Evaluation of Visual Navigation Methods for Lunar Polar Rovers in Analogous Environments

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I. Introduction

It has long been argued that "cold traps", i.e. permanently shadowed craters at the lunar poles, might hold repositories of water ice. Data from imaging missions, such as the LCROSS mission, the Clementine spacecraft experiment, and Lunar Prospector, have suggested the possibility of ice on the lunar surface. However, the only direct, unambiguous means of calibrating these remote sensing instruments is through ground-based data. Instrument calibration would benefit from data collection campaigns at or near the Moon's poles, instead of relying on data from the Apollo site, which is near the Moon's equator.

Closer to home, satellite-based instruments are now routinely used to map the surface of the globe or monitor weather conditions. However, these orbital measurements of ground-based quantities are heavily influenced by external factors, such as air moisture content or surface emissivity. This is particularly important for arctic environments, as the unique surface properties of packed snow and ice are poorly approximated by other terrain types. Currently, this process is human intensive, requiring the coordinated collection of surface measurements over a number of years.

Deployable, surface-based networks thus become a key component for resource prospecting and remote sensing calibration, both for lunar missions as well as terrestrial applications. For such a robotic system to be successful, a certain set of base functionality must be developed. Work will be presented which develops vision-based processing techniques that will enable an autonomous agent to successfully navigate in arctic environments. Additionally, the ability is needed to test and validate robotic control software within the design cycle, without requiring the time and effort of full field deployments to these remote locations. A case study will also be presented, detailing the development of a simulation system for testing an arctic robotic sensor node of possible use in the exploration of the lunar poles. Methods for developing visually faithful environments and local hazards are explored, with emphasis on the resulting performance of vision-based robotic algorithms.

II. Autonomous Arctic Navigation

Our case study involves deployment of an arctic robotic system in an environment potentially analogous to the lunar poles, namely glacial regions here on Earth. Currently, an autonomous mobile weather station is under development which will be suitable for deployment on the ice sheets in Greenland and Antarctica [5]. Satellites have been able to map the ice sheet elevations with increasing accuracy, but data about general weather conditions (i.e. wind speed, barometric pressure, etc.) must be measured at the surface. This situation is also characteristic of future missions to the Moon, where autonomous agents will be required to collect data in science-directed locations.

One of the major software challenges of this project lies within the navigation system. Within arctic regions there are many unique terrain hazards that must be detected and avoided for the continued survival of the rover. Due to the nature of these hazards and the terrain in general, visual input has been selected as the mostly likely means of detecting these hazards. Further, it is believed that a majority of arctic hazards are "slope-based." Steep snow drifts and vertical cracks in the ice are common in these areas, and research efforts have concentrated on methods of detecting or estimating the slope of the terrain. However, images of arctic terrain have very low-contrast surface texture. In order to analyze this texture, the foreground contrast must first be boosted. An adaptive, nonlinear preprocessing stage has been introduced, originally formulated to enhance x-ray images and CT scans [3], which results in smoothly varying, enhanced contrast.

The enhanced surface texture exhibits a desirable slope-alignment property, but alignment noise is an issue when dealing with small-scale texture features. Similar to the area of fingerprint enhancement [2] where it is desired to find and follow the small ridge details of a print, a ridge orientation can be defined not by the direction of a single texture element, but rather by the common direction shared by a small region around each pixel [6]. Figure 1 illustrates an example of the slope estimation method applied to an image of blue ice and a crevasse from Mendenhall Glacier. Versions of this technique have been analyzed qualitatively against human-estimated slopes on real images, as well as quantitatively through the use of simulation. The resulting slope information has also been employed as input to a fuzzy-logic navigation scheme, resulting in orientation-maintaining driving behaviors [4].

Visual odometry or visual SLAM (simultaneous localization and mapping) systems are common means to address the

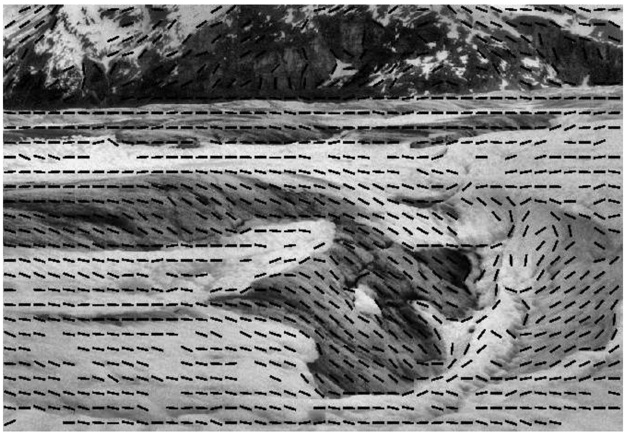
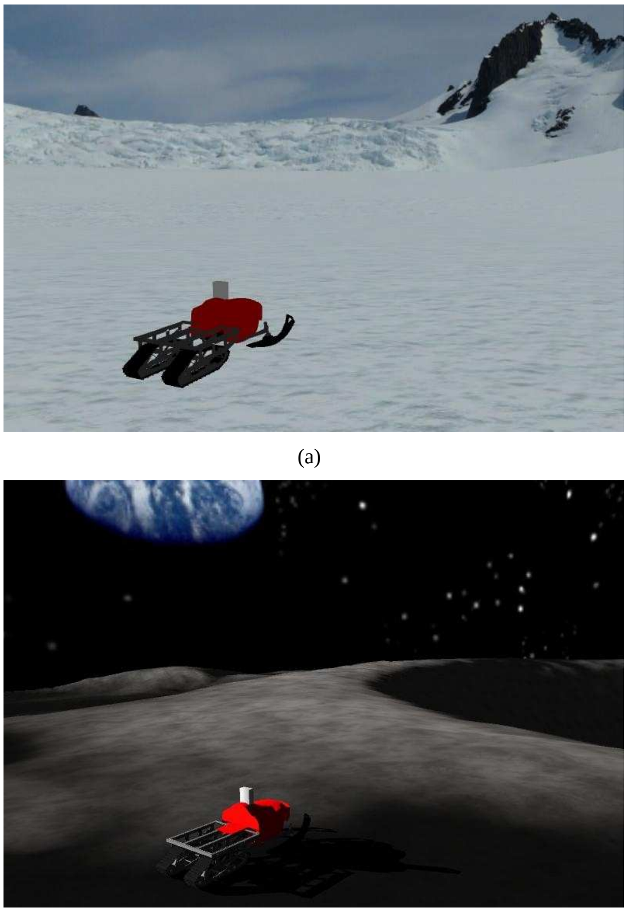


Fig. 1. An enhanced image of a large crevasse at Mendenhall glacier and the overlayed slope estimates. The slope profiles in clearly show the elevation changes at the edge of the crevasse.



(a)

(b)

Fig. 2. (a) An image from the simulated arctic environment, illustrating a terrain map constructed from SRTM DEM map, and photo-realistic background rendering. (b) An extension of the simulation system to lunar environments. DEM and terrain imagery were adapted from early results of the Lunar Reconnaissance Orbiter.

robot localization problem. However, these methods require strong visual features, or distinctive areas in the image. By leveraging the previous work in arctic image enhancement, a visual FastSLAM system has been implemented, which is capable of operating on glacial terrain.

III. Remote Environment Simulations

These computational navigation systems need to be tested in an environment that is both visually comparable to reality, and manipulable by the robotic agent. Such an environment would allow the visual system to be tested against scenes rendered from the agents perspective and dynamically updated based upon the pose and location of the agent, mitigating the shortcomings present in testing only against static, human-acquired images. This requires the creation of domain-specific photo-realistic terrains by the robotics programmer.

A simulated environment has been constructed using the Gazebo project [1]. The simulation system allows for the true robot pose and surface map to be queried, easing the collection of ground truth data. However, as vision is the emphasized sensing mode, the simulation must provide not only realistic physical interactions, but visually faithful 3D rendering as well. To that end, the base Gazebo simulation has been extended to allow photo-realistic background rendering, detailed surface texturing, including the ability to simulate the specular lighting in snow and ice conditions, and realistic, dynamic cloud effects. The simulation system will not only be evaluated qualitatively based on the visual similarity to the actual terrain, but also on how well the performance of visual algorithms compare when applied to simulated terrain versus the actual environment. Figure 2 shows a sample image from the Mendenhall Glacier simulation and corresponding extension to the lunar environment.

Further, science-driven navigation schemes are based not only on the terrain conditions and predetermined destinations, but adapt based on *in situ* sensor readings. In order to properly test such navigational routines, the simulation system must be able to provide generic "science sensor" data, upon which to base such decisions. A "science sensor" data provider has been incorporated into the Gazebo framework, allowing local sensor values to be interpolated from a provided, ground truth sensor data map, based on the true 2-D location of the sensor. Appropriate noise modeling can easily be incorporated into the output as well.

References

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