LOCOMOTION (TERRESTRIAL AND AERIAL) AND COMMUNICATION OF AUTONOMOUS ROBOT NETWORKS

Arvin Agah
Benjamin W. Shockley
Lakshmi N. Viswanadha
Brandon J. Warner

ITTC-FY2003-TR-27640-02
November 2002
Information and Telecommunication Technology Center
The University of Kansas, Lawrence, Kansas 66045

ABSTRACT

This report focuses on locomotion and communication aspects of mobile robot networks for harsh polar environments. The report is organized into seven sections: terrestrial locomotion, aerial locomotion, micro air vehicles, next generation robotic platforms, platform mechanics and materials, winterization of robotic platform, and communication in multi-robot systems.

KEYWORDS

Mobile robots, robots for harsh environments, flying robots, micro-air vehicles, robot communication, autonomous robot networks.

1. TERRESTRIAL LOCOMOTION

1.1 Introduction

Even the most technically advanced observational robot network is radically limited in its useful application without an ability to move around. Specifically, these rovers must be able to overcome the difficult challenges set forth by their environment while still maintaining superior levels of observational ability. The harsh environment conditions of Antarctica that must be sustained for an extended period of time by each rover pose a major challenge in design considerations. A rover must be capable of autonomously navigating terrain and surviving on its own in an extreme climate.

There are various methods of providing a rover with an independent system of locomotion. The focus of this report is to present each mobility option and to analyze the advantages and disadvantages of each. The options listed are limited to those which are best suited for the specific terrain and climate of the rover's target environment of Antarctica. Thus, these constraints are also examined and remain at the forefront of each and every logical analysis.

1.2 Terrain and Climate

The sheer mass of Antarctica provides one of the most challenging obstacles for a network of autonomous rovers. Antarctica is the fifth largest continent, slightly less than 1.5 times the size of the United States, covering 14 million square kilometers total during the winter months. Even during the summer months, almost the entire continent is covered by ice with an average thickness of almost 1.5 kilometers [1]. About 98% of the terrain is a thick continental ice sheet, with huge floating sheets of ice constituting nearly 11% of that total, and leaving only 2% as barren rock [2]. The elevation ranges from 0 meters at the 17,968 kilometers of sea level coastline to heights up to 5140 meters found in the mountain ranges. The average elevation is around 2300 meters, making Antarctica the overall highest continent in the world [3].

Perhaps the only obstacles more formidable than the terrain are the extreme climate conditions. During the year 2000, Antarctica recorded an average temperature of –54.6 degrees Celsius, with a high in the summer of –24.0 and a low in the winter of –76.0 [4]. The weather conditions seem to be evenly divided between clear, partly cloudy, and cloudy sky cover. There was an average wind speed of 18.1 kilometers per hour, with a maximum gust of 72.4 from the Northwest.

During the summer months, the climate is the most bearable, with temperatures rising rapidly in the spring (October and November) and averaging –28.0 degrees Celsius during the summer months (December and January). In the fall (February and March), the temperature drops at an average of one-half a degree Celsius per day until around March 22, when the sun drops below the horizon and is not seen again until September 22, when the long winter is over.

Despite being an enormous ice sheet, Antarctica is considered to be the largest and driest desert in the world, with an average relative humidity of only 0.03% due to the extreme cold. There is very little actual snowfall (only about 5.1 centimeters per year), but what does fall never melts. Even with such little snowfall, blizzards are common, with surface snow being blown along the surface by the wind, resulting in blinding conditions in which objects less than a meter away may be invisible.

1.3 Locomotion Options

In an autonomous rover network, the choice of a mobility system for locomotion is of the utmost importance. Since one of the primary goals is to have this network of rovers survive independently for an extended period of time in such harsh conditions, reliability and adaptability are key. Clearly there are options to choose from, and certainly each has certain advantages and disadvantages over another. The prime objective in this case is to decide on a system that will provide the most effective means of locomotion for the rovers without compromising reliability.

1.4 Legged Walker

Legged locomotion has long been an attractive alternative to wheels or tracks for mobile robots. Legged animals, for example, have the ability to negotiate rough terrain and obstacles far more easily than wheeled vehicles of similar size. However, current legged robots enjoy neither the simplicity of wheels nor the versatility of legged animals [5]. Legged robot systems have been developed most successfully in a hexapedal configuration for stability and their movement modeled after that of insects.

1.4.1 Advantages

Ideally, legged robot systems will mimic the movements of animals and provide a locomotion option that is comparable in terms of speed and stability to more conventional methods. While most of the work in this area is still experimental, small legged walkers have been developed that are capable of speeds of 2.5 body lengths per second and have proved proficient in quickly traverse large, hip-height obstacles. The distinctive goal of legged walkers will be their ability to negotiate variously structured terrain more quickly and successfully than their wheeled counterparts and push the limits of robotic exploration even further. These types of robots also tend to be powered exclusively by electric motors, which supports the ideal of a solar powered rover network.

1.4.2 Disadvantages

The current state of the art in legged walkers is very small in scale (about 16 centimeters long) and remains very experimental in terms of feasible locomotion. This lack of reliability and need for constant observation could prove devastating in an autonomous setting. Should a legged walker happen to fail, the entire project would suffer long, if not indefinite, delays. While a legged walker may be more capable of traversing rough terrain, there is a question in this case of necessity. Antarctica does provide the distinct advantage of being fairly uniform in its terrain, and the requirement to surmount every obstacle is simply not present in a project such as this. There is also the issue of stability concerning the array of observational equipment that the rovers will be carrying. It is unknown at this time whether or not a legged walker of sufficient size to support all of the computer systems would be able to keep them stable enough for ideal operation since each leg joint allows for up to three degrees of freedom in movement.

1.5 Tracks

Flexible tracks, usually made from either steel or steel belted rubber, are most commonly found on tanks, construction equipment such as bulldozers, or large farm machines and tractors. The tracks are installed on assemblies of wheels that provide both the driving power as well as support, and are situated on each side of the vehicle. Each side of the treads are allowed to be driven separately, allowing for skid steering, or the moving of the treads on one side at a faster rate than on the other side, thereby causing the vehicle to turn [6]. To travel both straight forward or backward, the treads are simply powered by the wheels at the same rate.

1.5.1 Advantages

Treaded vehicles tend to be much larger and heavier than their wheeled counterparts. The treads provide more contact area with the ground, thus distributing the weight over a larger area. This greater amount of contact area also results in more friction and better traction, especially in loose terrain, such as soft ground, sand, or snow. Since each set of treads is allowed to be driven separately, steering is relatively simple, and is mobile enough to turn in a circle while stationary. Tracks also provide a smooth ride across flat or uneven terrain, allowing the integrity of the observational equipment to perform without compromise.

1.5.2 Disadvantages

In their conventional form, treaded vehicles tend to require considerable more power to move than wheeled vehicles and therefore run on large gasoline or diesel powered engines. A large part of this is a natural consequence of the sheer size and weight of the machines to which they are applicable. In addition, however, the increased friction of a larger footprint as well as the fact that treads cannot be pointed in the direction of a turn will cause a larger power requirement to the wheel motors than would a wheeled machine of similar size. In addition to the natural complication of various drive wheels and suspension, treads also require the use of tensioning devices to keep the treads both on the drive wheels and in firm contact with the ground at all times.

1.6 Tracks and Skis

A slight alteration to the simple use of tracks as described above is to pair a singular track in the rear with slightly rotating skis in the front. This is a scheme almost exclusively seen in modern snowmobiles and is consistent whether the goal is power or speed.

1.6.1 Advantages

The skis on the front of a snowmobile allow the vehicle to very nimble on loose snow, while the tread in the rear provides rapid acceleration and a constant driving force. On a surface such as powder snow, the less friction between the vehicle and the ground, the faster the machine can travel. A single track in the rear and skis in the front clearly leave a smaller footprint than two full length tracks mounted on each side.

1.6.2 Disadvantages

As with treads, the power requirement to drive the wheels that move the tread is fairly high in comparison to the size of the vehicle. Modern snowmobiles are powered by two stroke gasoline and oil engines of various sizes, but not electric motors to date. In addition, while the nimble steering through loose terrain is clearly advantageous, it requires an operator to shift weight accordingly to make the turns possible. In an autonomous rover application, this becomes virtually impossible to duplicate.

1.7 Wheels

Wheeled vehicles currently provide the most common method of locomotion, found in modern cars, motorcycles, trains, and airplanes, not to mention the current state of the art in robots. The NASA rover on the moon, the small Sojourner that was part of the Mars Pathfinder mission, FIDO, one of the current prototypes for future Mars missions, and Nomad, the large autonomous vehicle designed for a variety of terrain mediums, all use wheels as their means of locomotion. Wheels provide design options that are comfortable both to visualize and apply as well as presenting a mobility system that is efficient and stable.

Many logistical variations are available in the design of wheeled vehicles. There are three wheeled machines with two wheels in back and one in front as well as some with two in front and one in the back. In each case, it is most common to see the single wheel be the one that steers. Many rovers use layouts of either four or six wheels paired on each side of the vehicle, much like in a car or ATV. These wheels can then be driven either collectively, in pairs, or independently and can be steered by either a single pair in the front, a single pair in the rear, or by both pairs together.

Wheels are very easily scaled to just about any size requirement. Sojourner, for example, was a small, six wheeled robotic vehicle built by the Jet Propulsion Laboratory for NASA's Mars Pathfinder mission. The rover was about the size of a milk crate and weighted just 11.5 kilograms. This rover was designed only to traverse distances of about 100 meters and survive for only 4 days. This small robot was powered by an array of solar panels and used only 16 watts of power to operate the computers, guidance system, and the wheel motors [7].

FIDO, which stands for Field Integrated Design and Operations rover, is essentially the newer version of Sojourner. This larger rover is also situated upon six wheels, each of them independently steered. FIDO is about 6 times the size of Sojourner and is able to travel for several kilometers on its steel cleated wheels and climb obstacles of about 30 centimeters, or about 1.5 times the diameter of its wheels [8].

Nomad is clearly the most similar in design requirements to the rovers that will be necessary for this mission. A four wheeled rover designed to traverse planetary analogous terrain, Nomad is 2.4 meters long and weighs in at 725 kilograms. All four wheels are powered independently and each are able to steer freely. Combined with the special transforming chassis, this allows Nomad to skid steer like a treaded machine, or perform Ackerman steering, where both the front and rear wheels turn in or out together for more nimble handling than the simple two wheel steering design of a modern automobile [9].

1.7.1 Advantages

Quite possibly the greatest advantage to wheels is their range of possibilities for specific application. As shown in the various examples above, there are many configurations that can help specialize a rover to fit its specific terrain requirements. For programming simplicity and greater reliability, each wheel can be independently driven by electric motors. With all wheel steering, the rover can become virtually as nimble as a treaded machine, but without the added weight. Suspension can also be configured independently for each wheel, adding to the simplicity and reliability of the design and aiding in the integrity of the observational equipment that the rover will transport.

1.7.2 Disadvantages

Unfortunately, no design option is without some disadvantages. Wheels lack some of the traction offered by treads, and should a wheel become stuck, the required troubleshooting would obviously cost valuable observation time. Steering of only two of the wheels, like a modern car, significantly limits the rover's ability to make sharp movements and can add considerable difficulty to programming tasks. This results from the different lengths traveled by the inside and outside sets of wheels.

1.7.3 Tires

Another concern with wheeled rovers is the type of tires to use. Rubber tires may not fair so well in the harsh environment of Antarctica, where the extreme cold and low humidity would quickly deteriorate the rubber, and the air pressure would have to be carefully regulated. Tires that would remain the same size are the clear goal to aid in steering and direction regularity. This design can be realized by manufacturing tires out of either metal or plastic and studs can be added for traction on the ice and packed snow. The non-deforming material would eliminate the issue of keeping internal air pressure constant and steering programs would not have to be altered to accommodate the changing tire size.

1.8 Wheels and Tracks

One moderate variation on the wheel design is to simply add a track system to each existing wheel. This is a fairly new technology that is available for trucks and ATVs. A relatively quick modification attaches small track units to each wheel, which are then driven by the same power that normally turns the wheels [10].

1.8.1 Advantages

Just as with a full treaded system, the main advantage is larger contact area with the ground, and therefore greater traction. Smaller, individual treads, can offer many of the same advantages as wheels, while providing greater security when traveling across loose terrain such as snow.

1.8.2 Disadvantages

Also, like the treaded system, the biggest issue is added weight. Current models, even at the smallest size, add approximately 50 kilograms per set. Equipping a four wheeled rover with treads, therefore, can increase the weight by nearly 200 kilograms. When power is at a premium, the benefits may not outweigh the consequences of such a system.

1.9 References

[1] "Virtual Antarctica Science: Snow and Ice."
http://www.terraquest.com/va/science/snow/snow.html.

[2] "CIA – The World Factbook 2000 – Antarctica."
http://www.cia.gov/cia/publications/factbook/geos/ay.html.

[3] "Virtual Antarctica Science: Geography."
http://www.terraquest.com/va/science/geography/geography.html.

[4] "Antarctica Weather – The Antarctic Connection." http://209.207.189.31/antarctic/weather/.

[5] Cham, Jorge G., Sean A. Bailey, and Mark R. Cutkosky. *Robust Dynamic Locomotion Through Feedforward-Prefix Interaction.* http://arnold.stanford.edu/~touch/me393/fall00/papers/dsc2000_final_v5.pdf.

[6] Brain, Marshall. "How Caterpillar Makes Challenger Agricultural Tractors." http://www.howstuffworks.com/cat-tractor11.htm.

[7] "Mars Microrover Power Subsystem." http://mpfwww.jpl.nasa.gov/MPF/roverpwr/power.html.

[8] Fordahl, Matthew. "NASA Tests New Mars Rover in Nevada." http://www.canoe.ca/CNEWSSpace0006/27_mars.html.

[9] "Robotic Antarctic Meteorite Search – Robot." http://www.frc.ri.cmu.edu/projects/meteorobot/Nomad/Nomad.html.

[10] "New! ATV Track Conversion." http://www.mattracks.com/atv.htm.

1.10 Additional Reading

Bekey, George A., ed. *Autonomous Agents.* Boston: Kluwer Academic Publishers, 1998.

"Coastal-Change and Glaciological Maps of Antarctica." http://pubs.usgs.gov/factsheet/fs50-98/.

Cox, I.J., and G. T. Wilfong, ed. *Autonomous Robot Vehicles.* New York: Springer-Verlag, 1990.

Ho, C.Y., and Jen Sriwattanathamma. *Robot Kinematics: Symbolic Automation and Numerical Synthesis*. New Jersey: Ablex Publishing Corporation, 1990.

"Michigan Engineers Build Mars Rover Prototype." http://www.umich.edu/~newsinfo/Releases/2001/May01/r052301b.html.

"NASA's Mars Rover Test Drive Racks up Miles and Smiles."
http://www.jpl.nasa.gov/releases/99/fido.html.

Sanders, David A. *Making Complex Machinery Move: Automatic Programming and Motion Planning*. England: Research Studies Press Ltd., 1993.

"Virtual Antarctica Science: Geology."
http://www.terraquest.com/va/science/geology/geology.html.

Vukobratovic, Miomir. *Applied Dynamics of Manipulation Robots: Modelling, Analysis, and Examples*. Berlin: Springer-Verlag, 1989.

Wright, Ron. *Yamaha Snowmobile Shop Manual.* Kansas: Intertec Publishing Corporation, 1990.

2. AERIAL LOCOMOTION

2.1 Introduction

A project, proposed by NASA, to study polar ice regions has brought forward the idea of autonomous remote vehicles for deployment of a sensor web intended to measure polar ice sheet characteristics. The reason for the ice sheet analysis is to determine accurately the makeup of ice sheet in order to postulate better the mass balance for long-term time ranges. Nearly sixty percent of the world's population lives in a costal region and the effects of a rising sea could be devastating.

These remote vehicles must be large enough to carry the required synthetic aperture radars (SAR), a Global Positioning System (GPS), communications, and data/signal processors. They must be agile enough to transverse the rough terrain and durable enough to survive harsh climate with little or no human intervention for long periods of time.

Determining the best design of a remote vehicle suited for the requirements of the project means exploring every angle, design, and possible structure.

The platform vehicle choices can be broken into two main types of vehicles; ground-based, and air-based. This paper will examine to validity of using Unmanned Air Vehicles (UAVs) as the base remote robot.

Unmanned Air vehicles date back as late as the 1960's 1. Mostly used for experimental military aircraft, such as The Northrop Grumman Global Hawk 2, some have been adopted for commercial or scientific purposes. The most logical step would be to take an existing platform and adopt it for our research. Finding a platform best suited for this project means considering many properties of UAVs. Such properties include flight characteristics, payload capacities, flight duration, and finally autonomy of the aircraft.

Flight characteristics include flight speed, and maneuverability. Two main types of vehicles were looked at: a hover capable aircraft, and forward flight aircraft. A hover cable aircraft is one such that no forward flight is needed to stay airborne, such as a helicopter or lighter than air vehicle (blimp). The average wind spends in Polar Regions is fairly high requiring a great amount of computational power, as well as vector controlling power to be spent just keeping the aircraft stable. Building and maintaining an aircraft such as that, would be an entire project in itself, therefore that design concept is ruled out. The forward flight aircraft are those, which use primary lift from dynamic pressure differences caused by air moving across a winged surface. These types of aircraft range from low altitude, high-speed aircraft, to high altitude, low-speed aircraft and everywhere in between.4

The required payload is around 50 pounds. This particular requirement can easily be met by many current UAVs. An unfortunate, but unavoidable, side effect is that the vehicle itself must have either a fairly large wing area or a high flight velocity to carry the weight. If the idea of a high air velocity is used then a large, fuel hungry engine must be used to produce enough thrust. This will shorten the flight duration making flight times relatively short. Such other considerations would be an airport or landing strip and even more human intervention with the project. This will defeat the purpose of having a remote vehicle, as a human crewed aircraft could do the same job better.

An alternative source of power would be solar energy. “Within two years, solar-electric airplanes incorporating energy storage for nighttime flight, will be capable of continuous flight for months at a time at altitudes of over 60,000 feet, powered only by the sun.”3 Although solar powered UAVs do exist and have been flying for sometime, their size and slow speed make them not viable. Solar powered air vehicles need large lightweight wings to help capture sunlight, at the same time the available power output is small due to the relatively weak electric motors, requiring the planes to be as lightweight as possible. The strong polar winds can easily take control of the vehicle. The whole airship is as vulnerable to the wind as a kite.

After examining all the possible variations and characteristics of Unmanned Air Vehicles the decision to not use one for this particular project has been made. While there are probably plenty of good uses that could be found with UAVs, in this case a ground based vehicle would prove to be much more feasible.

2.2 References

[1] Unmanned Combat Air Vehicles: A New Concept To Meet A New Challenge. Department of Engineering, The University of Texas at Austin. 05 July 2001. http://asme.me.utexas.edu/uer/UCAV/

[2] Global Hawk. FAS Intelligent Resource Program. 05 July 2001. http://www.fas.org/irp/program/collect/global_hawk.htm

[3] Unmanned Air Vehicles. AeroVironment 05 July 5001. http://www.aerovironment.com/area-aircraft/unmanned.html

[4] UAV Technologies and Combat Operations Air Force Scientific Advisory Board (SAB) SAF/PA 96-1204 – 1996 05 July 2001. http://www.fas.org/man/dod-101/sys/ac/docs/ucav96/index.html.

3. MICRO AIR VEHICLES

The physical dimensions that define when an air vehicle can be categorized as "micro" are outlined by DARPA, the Defense Advanced Research Projects Agency, to be smaller than fifteen inches in any dimension. That includes length, width, or height. Also, the vehicle must weigh no more than about 50 grams. Also, DARPA has established requirements that the air vehicle, be it fixed wing, or rotary wing, must be able to carry a payload of about 20 grams and fly for a time between 20 and 60 minutes. These miniature vehicles are to be used for surveillance or data retrieval. Items, such as cameras, microphones, and sensors will be fitted onto the vehicle to be deployed into the target area.

This is also due to small Reynolds numbers with the following picture showing relative scales of aircraft and associated Reynolds numbers.

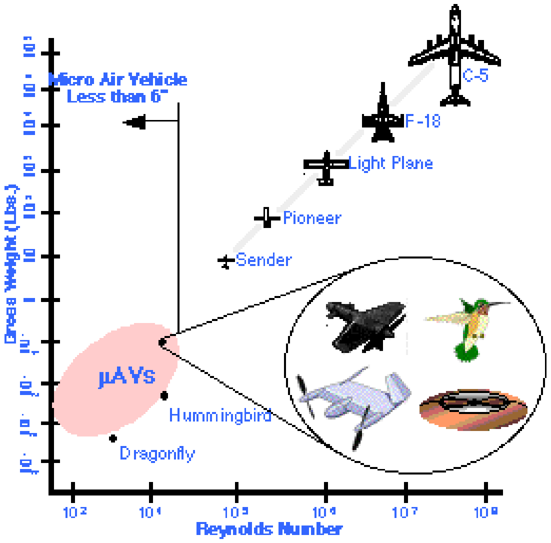

Figure 1. Reynolds numbers.

To power such a vehicle requires some radical and not so radical engines. To date, the most generally used power plant is a miniature two-stroke engine, such as the Cox Tee-Dee series .010 cubic inch engines. Universities such as Georgia Tech have been developing a small vehicle using a gas-powered engine. While this power system seems to generate enough energy to fly, the time aloft does not reach the intended goal of 20-60 minutes.

A less energetic power supply is from electric motors. This design is very simple and straight forward, but has a low power to weight ratio and has a very short flight time as well. One such vehicle is the Black Widow developed by AeroVironment. It is a small electric vehicle that has flown for approximately 16 minutes.

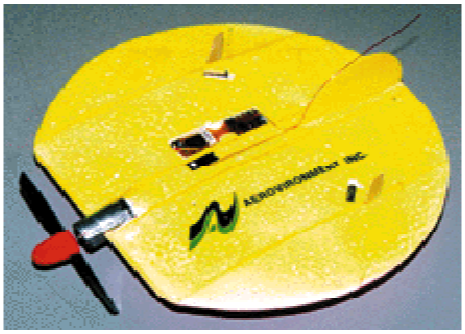

Figure 2. A sample MAV.

A more radical approach as seem from Robert Michelson's entomopter, which uses a micro propellant fuel to generate an up and down motion, such as beating wings or scurrying feet is also being developed. This approach seems the least likely to provide solid results, and the power source has yet to be proven efficient enough to develop into a vehicle.

While a winged design may appear most inefficient at this time, it is too difficult to estimate its potential at this time. Most studies will have to be conducted.

Some universities are more interested in the flight control such as the Aerospace Engineering, Mechanical Engineering and Engineering Science Department of The University of Florida. They are looking into an investigation of the use of Micro Electro Mechanical Systems (MEMS) to control the low Reynolds number flows about MAVs. “The Reynolds numbers for these flows are less than 100,000. Anticipated benefits from this research are improvements in MAV aerodynamic performance as well as the development of mechanisms for vehicle flight control.”

Control considerations would focus mainly around weight. To keep the control simple and the weight down, control surfaces should be reduced to a minimum. Meaning having a single control surface such as an elevator/aileron would be most efficient. Also, a super micro servo or activation arm would have to be used for electronic control.

This mock-up illustrates the Black Widow's flex circuit, which will incorporate all of the tiny plane's electrical connections and antennas (in the tail). Internal subsystems include linear actuators for the elevons, payload camera, three-axis magnometers, piezoelectric gyros, Global Positioning System receiver, a pressure sensor, a central processor, solar cells, and lithium and nickel cadmium batteries.

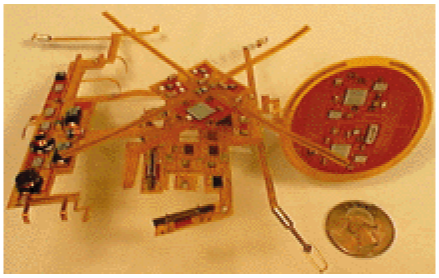

Figure 3. A MAV.

The flight characteristics have a wide range of possibilities. While the most conservative being the fixed wing design, other schools have been researching different techniques in hopes of finding a more efficient vehicle. University of Virginia: Carl Knospe

"Initial investigation has confirmed that a flapping-wing design, exemplified by the natural flight of insects, is a feasible solution for efficient flight in the required low Reynold's number flow regime of MAVs. Most insects that exhibit highly evolved flight characteristics fly in an intermediate Reynold's number range (10^2-10^4)."

Even alterations to the most simple of designs for flight can prove useful:

"Robert Englar, a principal research engineer at Georgia Tech Research Institute, is working on a fixed-wing model for the microflyer. By combining an altered wing design that has a rounded trailing edge and channeling the engine exhaust out of the wings through tiny slots, Englar's model employs what is known as the Coanda effect to greatly augment the wing's lift and control without any external moving parts. This results in an aircraft's ability to lift, land and turn, all at very low speeds without complex control devices. "

Because of the size limit, the onboard payload will have to be limited to around 20 grams. This includes any camera systems, sensors, radios, and control devices. While these items do exist, further development could prove to be most useful to carry a more in depth payload for better surveillance. The Black Widow, a small aircraft developed by AeroVironment, has been flown for about 16 minutes with its entire payload. It carried a small black and white video camera.

While each design does have potential not many people have thought about how to successfully control and develop a colony of micro air vehicles. With the initial request from DARPA for the air vehicles came standards and possible mission statistics that would be required from the MAVs. These were highly intensive reconnaissance and/or surveillance missions. With a colony of vehicles, some with redundant tasks, a high mission success rate could be attained. Even though the air vehicles are designed to be agile enough not to be shot down or destroyed during the mission, there is always a chance one could. If a colony existed where another vehicle could easily replace the first vehicles tasks, then the mission could continue without interruptions. Also, splitting up the tasks for the MAVs requires less equipment per vehicle, and they could be designed smaller or faster.

Finally, if there were a team or colony of MAVs in flight a proper control method would have to be developed, such as distributed control. Very little or possibly no research has been conducted on distributed control of MAVs working as a group. A network of communications could be established between vehicles to account for the lost of a percentage of the MAVs that would allow for continued missions. Also, would a central unit control them or would it be completely distributed evenly to all individual members.

4. NEXT GENERATION ROBOTIC PLATFORMS

The objective of this report is to investigate the possibility of building a lightweight remote vehicle platform for future research missions to Antarctica. It will be assumed that the platform is electrically powered and is wheeled versus legged or treaded. The platform should be self-sustainable, powered entirely by solar power, wind power, or a combination of the two. The platform needs to be structurally sound enough to withstand the design loads of the mission, yet light so that power requirements for movement are kept to an acceptable level so as to meet the power requirements. In order to achieve this a number of weight saving engineering approaches will be examined. This paper will look into the list of possible designs and materials for each design. The advantages as well as disadvantages of each design will be examined and compared to each other in terms of weight, cost, and building/manufacturing gains or losses.

4.1 Introduction

The polar ice caps have long been slowly melting, this is a known, what is unknown is at what rate. Geological surveying using RADAR systems could yield a tremendous amount of data about the ice caps, including the presence or absence of a film of water between the ice and bedrock, the ice thickness, and it’s internal layers. As stated on the project website, “The measurement of water at the bedrock level (basal water) is important basal water lubricates the ice/bedrock interface and makes it easier for the ice to flow toward the ocean. Data on near-surface internal ice layers will be used to estimate the average, recent accumulation rate, while the deeper layers provide a history of past snow accumulation and flow rates. This combination of data will help earth scientists determine more unambiguously how quickly the polar ice sheets are melting and to make more accurate predictions of the effects of this melting on sea level rise. Scientists have postulated that excess water is being released from polar ice sheets due to long-term, global climate change; but there are insufficient data to confirm these theories. Understanding the interactions between the ice sheets, oceans, and atmosphere is essential to quantifying the role of ice sheets in sea level rise. This, in turn, allows earth scientists to more accurately predict the probability of significant sea level rise. A significant sea level rise would have a devastating impact on world population, agriculture, and ecosystems since nearly 60% of the world's population lives in coastal regions which would become flooded.” (Reference __) Mapping the entire Antarctic using human sources would take a tremendous amount of time, money, and preparations. It would be most useful to use a remote, semi or fully autonomous vehicle with the appropriate equipment onboard to do the measurements. The goal of this project is to use a synthetic aperture RADAR (SAR) located on a remote vehicle to measure the significant data from the ice. Currently one vehicle is being developed that will be able to have direct human intervention daily. This takes more time to cover the same area and more workload on the human operators. If one remote vehicle could stay in the Antarctic for weeks or even months at a time without direct human contact a much larger area can be covered with the SAR than if the vehicle could only operate under direct human intervention, which would require the operators to be present in the polar region, and would require all the necessary provisions for the human operators as well. This approach would yield more results in less time, money, and risk to humans.

4.2 Robotic Platform

The first step in any design process is to decide what parameters or requirements must be met by the design. Once the requirements are set, then the design loads and parameters must be decided upon. In the case of this second-generation robotic platform the requirements are as follows: 1) The vehicle must be able to carry the design payload. 2) The vehicle must be able to withstand the polar environment. 3) The vehicle must be self-sustained using only the power is can obtain from solar or wind sources. All of those requirements must be met while still achieving the mission objective. The design loads will consist mostly of the payload weight (W_P), the vehicle weight (W_V), the wind loads (P_W), the propulsive loads (P_P), and to a lesser degree snow weight (W_S) and thermal loads (P_T).

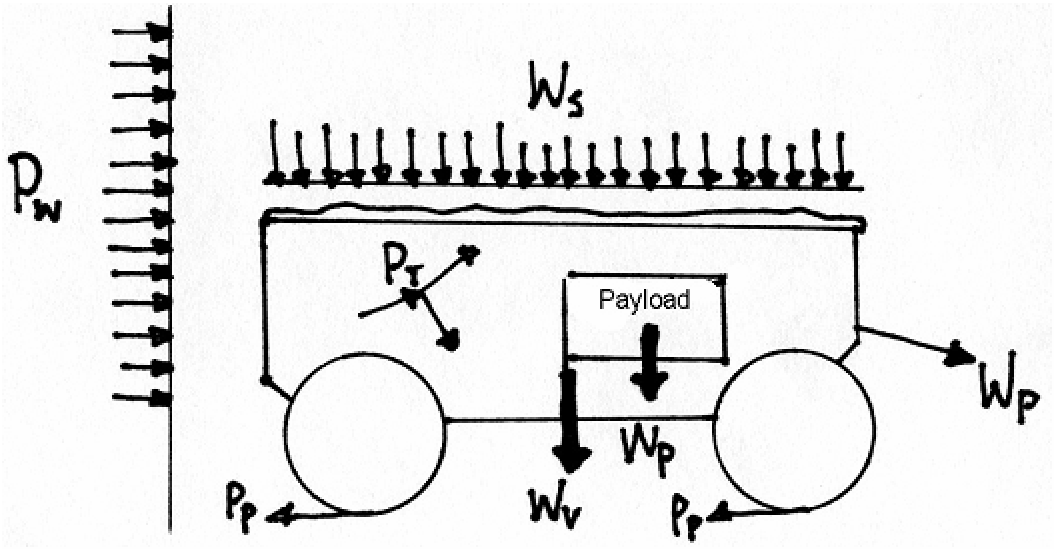

Figure 4. Load Distribution.

4.3 Design Loads

The analysis done in this paper will be very general preliminary work. Only a few general loads will be considered and many assumptions about those loads will be made in order to lessen the analysis workload and simplify the results. Above is a diagram of all the loads that should be considered for the design. Below is a breakdown of how each load will be considered, what assumptions about that load will be made, and the approximate value of the load that will be used.

4.3.1 Internal Loads

The assumption for this vehicle is that the payload will primarily consist of the SAR computer system and the antennae. The total mass of the payload will be roughly 250 N (W_P) and the antennae will be modeled two ways. One way will have the antennae in three sections, each about 1 meter by 3 meters (50 N). For the preliminary analysis the assumption will be made that the antennae sections will be modeled as distributed loads and the SAR computer system (100 N) will be modeled as a "black box" with a point load acting on the vehicle. The second model will have the antenna as a single piece (150 N) being dragged behind the vehicle. When the antenna is being dragged behind the vehicle it will be modeled as a point load where the antenna is "hitched" to the vehicle.

The mass of the vehicle will consist of everything else on the vehicle. This includes the structure itself, the electronics, motors, batteries, solar cells (if applicable), wind turbines (if applicable), and computer systems. It would be logical that each component of the system be lightweight, yet durable. The vehicle weight (W_V) will be modeled as another point force acting at the center of gravity of the vehicle. Again this is done to simplify the preliminary analysis conducted within this paper. The value of this load is variable and depends on the size and material makeup of the vehicle, but will begin with an assumed with of 750 N.

One last internal load to be considered would be thermal (P_T). These loads can come about from temperature changes from when the vehicle was manufactured to its mission operating condition and can come from differences in operating temperatures of the vehicle. Thermal expansion and contraction will result in internal stresses on the structure, but with proper precautions taken at the design and manufacturing stage these loads can be predetermined and accounted for. Because of this, it will be assumed that these loads have already been accounted for and will not be included in the analysis in this paper.

Also, pre-stresses due to manufacturing in the materials will also be ignored in this analysis.

4.3.2 External Loads

Another weight load to consider would be the load due to any snow mass that accumulates on the vehicle or antennae (W_S). To begin with it will be assumed that snow has about 1/8th the density of water. With water having a density of about 1000 kg/m^3 that yields a density of snow to be about 125 kg/m^3. Assuming a total area of the vehicle with the antennae to be approximately 10m^2 and a thickness of about 4 cm of snow on top of the vehicle gives a total mass of the snow to be about 50 N. This will be assumed to be the maximum amount of snow at one time on the vehicle. With the use of heaters and or wiper systems, the snow can be managed to never allow that much to accumulate and for all practical purposes the weight due to snow can be neglected.

For the purposes of design however, the assumption will be made that 4 cm of snow rests on the vehicle and will be modeled as a distributed load with about 5 N per square meter.

Wind loads (P_W) to be considered are due to the high wind velocity found in the Antarctic. The wind speeds have been recorded as high as 74.2 km/hour (Ref AGAH'S EMAIL) or about 21 m/s. The wind force will be modeled as being parallel to the horizon on to the vehicle. To find the magnitude of the force caused by wind the velocity of the wind is squared and multiplied by the area the wind will act over and the density of the air.

$$F=\rho AV^2$$

For the purpose of this paper, the wind velocity will be assumed to be 20 m/s, and the area of the vehicle will be assumed to be about 3 m^2. Assuming the density of air is approximately 1.20 kg/m3 (1 atm, 20^o C), this will equate to a force of 1440 N. This force will be modeled as a point force through the center of gravity.

Propulsive loads are the loads due to the locomotion of the vehicle. These loads will include friction between the vehicle and the ground, and vehicle/environment interactions that include loads such as point loads from collisions with objects in the field. An assumption of a point load of about 500 N will be made concerning collisions with objects. This value will be added onto the horizontal wind force and onto vertical weight forces. The frictional propulsive load will be assumed to be small due to the fact the vehicle will be moving at a relatively slow rate and the magnitude is relatively small compared to the wind and weight forces. Therefore those loads will be ignored. Torque loads due to the motor will also be neglected becomes of the relatively small magnitude compared with the rest of the loads.

All of these loads will be utilized later in the paper during the structural analysis portion to find estimates of material needs.

Wind Loads	Vehicle Weight	Snow Weight	Thermal Loads	Point Loads	Payload Weight
1440 N	750 N	50 N	~	500 N	250 N

Table 1. Design Load Summary

5. PLATFORM MECHANICS AND MATERIALS

5.1 Structural Considerations

- Build from Scratch
- Purchase Partial Chassis
- Purchase Full Chassis and Modify

5.2 Build From Scratch

- Materials
- Design
- Building cost
    - Man hours
    - Dollars
    - Calendar Days

5.3 Materials

- Aluminum
    - Low cost
    - Easy to Machine
- Stainless Steel
    - Low cost
    - Heavy
- Titanium
    - Light Weight
    - Small Coefficient of Thermal Expansion
    - Hardest to Machine
- Carbon Fiber

    - Expensive
    - Fragile
    - Smallest Coefficient Of Thermal Expansion

5.4 Cost of Material Choice

- Cost
    - Purchasing Price
    - Machining Price
    - Replacement Price
    - Shipping Costs (Weight issue)

5.5 Aluminum Alloys

- Cost per pound is about 75–80 cents
- Very easy to work with
- Light weight (0.1 lb/in^3)
- Non-Corrosive in most applications

5.6 Stainless Steel

- Costs about 80 cents per pound
- Fairly easy to work with – but still some skilled workmanship needed
- Heaviest of the four materials (0.284 lb/in^3)

5.7 Titanium

- Costs 10-15 dollars per pound
- Very hard to fabricate finished products
- Alloys such as Ti64 (Ti-6% Aluminum 4% Vanadium) are commonly used
- Tensile strength of about 135,000 psi, 40% lighter than steel
- Low weight (0.160 lb/in^3)

5.8 Carbon Fiber

- Costs roughly 45-50 dollars a pound (Aerospace Grade)
- Can be molded
- High specific Strength and Rigitity
- Corrosive to Aluminum
- Radio interference, negligible

5.9 Thermal Expansion

- Al – 13.7 x 10^{-6} in/in/F
- For a 5 foot section from 100 degree to –22 degree is: .1003 inches
- If the entire machine is the same material, the entire machine shrinks or expands similarly

5.10 Partial Chassis

- ATV Chassis
- Buggy Chassis

5.11 Buggy

- Tube Frame
- Roll Cage
- 4 Wheeled

5.12 ATV

- Smaller Tube frame
- Usually odd Shaped
- No Roll Cage

5.13 Full Chassis

- More complete – Just have to modify to meet our needs.
- Nothing is perfect, but we can narrow it down to the best choice.

5.14 Choices

- ATV
- 6 – Wheeled Amphibious
- Snow Mobile
- Tank
- How much are we willing to spend (Time and Money)?
- Which option will yield the best results?

6. WINTERIZATION OF ROBOTIC PLATFORM

The first steps taken were to determine the best method for protecting and weather proofing the interior of the vehicle. Ideas such as an aluminum shell, a fiberglass shell, or a carbon fiber shell were entertained. After initially discussing the preliminary design it was decided a fiber shell would be most useful. Its weight savings meant less work to remove the shell and transport it to the Antarctic. Manufacturing the shell versus the aluminum one seems to be about as difficult, and I was able to find a supply for the fiber.

The next step was to build a model of the shell. The model wasn't scale, but more of a rough shape, in order to test the method of building a mold and then making the shell. Large sheets of pink insulation foam and support 2x4 and 1x2s were purchased to use as the mold.

It was found that cutting the foam and assembling the mold neatly was very difficult to do. Trying different techniques such as cutting more foam to use as the corner pieces, using a spray on insulation foam, and finally using plaster in the corners helped to determine the best method. I had found that just using the foam alone is the best method. On the final vehicle, tools should be made to help cut the foam accurately to produce the best fitting.

At this time the initial model structure for the shell of the autonomous vehicle has been built. The model was made using fiberglass mainly because of the lack of loads on the structure. The model was built using the test mold. It was found that come of the corners in the model were too sharp to obtain a well made shell, but the corners of the actual vehicle can be made with large radii. Also, the mold was night airtight and a vacuum could not be made around the shell, this allowed the extra resin and air to remain in the shell. This greatly increased the weight and decreased the strength.

At this point, if the final vehicle dimensions are available, the full-scale mold should be built. This will be a lengthy process, as the mold should be as smooth as possible, because any sharp corners or ridges will be transferred to the shell later. Once the mold is built, it should only take a couple of days to lay-up the fiber and cure it.

The protective shell of the vehicle is needed to keep the weather from disrupting the electronics of the vehicle inside. The shell's design was decided to be as smooth and curved as possible so that no corner point loads would develop. The shell could be made from either carbon fiber or fiberglass. The latter should be used if the shell has no specific loads that it needs to carry and the carbon fiber should be used it the shell will take on large loads. Such loads could be carrying equipment, or in case the vehicle rolls over and the shell needs to hold it.

Another option could be a cage feature built on the outside of the vehicle to protect in case of roll over. This cage could also support any equipment mounted to the outside of the vehicle. This would complicate the design, but allow for a much less robust shell.

Finally, doors need to be placed in the shell design. To simplify the door design, the area around the door should be as flat as possible. The door design should be incorporated into the shell while it is being built. This would include the opening and a flange built around the opening for the door to rest on. The attachment mechanism for the door could be a latch and hinges, or simply a couple latches and the entire door could be removed. The latter would allow easier access to the vehicle.

Around the door and around the shell, between the interface of the shell and the vehicle, rubber gaskets should be used to allow for a tight seal. The temperature extremes should be considered when choosing the gasket.

When the final vehicle dimensions are decided upon, a mold must be built from which the shell can be built into. Using the pink insulation foam seemed to work well for large areas, and around the curves I would suggest using foam again. For each curve a tool should be built so that the cutting wires can have a guide for cutting the foam. The KU aerospace department has a larger hotwire, which would be useful for large areas that need to be cut. Assembly should be adequate enough that the mod does not break during transportation. It could be possible to have the equipment brought to the Nichols hall lab if the situation calls for it. Once the mold is made, it should be thoroughly sealed to allow for an airtight vacuum to be placed over it. The process takes many hours, and should require at least three or four people. Each sheet of material is first cut into shape for the vehicle. Many layers will be needed depending on the strength required. Once all the pieces are cut, included the release film, the bleed film, resin blanket, and vacuum bag, then the epoxy is mixed. The epoxy has a work time of about 2 hours. Each sheet must be wetted through out both sides and placed in to position. Then the bleed film, resin blanket, and vacuum film is placed on top and a vacuum seal is obtained to pull out any extra resin and air bubbles.

When attaching the shell to the vehicle, point loads should be avoided if possible. Since the shell shouldn’t be taking too much load, these point loads won’t affect the structure very much, but they should be avoided as the produce stress concentrations in the fiber.

7. COMMUNICATION IN MULTI-ROBOT SYSTEMS

7.1 Introduction

Today Robot Systems are becoming more and more significant in various aspects of human life, for example in industrial, commercial and scientific applications. As a result of scientific achievements and industrial development, the number of robots currently being used is fast increasing. However, robotics have been evolving in the last years and there has been an increasing interest in developing Multi robot systems, capable of performing robust cooperative work.

Multi robots or Multibots as they are usually termed is a group of robots, cooperating and coordinating each other to work efficiently in realizing a common goal. Multirobot systems are becoming a large topic of research in the robotics field.

7.2 Communication in the Multi Robot System

(In the present scenario), there are three types of communication between the master(main robot) and the slave robot(remote unit or remote agent).

The first is the control communication in which the master gives the slave, the motion commands, the direction specification, the path to be followed by the slave and so on. This communication also includes sending the critical information to the slave along with the usual control data. The channel used for this communication is termed the command channel.

The second is the state communication between the slave and the master. This includes the communication of the state of the system of the slave to the master. The master takes care of its own state by analyzing the sensor data obtained by its sensors. But the slave has to be taken care of, which is done by sending the state information. A separate channel can be used for state communication which includes the data from the onboard sensors, the energy level of the slave robot, the critical state of the robot and so on.

The third is the data communication. This involves communicating the obtained data of the results performed by the slave robot in the harsh environmental conditions. The data usually is made up of radar data and the onboard equipment conducting the various experiments analyzing the thick ice glaciers.

Three separate channels may be required for the communication between the master and the slave for the three communication modes. It is also very important to see to it that no information is lost in between. So Reliable communication schemes have to be deployed. Let us consider the cases when there could be some loss or delay in communication between the two agents.

If the control communication is compromised, then it is obvious that the slave will not get the required control command in time and the system may become unstable. If the state communication is lost or delayed then the user will not be able to determine the state of the remote agent and cannot issue the command to the agent. If the data communication is lost, then the control communication is not affected, but the sole purpose of the project is lost, since the agent is unable to give the data it has collected while conducting the experiments.

It is also observed that the data communication between the remote agent and the main robot requires most of the communication resources and there is lot of information being forwarded in this channel than the total combined of the other two. So this communication may be assigned more channels than the other two.

7.3 Wireless Communication

Most single robot systems communicate with some sort of base station or controller. These robots might even send information to servers so Internet users can view in real-time the data processed by the robots. These mobile robots cannot afford to have tethers attached to them if they want to explore large spaces. Wireless communication devices are required to transfer control and telemetry information to and from the robots.

Successful control and coordination of a group of wireless networked robots relies on effective inter robot communication. With increased use of wireless communications, transmission power can be a significant system cost, given the life of the robots. Wireless Ethernet is far more energy expensive but is a natural medium for communication between mobile robots. Minimizing the transmission time can save power for other useful work. Robots typically act in strict real time constraints of fast navigation and rapidly changing environments that require the control input to the agent be acquired on a regular basis. Heavy load on a wireless network increases the average data transmission time, reducing the frequency response of the agent's controllers. Reducing load by efficient communication can decrease latency of the system and allow robots to be more responsive to the ever-changing, unpredictable environments. Also bandwidth is also a precious resource given the amount of data that is being sent in both the directions. Communication therefore has the implications of the controllers' robustness, efficiency and capability. The communication should be as efficient as possible, to save power and reduce the latency.

7.4 Wireless Ethernet for Communication

There are three basic products in the wireless Ethernet world- bridges, access points, and adapters. The bridges are stand-alone units, which have a network jack that connects to a hub. They allow multiple computers of one side of the link communicate with multiple computers on the other side of the link. The access points connect to a hub and allow multiple computers attached to that hub (which could include the entire Internet) talk to single computers, each with their own wireless adapter. A wireless adapter allows one and only one computer to communicate over the link. Adapters come in the form of PCI, PCMCIA, and ISA cards and also standalone units.

The FCC (Federal communication Commission) has designated three bands in the Industry, Scientific, and Medical (ISM) spectrum that wireless Ethernet can operate without a license. These are set at 900 MHz, 2.4 GHz, and 5.8 GHz. It is possible to achieve bandwidths anywhere from 500 kb/s to 33 Mb/s. The 33 Mb/s device work by running three 11 Mb/s links in parallel on three different channels. The newest Ethernet cards run at 11 Mb/s and are the cheapest ones on the market. (A comparison table of all the available wireless bridges is provided)

Radio communications make use of a spread spectrum technique, which allows for reliable communication even with external interference. The types of transmissions are frequency hopped spread spectrum (FHSS) and direct sequence spread spectrum (DSSS). FHSS is supposedly better than DSSS when used with many other devices operating in the same band on different channels because of the least overlap. DSSS is good when there is a lot of noise in the spectrum, for instance noise from microwave ovens or some other equipment working in the same vicinity.

A wireless Ethernet bridge allows multiple computers with their own Ethernet addresses to connect to multiple computers on the other side of the link. These bridges can work in a multipoint or point-to-point configuration [8].

7.5 Wireless Bridges

The Wireless Bridge is similar to a router, but routers do not have the bridge's ability to learn addresses and end up doing more data processing than bridges do.

A bridge connects two LAN segments into one larger continuous LAN and works by building an internal list of addresses of the attached network devices in both sides of the network. When a packet is forwarded to a bridge, it checks the packet's address against its internal list; if the destination address is on the other side of the segmented LAN, then the bridge forwards the packet. The packet is also forwarded if the destination address does not match with any of its lists.

Bridges operate in the Data-Link layer of the OSI (open System Interconnection) model. They can distinguish local and remote data and the data supposed to be for a node with in the same segment of the LAN need not have to go over the bridge. All Bridges act on MAC (Medium Access Control) Layer addresses. They are protocol independent (unlike the routers which need to have a knowledge of all the protocols used to forward a packet), so can transfer data between workstations without actually knowing the protocol. This would imply that the bridges need very little configuration (compared to routers).

There are two main types of wireless bridges--local and remote. A local bridge connects two LANs within close proximity. Organizations use local bridges to segment traffic within a facility by having each department or workgroup connect to a corporate backbone via a local bridge. On the other hand, remote bridges connect networks separated by longer distances. A Company will usually install remote bridges to provide network connectivity between buildings, cities, and even continents. This requires a pair of bridges, one at each site, and a circuit between them to provide a physical layer connection. Traditionally, organizations have used the analog telephone system and leased 56Kbps and T1 digital circuits to provide the connection between remote bridges.

Wireless remote bridges are very similar to traditional bridges, except wireless bridges use a wire-free medium, such as spread spectrum radio or infrared laser light, to provide a physical layer link. These bridges provide links that can span up to 25 miles, but, to do so, they require highly directive signals to concentrate signal power at the destination. Therefore, wireless remote bridges normally require a line-of-sight path between source and destination. Organizations can use wireless remote bridges to permanently connect networks together, provide emergency back-up circuits for disaster recovery, or support immediate temporary data links while other connectivity is being installed.

Wireless remote bridges, which can range from $10,000 to $25,000 a pair, are somewhat pricier than traditional bridges. However, given the advantages they have over the traditional bridges, they are probably a more economical solution.

7.5.1 Applying Wireless Remote Bridges

A set of wireless remote bridges may be the best alternative to provide connectivity between networks located within semi-local areas, such as office parks, campuses, hospitals, and metropolitan areas. In the present case where the robots are supposed to be 6 to 10 kilometers apart the local bridges with a maximum range of 3 miles may not be able to ensure connectivity in all cases. The remote bridges however will remain connected in this case.

The wireless remote bridges can be classified as radio based and laser based depending on the type of technology they use for communication.

7.5.2 Radio-Based Remote Bridges

Most wireless remote bridges use radio waves to provide connectivity between networks. To facilitate the radio connection, these bridges consist of a radio modem and an antenna. A radio modem is similar to the common telephone modem converting digital signals into analog signals suitable for propagation through a medium. Telephone modems send analog signals at low audible frequencies through the telephone system. But, with radio modems the analog signals are at HIGH frequencies and are sent through the air.

The radio modem uses digital Ethernet or token ring signals to modulate a radio wave signal. The antenna couples this signal to the air, which enables transmission of the signal to the distant modem at the opposite site. The range of a wireless link is based on the point at which a connection still remains. Moving out beyond that point will cause a loss of a connection. A proper connection exists if the destination can correctly receive data from the source at a specified minimum data rate. If the reception of data on a particular channel results in a number of bit-errors that exceeds the desired maximum error rate for that link, then the connection no longer exists.

High output power of the radio modem, antenna directivity, and the environment can reach the transmission to farther sites apart and still maintain the connection. At higher transmit power, electrical noise has less affect on the information signal. Thus, the received signal will have a lower error rate. The problem, though, is that the Federal Communications Commission (FCC) requires radio modems to work at very low power levels, which physically limits the range to semi-local areas.

Most wireless LAN bridges use an Omni directional antenna that broadcasts the signal in all different directions. These antennas provide relatively short ranges because the antenna spreads the power out. The signal does not have much strength in any direction, which limits range to less than 1,000 feet. But, this is fine in a LAN because you want full connectivity, and extensive range isn't very important. But with Remote bridges, large range for connectivity is required. To achieve appreciable ranges, remote bridges use antennas that produce a highly directive radio signal that adds gain to the signal. These antennas focus the power into a narrow beam-width aimed at the receiver. This allows the modems to be farther apart, than the normal value.

The environment also affects the range of radio signals. Highly directive radio signals mostly require a line-of-sight operation because they don't propagate very well through or around large solid obstacles, such as buildings and mountains. Thus, these obstacles can severely limit the radio modem range. Interference from rain, fog, and falling snow can moderately limit the range of directive radio signals.

Most radio-based remote bridges utilize spread spectrum modulation. Spread spectrum, developed originally by the military, spreads a signal's power over a wide band of frequencies. The main reasons for spreading are the signal then becomes much less susceptible to electrical noise and less interfering with other radio-based systems. Most interfering noise is narrow in bandwidth; therefore, noise only interferes with a narrow part of the wide band spread spectrum signal. As a result, when the receiver spreads the signal, the resulting noise power is negligible. The reason spread spectrum systems don't cause much interference with other systems is that the spread signal is much lower in amplitude than conventional radio signals. Therefore, very little interference occurs.

Most wireless remote bridges on the market use spread spectrum radio for the medium equipped with an Omni directional antenna, that provides local wireless bridging, or a directional antenna that provides the range needed for remote bridging. In addition, these products offer Simple Network Management Protocol (SNMP) as an option to allow effective network management through the use of SNMP-based management platforms and applications. For encryption, most of the products offer optional DES encryption chips to keep the bad guys off from stealing the data.

Some wireless remote bridges operate in the narrow band 18-19 GHz frequency range. These bridges do not use spread spectrum modulation, and the FCC requires users to obtain licenses to operate them. This allows the FCC to control the use of these frequencies to avoid interference problems.

7.5.3 Implementing Radio-Based Remote Bridges

The implementation of wireless bridges varies from the traditional bridges in that the wireless has potential interference problems and security issues, which are of utmost concern.

Because of the propagation techniques that radio-based wireless bridges use, it is nearly impossible to completely contain the radio signals within an area equivalent to wire medium. With radio wave systems, a signal is transmitted with lots of energy in the direction of the destination. The reason is, it can be expected that someone can detect wireless signals relatively far away using less sensitive equipment. Therefore, in terms of security, the main difference between radio-based and wired networks is that a wireless network propagates the signal power over a larger area. Because of this, a bad man can easily receive the radio signals at a significant and safe distance. However, bridges usually employ an encryption scheme so that the data even if captured by the bad man would make no useful sense to him. Another security concern is that the radio based network can be sabotaged by using high power transmitters to block the radio transmissions. But this is avoided by the use of spread spectrum.

Signal interference could be a problem with spread spectrum systems because many products share the public ISM bands. Since the FCC does not require licenses in the ISM bands, they do not regulate use of these frequencies. So, the users have to fend for themselves when it comes to frequency management.

7.5.4 Laser-Based Remote Bridges

Some wireless remote bridges use infrared laser light as a medium to carry data between networks, instead of radio transmissions. Laser modems produce light with a wavelength of 820 nm. This wavelength produces light just below the color of red. Under most lighting conditions, these laser beams are invisible to the naked eye. Laser light is also naturally highly directive, and the laser beam does not spread as it travels from the source to destination. This means that there must be a stringent line-of-sight orientation between the source and destination. Typical transmission distance with laser-based remote bridges is 4,000 feet, which is relatively short compared to the radio based bridges, because of limited laser power.

One of the main advantages of using infrared light as a medium is that it has an abundance of bandwidth. Thus, laser remote bridges can offer very high data rates. Most laser systems can support transmission of data signals that can easily match Ethernet and token ring speeds.

The price of a set of Ethernet-compatible laser modems is approximately $20,000, which does not include the traditional bridges. The complete laser bridge system can be more expensive than radio-based bridges, but the higher data rates supported by laser may be worth the extra money.

Another advantage of laser light is that it is not susceptible to interference from the wide array of radio-based systems. Therefore, laser bridges will operate very well in areas where the radio spectrum is crowded, which is the case in very large metropolitan cities or in and around military bases. In addition, laser systems do not project outward interference that can interfere with radio systems. In fact, infrared laser frequencies are so high that laser-based remote bridges do not currently require FCC licensing.

Laser bridges also offer a high degree of signal privacy, similar to that of an optical fiber system. To intercept a laser signal, a person would have to locate himself directly between the laser's source and detector, which is rather a difficult task to do without getting noticed. In addition, extracting part of the laser signal from the point-to-point path would decrease the power at the destination, which could alarm network management operations. Of course, proper encryption will keep a data pirate from making sense of the information.

7.5.5 Implementing Laser-Based Remote Bridges

While implementing a laser bridge system, the affects of weather, orientation, and potential health risks are the first to be considered. Weather has a greater affect on laser light than radio waves. Heavy rain, snow, and fog can cause a significant amount of scattering, which diverts the laser beam in many different directions. The scattering results in a reduction in signal power, decreasing the operating range between source and destination. For example, a one-kilometer laser link would probably lose connectivity if it was raining or snowing at least three inches per hour.

While installing a laser system, it has to be made sure that the line of site is always maintained for proper working of the bridge. Laser installations should also avoid East-West orientations because sunlight can cause interference during sunrise or sunset.

Laser systems require more caution than radio bridges. In the United States, the Center for Devices and Radiological Health (CDRH) of the U.S. Food and Drug Administration reviews laser products for possible health risks. The CDRH specifies four classes of lasers according to their ability to cause harm. The CDRH rates most laser bridges as Class III, which have the potential of eye damage if someone looks directly at the beam. Thus, care should be taken when aligning the lasers during installation.

7.6 Conclusion

The present communication system is being analyzed to be employed in Antarctica where the temperature conditions are at their extremes and totally unpredictable. The robots being employed in this project are mobile and can work in autonomous and manual modes. The robots being mobile, wireless communication is being employed for the control, state and data communication.

The wireless communication makes use of wireless bridge to connect the segmented LAN of the master and the slave units. The robots are mounted with a good number of computer workstations and laptops connected to a LAN. The pair of bridges provided with antennas and amplifiers connects all these workstations into a bigger LAN. The bridges being employed are remote bridges given the range of their connectivity.

When it comes to whether the Laser Bridge or the Radio Bridge, the fog and snow factors limit the usage of the laser based remote bridges. Also the laser bridges would require that the antennas of both the bridges be facing each other, which is not possible, given the mobility of the robots in all directions. Also the potential health risk provided by the Laser Bridge restricts its usage.

As for the Radio Bridge, the Frequency hopping bridge has little interference compared to the Direct Sequence Spread Spectrum. But in a place like Antarctica where the occurrence of radio interference is little, we would not be worrying about the possible loss of data due to interference. The bridges employed for the purpose confirm to the IEEE 802 standards. They employ the 802.3 standard for physical interface and 802.11 for wireless interfacing.

7.7 Glossary

7.7.1 The OSI Model for Open Systems Interconnection.

In 1978, the International Standards Organization (ISO) created a universal standard for exchanging information between and within networks and across geographical boundaries. This standard for network architecture is the seven-layer model for Open Systems Interconnection (OSI), which has encouraged conformity in designing communications networks and controlling distributed processing.

Manufacturers are developing intelligent computers and equipment, and numerous private and public data networks have been created to connect it. But communication among these distributed systems and networks requires a standard approach to network design, one that defines the relationships and intersections between network services and functions via common interfaces and protocols.

The layered approach to network architecture stems from the operating system (OS) design. Because of their complexity, most computer OSs are developed in sections, each of which has a particular function. This makes it simpler to refine each section to meet its functional goal. Ultimately, all sections are integrated to provide complete capabilities and services with a smooth-running OS.

The same is true in designing networking systems. Network architecture specifies a hierarchy of independent layers that contain modules for performing defined functions.

This translates into a set of rules that defines the way participating network nodes must interact to communicate and exchange information. The OSI Model defines standard relationships between the hardware and software in today's complex computer systems

Each layer of the OSI Model shown provides specific services that contribute to overall network functioning.

- The Physical Layer defines the electrical and mechanical aspects of interfacing to a physical medium for transmitting data, as well as setup, maintenance, and disconnection of physical links. When implemented, this layer includes the software driver for each communications device, plus the hardware itself (interface devices, modems, and communications lines).

- The Data-Link Layer establishes an error-free communication path between network nodes over the physical channel, frames messages for transmission, checks the integrity of received messages, manages access to and use of the channel, and ensures the sequence of transmitted data.
- The Network-Control Layer addresses messages, sets up the path between communicating nodes, routes messages across intervening nodes to their destinations, and controls the flow of messages between nodes.
- The Transport Layer provides end-to-end control of a communication session once the path has been established, which enables the reliable and sequential exchange of data independent of both the systems that are communicating and their locations in the network.
- The Session Layer establishes and controls system-dependent aspects of communication sessions provided by the Transport Layer and the logical functions running under the OS in a participating node.
- The Presentation Layer translates and converts transmitted encoded data into formats that can be understood and manipulated by users.
- The Application/User Layer supports user and application tasks and overall system management, including resource sharing, file transfers, remote file servers, and database and network management.

7.7.2 IEEE Standards for Local and Metropolitan Area Networks.

IEEE 802.3

This is a comprehensive International Standard for Local Area Networks (LANs) employing CSMA/CD as the access method. This international standard is intended to encompass the several media types and techniques for signal rates from 1Mbps to 1000Mbps.

IEEE 802.11

The scope of this standard is to develop a medium access control(MAC) and physical layer (PHY) specification for wireless connectivity for fixed, portable and moving stations within a local area.

The purpose of this standard is to provide wireless connectivity to automatic machinery, equipment or stations that require rapid deployment, which may be portable or hand held, or which may be mounted on moving vehicles within a local area. The standard also offers regulatory bodies a means of standardizing access to one or more frequency bands for the purpose of local area communication.

This standard specifically

- Describes the functions and services required by an IEEE 802.11 compliant device to operate ad hoc and infrastructure networks as well as the aspects of station mobility (transition) within those networks.
- Defines the MAC procedures to support the asynchronous MAC service data unit (MSDU) delivery services.
- Permits the operation of an IEEE 802.11 conformant device within a wireless local area network (LAN) that may coexist with multiple overlapping IEEE 802.11 wireless LANs
- Describes the requirements and procedures to provide privacy of user information being transferred over the wireless medium (WM) and authentication of IEEE 802.11 conformant devices.

7.8 References

[1] ‘A multiagent Robot Language for communication and concurrency control’, Horoyuki Nishiyama, Hayato Ohwada and Fumio Mizoguchi.

[2] ‘Communication In Reactive Multiagent Robotic Systems’, tucker Balch and Ronald C.Arkin

[3] Cooperative mobile robotics, Y. Uny cao, alex Fakunaga, andrew and frank meng

[4] Coordination models for multi agent systems

[5] Coordination of mobile robots for large scale assembly, Ried Simmons, Sanjiv singh, David, Josue Ramos, Trey Smith

[6] Command control tools for many robot systems, Douglas W.Gage.

[7] How to communicate with robots, Douglas W.Gage

[8] Wireless Remote Network Bridges, by Jim Geier.

[9] Wireless communication Technologies,

[10] Evaluating Control Strategies For Wireless-Networked Robots Using An Integrated Robot And Network Simulation, by Wei Ye, Richard T. Vaughan, Gaurav S.Sukhatme, John Heidemann, Deborah Estrin Maja J.Mataric.

[11] Mathematical theory of communication, C E Shannon

[12] Evaluating Control Strategies for Wireless networked robots using an integrated robot and network simulation, Wie Ye , Richard T.Vaughan, Gaurav S.Sukhatme, John Heidemann, Deborah Estrin, Maja J. Mataric.

[13] Routers and Bridges, a white paper.

[14] Mobile MultiRobot Cooperating Systems using Real time Communication, by Miguel Angel López Bernal

[15] Marvin Conception, TU Berlin, Department of Computer Science, Real Time systems and Robotics.

[16] Tele-autonomous Obstacle Avoidance, by Johann Borenstein and Yoram Koren, The University of Michigan

[17] Brown robotics Projects – Urchin.

ACKNOWLEDGEMENTS

This work was sponsored in part by a grant from the National Science Foundation, entitled: "ITR/SI+AP: Mobile sensor web for polar ice sheet measurements."