Autonomous Exploration Rover for Sample Search and Acquisition in Unstructured Environments

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Abstract— **This research outlines the design and development of the Autonomous Exploration Rover at Worcester Polytechnic Institute to compete in the 2013 NASA Sample Return Robot Centennial Challenge. The robot is designed to autonomously navigate a large outdoor area while locating and retrieving various samples using only space-compatible technologies.**

I. INTRODUCTION

The insatiable human curiosity and desire to explore proved Earth is neither the sole planet in the solar system nor the center of the universe. Technologies developed over the last 40 years have significantly enhanced humanity's ability to explore extraterrestrial bodies with teleoperated robots returning stunning images and scientific data of distant planets. We are developing AERO, the Autonomous Exploration Rover shown in Figure 1, to advance the next evolution in space exploration. The next generation of exploration robots need to go where teleoperated robots cannot bring us.

Fig. 1. CAD rendering of the Autonomous Exploration Rover showing the four-wheeled differential drive platform with 6-DOF manipulator, SICK LMS151 LIDAR, and stereo vision cameras.

AERO is comprised of a differential-drive four-wheeled mobility platform and 6-DOF manipulator designed to participate in the NASA Sample Return Robot Centennial Challenge in June 2013. The task is to navigate a large outdoor area, find and locate various samples, and return them to the starting platform. Samples are defined in three broad categories: easy, medium, and hard. The easy samples are fully defined in terms of physical characteristics, the medium samples are defined in broad terms about general size, color, or texture, and the hard samples are vaguely defined, engraved with a small unique marking.

Fusing a combination of data from a fixed, forward-facing stereo vision system, LIDAR, and IMU, AERO implements a simultaneous localization and mapping (SLAM) algorithm to mark what areas are searched and return to the starting platform at the end of the competition. A second panning stereo vision system on a mast is used to locate and identify samples using object classifier and texture-based algorithms.

Because the time-delays for teleoperated robots beyond the moon are unacceptably long, the algorithms developed to identify samples defined by high-level descriptions will allow humans to efficiently explore distant celestial bodies. These algorithms with slight modifications can also alleviate problems on Earth including agricultural robots identifying crop diseases, security robots identifying security breaches, and home-care robots identifying household risks to seniors.

II. SYSTEM ARCHITECTURE

AERO's misson can be split into three main subtasks: navigating and localizing within the large outdoor area, identifying and classifying samples, and retrieving the samples with a manipulator. The system architecture is designed with these tasks in mind. AERO is designed to leave the maximal amount of space on top of the robot for sample storage. The sensors are selected to comply with the competition rules, but also provide useful data to complete every subtask. A 6-DOF manipulator was selected to provide the most flexibility in sample handing, especially with the hard, undefined samples.

Inside AERO, a Roboteq MDC2250 dual output 60A motor controller implements closed loop velocity control on the primary drive motors. The control loop is closed using standard quadrature output optical encoders. The primary battery pack is also inside the robot towards the rear consisting of sixteen 40Ah CALB LiFePO4 cells in an 8s2p configuration to provide 25.6V, 80Ah nominally. LiFePO4 cells were selected because of their good compromise between energy density, safety, and charge cycles. Two Manzanita Micro MK3x8 battery management systems ensure the safety of the lithium battery pack. Towards the front on a server motherboard, dual 8-core Intel Xeon processors provide the main computing power complemented by a NVIDIA Tesla K20 GPGPU solution. The Tesla GPGPU excels at image processing because of its highly parallel nature and significantly increases the vision processing capabilities of AERO.

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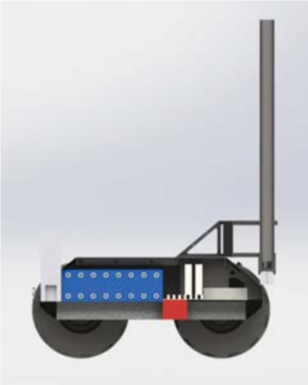

Fig. 2. CAD cutout showing the battery pack (blue), computer, IMU (red), battery management systems, and manipulator mounting hardware in AERO.

A. Navigation Sensors

The main sensors AERO uses to navigate are the LIDAR, IMU, mast-mounted stereo vision system, and wheel encoders. GPS and other satellite based navigation aids are not used because they are not compatible with challenge rules. We selected a LMS151 LIDAR from SICK because of its 50 meter maximum range and excellent outdoor performance. The LIDAR directly feeds the SLAM algorithm by very accurately providing ranging data to trees and man-made features in the environment. A KVH 1750 fiber optic ring gyro IMU provides accelerations and angular velocities to enable AERO to dead-reckon when no good LIDAR features are available. A fiber optic ring gyro was selected because of its excellent stability and very low drift rates, providing accurate dead-reckoning for extended times without absolute positioning information from the LIDAR. The mast-mounted cameras periodically pan and extract trees from the scene to help localize the robot as well. Finally, wheel odometry from the motor encoders is fused with all the available data in an extended Kalman Filter (EKF) to localize the robot beter than any one sensor can by itself.

B. Sample Detection and Classification

Sample detection and classification is entirely implemented by the computer vision system. The top mast cameras identify anomalies in the grass that could potentially be samples and mark them on a probabilistic map on the robot. The robot inspects each potential sample from a close distance using the fixed, front-mounted stereo vision system. The easy and medium samples are identified and classified using a scale invariant feature transform (SIFT) classifier. Because the features of the easy and medium samples are known ahead of time, the robot is preloaded with a training set of data helping it identify these samples. The hard samples are identified by their generally different appearance in the environment. The grass blades contain very high frequency vision information due to the many edges, and the samples are man-made containing relatively low-frequencies. Combining this information with another classifier to recognize the small engravings enables AERO to identify the hard samples. In addition, the fixed forward facing vision system extracts the location, major axis, and bounding box of each sample in order to assist in planning a suitable approach vector for the manipulator.

C. Manipulation

A Kinova Jaco 6-DOF manipulator was selected to collect samples shown in Figure 3. It is a commercially available system that provides AERO with the needed flexibility to pick up samples of different sizes and place them on different locations on its top plate. The manipulator has a three-finger underactuated and compliant gripper with individual control over all fingers. The manipulator utilizes brushless DC motors with Harmonic drives resulting in very low power consumption while still providing up to 1kg payload capacity.

Fig. 3. Jaco 6-DOF manipulator with one of the easy samples grasped.

III. SAMPLE RETURN ROBOT CHALLENGE STRATEGY

The general strategy for competing in the 2013 Sample Return Robot Challenge is to approach the challenge in three stages. In the first stage, the robot traverses the entire field in a large loop to map the large obstacles such as trees. Any potential samples spotted during this loop will be mapped and explored later. This map will be used to localize the robot accurately over the entire field. In the second stage, a 15 meter exclusion zone will be marked around each tree and man-made obstacle where no samples will be located according to challenge rules. Finally in the third stage, the robot will methodically explore all areas that are not in the exclusion zones for samples. This strategy minimizes the amount of area that needs to be covered, maximizing the time the robot will be searching for samples.

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