Preliminary Results on the use of Stereo, Color Cameras and Laser Sensors in Antarctica

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Abstract: In November of 1998, an expedition from Carnegie Mellon University travelled to the Patriot Hills, Antarctica. The purpose of the expedition was to demonstrate autonomous navigation and robotic classification of meteorites and the characterization of various robotics technologies in a harsh, polar setting. This paper presents early results of experiments performed on this expedition with CCD cameras and laser range finders. It evaluates the ability of these sensors to characterize polar terrain. The effect of weather on this characterization is also analyzed. The paper concludes with a discussion on the suitability of these sensors for Antarctic mobile robots.

1. Introduction

Antarctica is a unique area on Earth for meteorite search. The flow of blue ice causes meteorites to concentrate on stranding surfaces, often near mountains. The cold and relatively dry environment in Antarctica helps to protect meteorites against significant weathering. Also, as meteorites commonly occur as

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dark objects against a lighter background, they are more easily spotted. Meteorites are typically 3cm in diameter and search is performed by humans on foot or skidoo. The search and initial identification is done using vision alone, and up to now no practical method exists to detect meteorites buried in ice or snow.
Systematic search and reliable identification of meteorites in Antarctica can be difficult for humans [1]. The development of robotic capabilities can help scientists find buried meteorites as proposed in [2] and in surface detection and classification as performed currently at Carnegie Mellon University (CMU) [3]. Robots can also be used to support human activities in Antarctica with logistical applications and could be a powerful tool to deploy instruments for Antarctic exploration and study as proposed in [4].

1.1. Expedition Overview

As part of the three year Robotic Antarctic Meteorite Search program [3] at CMU, the rover Nomad, designed for the Atacama Desert Trek [5], was deployed at Patriot Hills (80S,81W) in Ellsworth Land, Antarctica in collaboration with the University of Pittsburgh and the NASA Ames Research Center. The deployment was for 35 days in November and December 1998.
The expedition demonstrated autonomous navigation in polar terrain [7] and meteorite detection and classification [8]. Experiments were also performed on systematic patterned search [9], ice and snow mobility, landmark based navigation and millimeter wave radar. Foot search by the expedition found two meteorites [1].

1.2. Robotic activities in Antarctica

Previously underwater vehicles like ROBY and SARA from Italy [10] and TROV from NASA Ames [11] have explored the sea near coastal bases. On land, the walking robot Dante explored Mt. Erebus [12]. Italy has also conducted mobile robot research for robotic applications in Antarctica with the RAS project as detailed in [13]. We can also note the design of a chassis, see [14], for an Antarctic rover lead at LAAS.

2. Camera and Stereo Results

Vision, and in particular stereo vision, is a common sensing modality for robots. Antarctica provides many challenges to the use of vision for navigation and other tasks. The cold temperatures mean that the cameras must be heated and kept in sealed enclosures to prevent snow melting on the warm camera. Ice may form on the lenses, distorting and obstructing the view (Figure 1). Further, the nature of the terrain - large, featureless plains of white snow and blue ice, make it difficult for stereo matching.
This section presents the results of experiments performed using color cameras mounted on a tripod and Nomad's stereo cameras. Nomad has two pairs of B&W stereo cameras mounted on a sensor yard 1.67m above the ground (Figure 9).

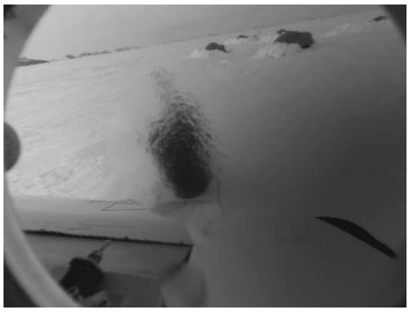


Figure 1. Image with ice on lens

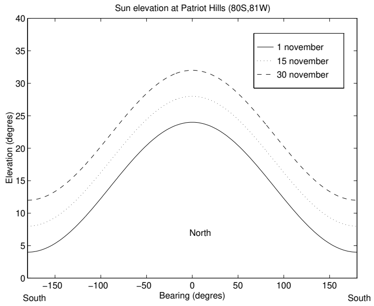
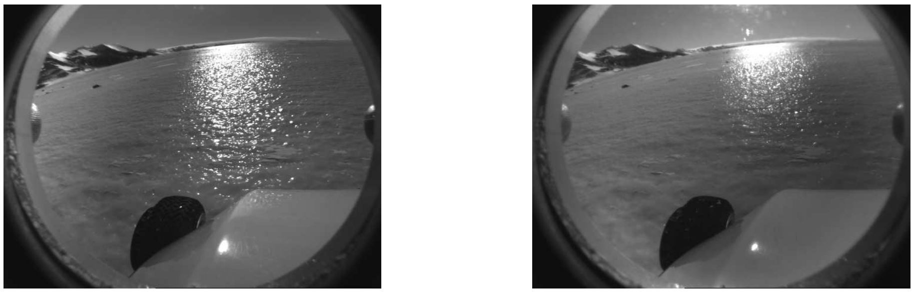


Figure 2. Sun elevation

2.1. Sun Influence

In the austral summer, the sun is above the horizon 24 hours a day but always remains low on the horizon as seen in Figure 2. The terrain in the Patriot Hills region is also highly reflective, consisting largely of snow and ice, and so a high level of glare was expected. It was anticipated that this glare, combined with low sun elevation, would cause high light levels producing pixel saturation and blooming in the CCD cameras.

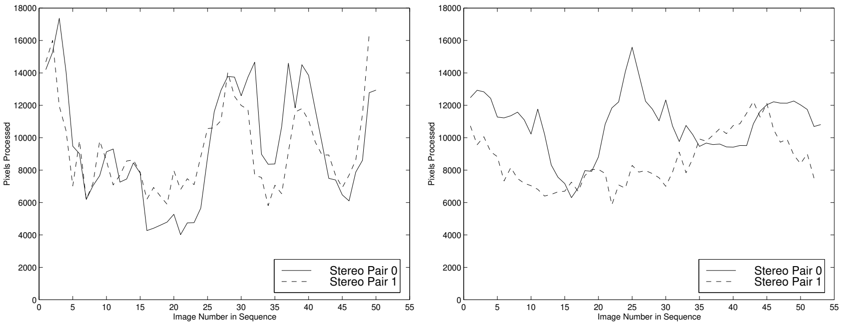
In practice sun influence was not an issue. Conditions were bright on sunny days but the camera iris and shutter were sufficient to regulate the ambient light and produce good pictures. As seen in Figure 3 glare was present in the images taken on blue ice fields. The use of linear polarizing filters reduced the glare but had little effect on the number of pixels matched in stereo processing. Direct viewing of the sun by the stereo cameras was also not a problem. The local topography of the Patriot Hills helped to reduce this problem. Since the Patriot and behind them the Independence Hills occupied the entire southern horizon, the sun was behind them when it was at its lowest point - at midnight.



(a) (b)

Figure 3. (a) Image without any filter (b) Image with linear polarizing filter.

To demonstrate the effect of sun position on stereo matching image sequences were captured as Nomad drove in circles of 4.0m in radius. The number of pixels matched in each image pair are shown in Figure 4. The graphs show minor dependence on sun position. The sun was in front of Nomad in images 0 to 7 and 34 to 42 in Figure 4(a) and 13 to 25 in Figure 4(b).



(a) (b)

Figure 4. (a) Pixels processed for stereo pairs 0 and 1 while driving in 4.0m radius circle on snow. (b) On blue ice.

Terrain Type	**Av. Num. of Pixels Pair 0**	**Pair 1**
Snow	9526	9231
Ice	10800	8602
Moraine	9460	10637

Table 1. Effects of Terrain on Stereo

Weather	**Av. Num. of Pixels Pair 0**	**Pair 1**
Sunny	9526	9231
Overcast	4973	5960
Blowing Snow	14223	9917

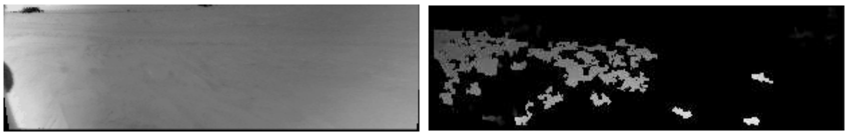
Table 2. Effects of Weather on Stereo

2.2. Terrain Effects

Three common Antarctic terrain types - snow, blue ice and moraine - can be found in the Patriot Hills region. The snow fields consist of hard packed snow which is sculpted by the wind to resemble small sand dunes. These snow dunes are referred to as sastruggis and can be obstacles for Nomad. The blue ice forms large plains that seldom have features to impede a robot. The surface of the ice is pock marked with many small depressions (5cm diameter) called sun cups. A moraine is a large collection of various sized rocks on ice. The rocks at the Patriot Hills moraine were very sparsely distributed. Blue ice with small snow patches made up the terrain between the rocks.

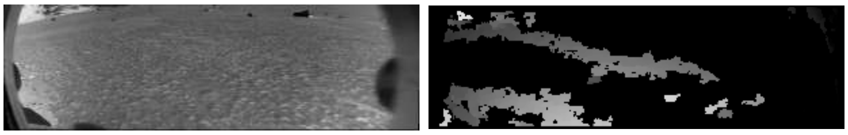
The ability to model the terrain in sufficient detail to permit navigation is an important factor. Several images were taken to compare stereo's ability to function on each terrain type. Pixel matching was performed on an area 1.5m to 750m in front of the robot (308x480 pixels). The average number of pixels matched on each terrain, for image sequences to 50 images, is presented in Table 1.

The results indicate that the terrain type had little effect on the number of pixels matched. For comparison a typical disparity map from each terrain type and one of the corresponding stereo images can be found in Figures 5, 6 and 7. Unfortunately, the low density of matched pixels in the images meant that stereo was insufficient for navigation. Determining if the low pixel count is due to poor calibration or low image texture is still to be done.



(a) (b)

Figure 5. (a) Image of snow. (b) Disparity map.



(a) (b)

Figure 6. (a) Image of ice. (b) Disparity map.

2.3. Weather Effects

Another thing which can affect the results of stereo vision is the weather. Images were collected under three types of weather conditions - sunny, overcast and blowing snow. The average number of pixels processed under these conditions is presented in Table 2. These sequences were taken on snow terrain.
It is interesting to note that blowing snow has very little effect on the stereo results. In fact, it is difficult to see the blowing snow in the images. Overcast weather creates diffuse lighting conditions which cause the terrain to have no contrast and makes it impossible, even for a human, to see depth. The first two authors both managed to fall into holes left from dug out tents without seeing them under these types of conditions, so it is not surprising that stereo works poorly.

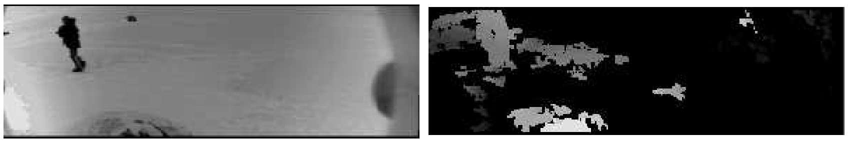
2.4. Color Segmentation

We use the method presented in [15] to segment[1] color images in order to extract skyline and ground features such as rocks - or meteorites - and sastruggi shadows. The segmentation method is a combination of two techniques: clustering and region growing. Clustering is performed by using a non supervised color classification method, this strategy allows the growing process to work independently of the beginning point and the scanning order of the adjacent regions. Figure 8 presents an example of image segmentation on a snow field.
On a snowy flat area - the Twin-Otter runway - we took images of a collection of rocks of different sizes - 3cm to 5cm - at several distances - 2m to 11m. Unfortunately, we were not able to extract 3cm rocks - the standard size of a meteorite - with our 4.8mm lenses in a reliable fashion because they were too small.

3. Laser Results

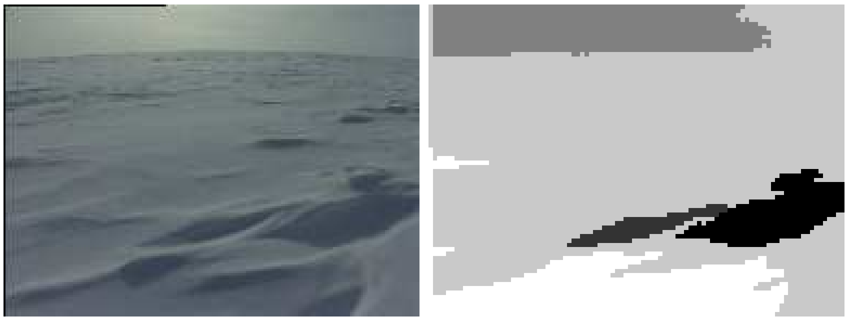
Two different lasers (Figure 9) were used in Antarctica to perform a set of common and complementary experiments dealing with obstacle detection, ground classification, weather influence and range capability (Table 3).

[1] This method was developed at LAAS-CNRS by R. Murrieta-Cid during his Ph.D thesis



(a) (b)

Figure 7. (a) Image of rock on ice. (b) Disparity map. Note the good disparity on the rock (lower middle) and the person, but not the surrounding ice.



(a) (b)

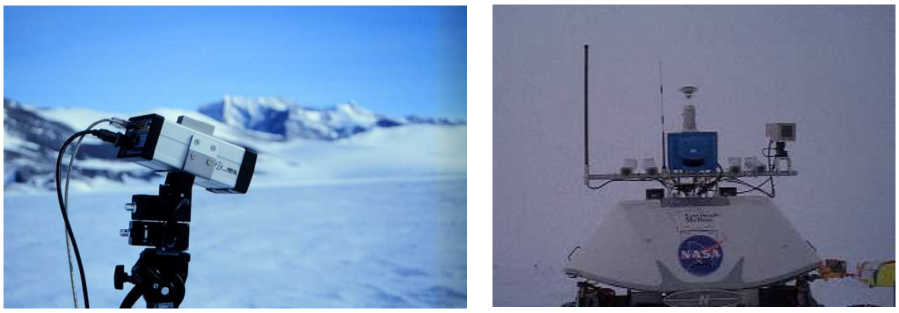
Figure 8. segmentation examples : (a) original (b) segmented image

3.1. Ground Classification

On blue ice fields snow patches can hide crevasses, so differentiating between snow and ice may be the first step towards crevass detection. Towards that goal, an attempt to classify the ground based on the energy return of a laser is presented. Using the Riegl, the energy return and distance were recorded for measurements of rocks, blue ice and snow at close distances. This data is plotted in Figure 10. The "rock phg" was taken on Antarctic rocks brought back to Pittsburgh. This graph shows that for a given distance, snow usually has a higher energy return than blue ice and rocks. Thus it appears possible to distinguish snow from blue ice and rocks but a better model of the laser is needed to decorrelate the influence of temperature, distance and photon noise before implementing a classification process using, for example, Bayesian rules.

Characteristics	**Riegl laser LD-3100HS**	**SICK laser LMS-220**
Type	telemeter	laser stripe
Wavelength	900±100 nm	920 nm
Beam divergence	3 mrad max.	7 mrad
Information recorded	Distance (12 bits) Energy returned (8 bits) Temperature	Distance (13 bits)
Theoretical range	50 to 150 m	50 m
Accuracy (mean value)	±20mm	±20mm in single scan mode
Operation Temperature	$-30..+50°C$	$-30..+70°C$

Table 3. Laser characteristics



(a) (b)

Figure 9. Lasers used in Antarctica (a) Riegl (b) SICK

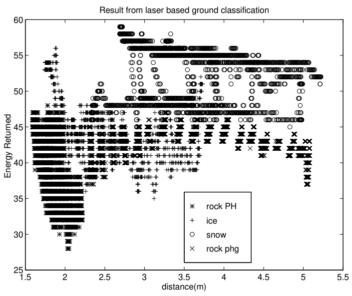


Figure 10. Ground Classification

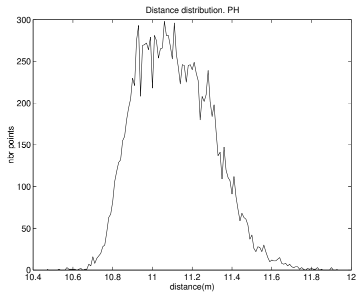
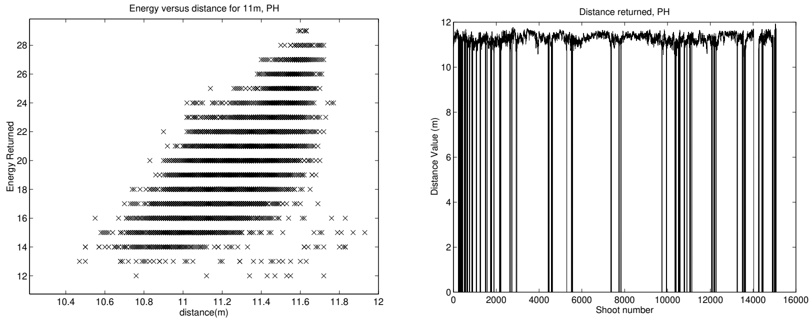


Figure 11. Distance Distribution

3.2. Weather Influence

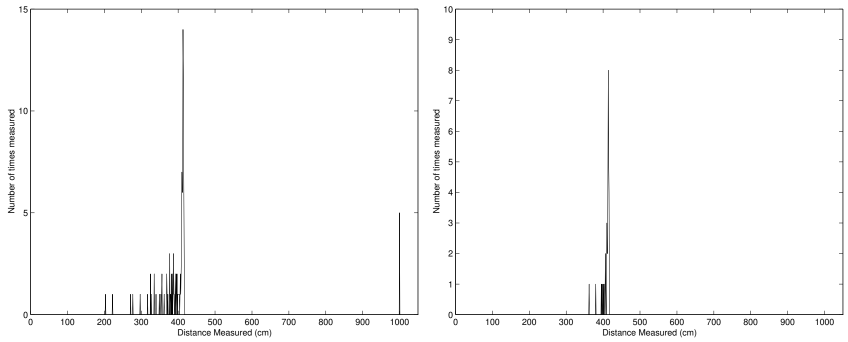
Figures 11-14 show that both the Riegl and SICK lasers were affected by the presence of blowing snow. Figure 11 shows the distribution of distance returns of the Riegl laser pointed at a static object 11m away during a period of heavy blowing snow. The snow has two effects on the distance measurements. First, the standard deviation of the data is much greater with blowing snow than for clear conditions. Second, the presence of a large spike of data at a range of 0m (Figure 12(b)). This corresponds to readings which had no return. Figures 13(a) and 14(a) show the distribution of distance returns for a single direction (straight ahead) of the SICK laser scanner mounted on the Nomad robot. They correspond to conditions of moderate blowing snow and heavy blowing snow respectively (this data was taken at the same time as the stereo blowing snow data reported in Table 2). Under clear conditions the SICK laser reports the distance $\pm$2cm. Two differences with the Riegl data are apparent. First, a no return is interpreted as having a distance measurement of infinity (1000 cm) instead of 0. Secondly, the SICK laser will produce readings with very short distances at times, the Riegl will not.

For navigation in blowing snow it is useful to think of the distance measurement as confirmation that nothing lies between the laser and that distance, not that an object exists at that distance [16]. Using this interpretation the SICK laser data was filtered to attempt to remove the effects of blowing snow. Three



(a) (b)

Figure 12. (a) Energy versus distance (b) Distance signal over time



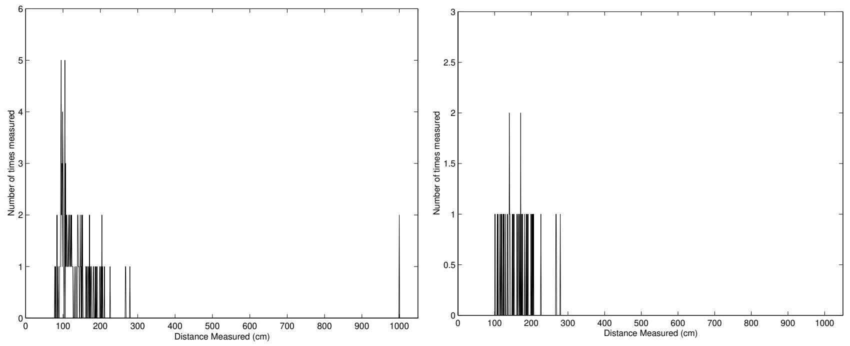
(a) (b)

Figure 13. Distance Distribution Medium Snow - (a) Raw data (b) Filtered

measurements of the scene were taken. Measurements of infinity were discarded unless all three readings were infinite. The largest remaining measurement was used as correct. This filter was applied to the data from Figures 13(a) and 14(a). The results are shown in Figures 13(b) and 14(b). For a moderate amount of blowing snow the filter does a very good job of reducing the error in distance. However, for heavy blowing snow, we can see that the filter is still not adequate for navigation purposes since none of the raw data contains the proper distance of approximately 4m.

3.3. Maximum Range

The Riegl laser was tested to detect the maximum useful range on snow terrain. A flat area with slight undulations and sastruggis less than 30cm in height was chosen near the main Chilean Patriot Hills camp. The laser was mounted 2m above the ground and the incidence angle was changed until the signal was lost. A distance of 55m was reached with a reliable signal. It was possible to get readings from as far as 64m but not reliably. The experiment was repeated on another snow field approximately 8km away and produced similar results.



(a) (b)

Figure 14. Distance Distribution Heavy Snow - (a) Raw Data (b) Filtered

4. Conclusion

This paper presents early results from camera and laser tests performed in Antarctica. As this was the first deployment of an autonomous mobile robot to Antarctica very little was know beforehand on the performance of these sensors.

The results presented show that stereo vision was largely unaffected by the terrain type but performed very poorly on cloudy days. Polarizing filters were able to reduce glare from the sun on blue ice fields but in general the low sun angles and high light levels did not present a problem for stereo. Color segmentation was able to segment out sastruggi on snow fields.

The laser sensors worked well on both snow, ice and rocks. By measuring the energy returned and distance it is possible to distinguish snow from blue ice and rocks. This is important since it could allow a robot to find crevasses as well as areas where a visual meteorite search will not find meteorites. The main limitation of the laser sensors was during periods of blowing snow. The snow reflects the laser resulting in bad distance measurements.

Since stereo failed on cloudy days and laser on blowing snow, it is possible that a rover equipped with both sensors for navigation could operate under a wide range of Antarctic weather and terrain conditions.

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