Final Technical Report

Robotic Rock Classification

NASA Grant NCC2-5319

Period of Performance: 5/15/99-8/14/99

The Robotics Institute
Carnegie Mellon University
5000 Forbes Avenue
Pittsburgh PA 15213

Abstract

This report describes a three-month research program undertook jointly by the Robotics Institute at Carnegie Mellon University and Ames Research Center as part of the Ames' Joint Research Initiative (JRI.) The work was conducted at the Ames Research Center by Mr. Liam Pedersen, a graduate student in the CMU Ph.D. program in Robotics under the supervision Dr. Ted Roush at the Space Science Division of the Ames Research Center from May 15 1999 to August 15, 1999. Dr. Martial Hebert is Mr. Pedersen's research adviser at CMU and is Principal Investigator of this Grant.

The goal of this project is to investigate and implement methods suitable for a robotic rover to autonomously identify rocks and minerals in its vicinity, and to statistically characterize the local geological environment. Although primary sensors for these tasks are a reflection spectrometer and color camera, the goal is to create a framework under which data from multiple sensors, and multiple readings on the same object, can be combined in a principled manner. Furthermore, it is envisioned that knowledge of the local area, either a priori or gathered by the robot, will be used to improve classification accuracy.

The key results obtained during this project are: The continuation of the development of a rock classifier; development of theoretical statistical methods; development of methods for evaluating and selecting sensors; and experimentation with data mining techniques on the Ames spectral library.

The results of this work are being applied at CMU, in particular in the context of the Winter 99 Antarctica expedition in which the classification techniques will be used on the Nomad robot. Conversely, the software developed based on those techniques will continue to be made available to NASA Ames and the data collected from the Nomad experiments will also be made available.

1. Introduction

Spacecraft and robotic explorers in remote locations or other planets are faced with severe communications restrictions that prevent them from returning more than a fraction of the scientific data they are capable of acquiring. A craft capable of autonomously (and efficiently) exploring an area without micro-management from mission control is clearly an advance on the state of the art. Such a vehicle would not need to await instructions from mission control between sensor readings but could continue gathering data. Using efficient data structures, a model describing the environment would require considerably less storage (and communications bandwidth) than all the sensor data required to construct it in the first place. Furthermore, anomalies that might otherwise be missed can be detected. The next wave of NASA missions to Mars and beyond would benefit greatly from such a capability.

CMU has been conducting a project involving the development of a robot, Nomad, for exploration and terrain analysis. At the same time, NASA Ames is embarked in research to automate remote robotic geological exploration through the On-Board Science Understanding project (informally known as the "Graduate Student on Mars" project). The goal of the present project was to bring to NASA Ames the algorithms developed and demonstrated at CMU, and to further progress through collaboration with Ames scientists.

The goals of the project were to make progress along three directions:

- To automatically classify rocks in different types based on sensor readings.

- To use geological knowledge of the environment to enhance the classification rate.

- To automatically select the optimal sensors out of a suite of sensors based on measures of cost and utility.

- To learn from existing libraries of rock spectra in order to enhance classification rates.

The background from the work described here comes from work performed in the CMU's meteorite search project and a prior CMU/Ames JRI project conducted in the Summer of 1998, also with Mr. Pedersen. The results of this prior collaboration are described in detail in [1] and form the basis for the work described here.

2. Technical Results

Specific results in each of the four areas or research are described briefly below. We show in section 2.5 a complete result based on data from the Antarctica 98 expedition, which shows the improvement obtained by using the algorithms developed during the Ames/CMU JRI.

2.1 Rock classification

We started with a rudimentary Bayes network based rock classifier that uses reflection spectra and features extracted from color images of rocks in order to identify them. The classifier is not described in detail here, a detailed description can be found in a paper based on the first Ames/CMU JRI [1].

During the 1999 Ames/CMU JRI, we have continued the development of the rock classifier in two main directions. First, we have refined the selection of features extracted from spectra in order to increase the classification rates. Specifically, in addition to the features previously used, essentially peaks and valleys of the spectra, new features are extracted from the data, to simulate sensor response in the field. In particular, the sensor may be placed at different positions on the object and the data needs to be modified accordingly. In addition, we have refined the algorithm used for selecting the scale at which the features are detected. This was an important practical consideration because the scale of the spectra may vary substantially due to normalization.

Second, we have extended the classifier to handle more (terrestrial) rock types as well as selected minerals. This was an important step because the classifier was so far designed for discriminating between meteorites and non-meteorites. The generalization to more general types of mineral is critical in order to make the classifier more useful to the geological community.

Because of the considerable variations in rock types and mineral classes, this is a very hard problem, however. In particular, the classifier was extended to handle many classes and was trained on database spectra. The rock classification problem is hard, and continued access to the geologists (Dr Ted Roush and Dr V. Gulick) at Ames proved invaluable to effectively generalize the classifier, and to educate the CMU student in the technical aspects of geological classification.

2.2 Environment Modeling

Similar types of rocks tend to abound in certain geographical regions. By attempting to model these regions as a robot acquires more sensor data, this fact will be exploited to improve classification accuracy. A fortunate side effect is that the geology of an area traversed by a robot will be autonomously characterized.

We continued theoretical development of statistical methods to incorporate information from the gross geology of an area, and previous observations in the area, in order to identify rocks and (robotically) survey an area. Interaction with Dr Peter Cheeseman at Ames was helpful, in particular, in formalizing the probabilistic framework for the environment modeling. This work was initiated at Carnegie Mellon University and is currently being implemented for field trials in Antarctica on the Nomad robot.

2.3 Sensor Selection

Continued work with methods for evaluating sensor utilities for a robotic geological exploration vehicle. This is ongoing work at Carnegie Mellon University.

2.4 Spectra Database Analysis

Currently the data set used to train the classifier network is limited to the spectra obtained during two expeditions to Antarctica. There is significantly more data available on the Internet. Unfortunately, this is usually for pure samples of powdered minerals (not rocks), examined under laboratory, not field conditions. One direction suggested for this project is that, by modeling spectrometer noise, and redesigning the classifier to both identify rock types and the presence of minerals it is possible to generate usable data sets of significant size.

In order to investigate this direction, we experimented with data mining techniques on spectral library at Ames to elucidate structure useful for autonomous decision making by a robotic rover. Specifically, the classifier is trained both on real data and on data for the stored database. The data from the database is further corrupted in order to simulate typical sensor readings under field conditions. Preliminary results show that the use of prior knowledge from the databases greatly enhances the performance of the classifier.

2.5 Summary Result

As a summary of the enhancements developed during the Summer 1999 Ames/CMU JRI, Figure 1 shows the ROC curves based on Antarctica data acquired with Nomad in December 1998. The graph shows the detection curves for images, metal detector and spectra separately, as well as the classification curve for the three sensors combined. The classification rates shown in this graph are obtained using the following enhancements developed during the Summer 1999 project:

- The classifier used the spectral features extracted using the improved spectral feature extraction algorithms.
- The classifier was trained by using simulated of spectral features given real data, in addition to the normal features extracted from the data.
- In addition, the classifier was trained by using mineralogical laboratory data from Aster spectral library to complement field data.
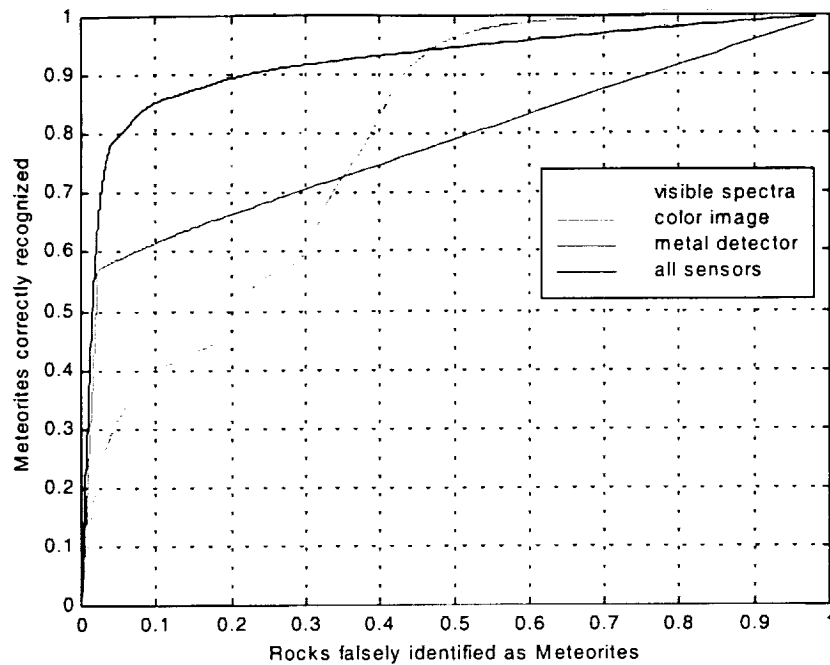
Figure 1: Summary of classification rate enhancement.

3. Developments

The improved classifier and the other associated software developed above are implemented onboard the Nomad robot for final trials in Antarctica, where it will search for meteorites and do experiments for onboard science data analysis and in situ rock classification, using a spectrometer and other sensors on the vehicle. These experiments, scheduled for January 2000, will be the first of their kind. Results will be available in February 2000, and several publications are in the pipeline to follow. Data and results will be communicated to NASA Ames.
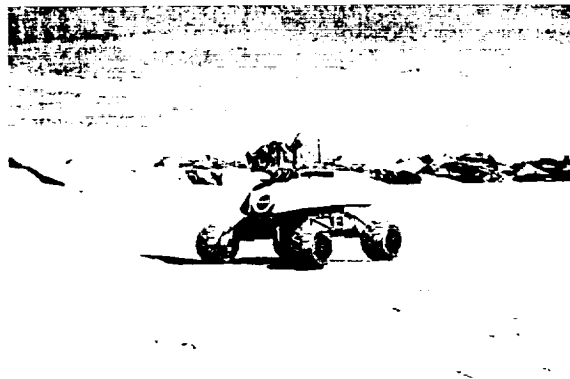

Figure 1: Composite image of Nomad robot on the Antarctic ice sheet.

4. Publications

No publications are available yet. This work will be published next year after the January field trials in Antarctica. Copies of the papers will be forwarded to NASA Ames.

References

[1] L. Pedersen, D. Apostolopoulos, W. Whittaker, G. Benedix, and T.Roush. Sensing and data classification for robotic meteorite search. Proc. SPIE. 1999.