are on the Carnegie Mellon Robotics Institute web page (http://www.ri.cmu.edu/projects).

A great deal of this research involves the use of heterogeneous robots collectively performing a task. The main ingredient in these projects is the use of communication and task allocation routines. The agents are either centrally assigned a task using some sort of control hierarchy, or using pre-programmed control routines in individual robots (i.e. each robot knows its task ahead of time, and the communication system allows it to know when it should perform its task and allows to transmit its results to the other agents).

The second area of interest is the use of distributed processing in robotic systems. Unfortunately, the notion of distributed often seems to mean “parallel.” The use of distributed processors at this point seems to be closely related to speed of computation and overall processor load on the robot as opposed to dividing up sensory and cognitive functions into separate processor modules. In actuality many of the current robots use multiple processors for computation, but in many cases it almost seems it is out of convenience instead of a true design intention. For instance, using a computer (PC) to control the vision of a robot because the camera system that was purchased uses Windows, and then use another PC to control navigation because the GPS unit runs well under Linux. A third computer is then used as a central brain to collate the information from the other two and make decisions about what course of action to take. This piecemeal approach is practical, but not innovative in a design sense as it is task oriented and does not attempt to approach a cohesive control model.

The third area of interest, Neural Networks, seems to be more closely related to the concept of distributed control. A great deal of research is now underway in the use of Neural Networks to automate low-level response in robotic systems and to synthesize higher-level behaviors. In a paper entitled Analog neural networks and behavior based robotics (http://citeseer.nj.nec.com) neural networks are explored as a method of improving low-level behavior and path planning. The use of parallel neural networks closely coincides with brain functions through the use of parallel networks solving individual tasks and communicating results to each other to achieve a cohesive action or decision. One current understanding of neural networks is almost non-existent except of on a very vague conceptual level. As far as current applications, Neural Networks seem to be quite the rage for path planning and image recognition. The adaptability of networks to VLSI or other low-level hardware also has a great appeal as it would allow a small number of low-cost processors to be used without the overhead of a standard computer, i.e., hard disk, etc.

Research into fault tolerant robots led to three very different concepts, two of which are mostly in heavy use by NASA. The first concept is the use of the word “redundancy.” Apparently redundancy in robotics seems to be synonymous for kinematic redundancy, or basically redundancy of motion. Numerous researchers are interested in kinematic redundancy with regards to robotic arms and in some cases walking or other robotic locomotion. Much of this research seems to be centered on the mathematics of designing systems that will follow through with a motion in an accurate of semi-accurate way (depending on how precise the robot needs be) given mechanical degradation for unforeseen environmental hazards. This kind of fault-tolerance is for physical motion only, and is therefore only a partial solution to a complete fault-tolerant system.

The second approach encountered is the use of complete hardware back up. In other words, using two or more computers, a primary and a secondary where if one system fails the other one can take over the load. This approach has the obvious limitations of size, cost and power consumption. This approach tends to be used in only the most extreme of cases where it is absolutely necessary to have a system function at all times. Consequently this approach tends to be used a great deal by the military in weapon systems and in extremely expensive pieces of hardware. Unfortunately this approach is somewhat impractical for most applications because of the obvious drawbacks. In the polar robot case, the size and power consumption being the largest problems.

The third approach, which is actually the goal of some entire research projects, is the multi-agent system. The line of thought in this case is that by having multiple simple agents if one or more fail then there are going to be other agents that can take up the slack. In some cases this involves building multiple agents (or robots) with identical features and characteristics so that one can replace another, or building some functionality of a certain agent into others so that if it fails a number of other agents can collaborate to perform its function. While this approach does require a hardware redundancy it is not nearly as costly as putting a back-up computer in every system, as agents tend to be smaller and designed to perform a specific task.

In extensive searching it would seem that fault tolerance has up to this point been an area of interest only to NASA and the military. To a great extent it is in its infancy as an area of research, where most of the approaches are the obvious ones. Similarly, distributed control in most cases is not what people would normally associate with that name. Most of the true distributed control research is being done in multi-agent systems with various protocols and hierarchies being explored to cohesively control a group of heterogeneous agents. The number of ways to achieve this goal seems almost endless as every project seems to be using a variation of an existing idea of a completely new one. In many cases, these approaches are very task specific, but a great deal of research is also underway to create a general multi-agent system hierarchy not designed for one specific task. Currently there does not appear to be any research (that could be found) on using neural networks as a method of redundancy, although it is being explored as an approach to internalized distributed control.

## ACKNOWLEDGEMENTS

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# APPENDIX A

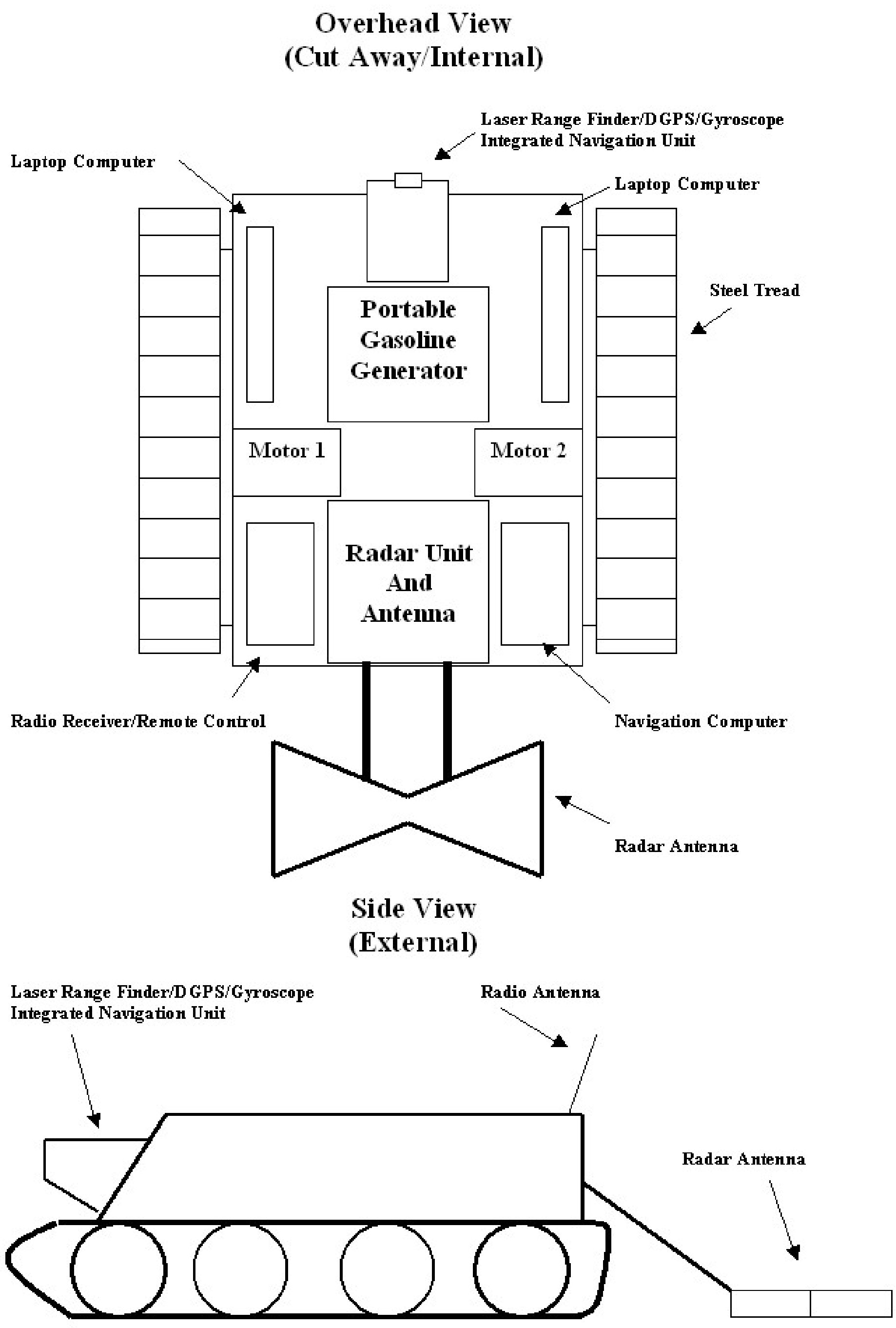


**Figure 1. Schematic drawing of a mobile radar system.**

**Figure 3. An artist's rendition of the snow vehicle with two autonomous rovers.**

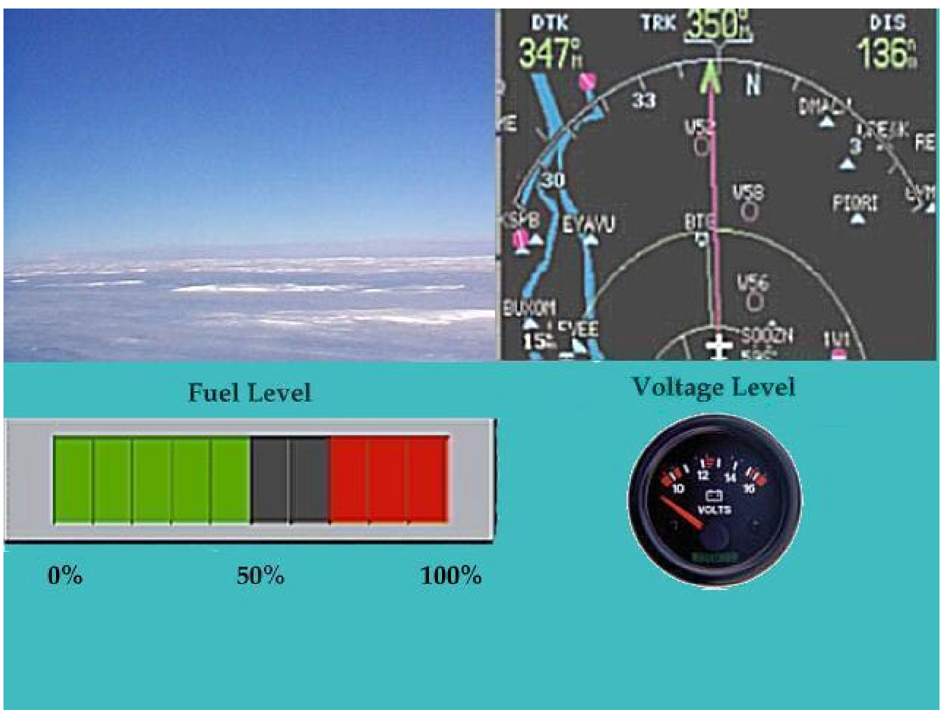


**Figure 2. A graphical user interface for a polar robot.**