1. Introduction

Autonomous robotics technology is improving at an exponential rate, and has the potential to be the largest leap in technology since the invention of the personal computer. Robot Operating System (ROS) [1] is a catalyst in the development of fully autonomous robots. With a large community of developers and many resources available, it allows researchers to focus their time on implementing fully autonomous systems on their robotic platform, instead of spending time developing algorithms. This research focuses on the development of an autonomous robotic system using ROS, with the purpose of competing in the NASA Robotic Mining Competition [2]. While completing this research, many discoveries were made in the importance of sensor selection, limitations of current autonomy algorithms, and how to correctly integrate custom robotic platforms into the ROS framework.

2. Methods

In order to design an autonomous robot you must first understand what the robot needs to accomplish. Systems are then identified and designed to achieve those goals. The following requirements were identified:

- The robot must weigh no more than 80kg.
- The robot must fit within 1.5 m x 0.75 m x 0.75m.
- The robot must be able to mine Martian soil simulants (known as regolith).
- The robot must be designed to lift 10kg of regolith material above 0.5m above ground level.
- The robot must be able to move well in the unique regolith.
- The robot should be able to dig, move, and deposit without any user input.
- Power consumption and Bandwidth usage are premiums, and should be minimized whenever possible.

The Mechanical System was designed in Solidworks, and checked to see that it would meet the above constraints, then built according to the design (as shown on the left).

The Electrical and Control Systems were then spec’d and designed with the mechanical design. Phidget Motor Controllers [3], NiMH batteries, a custom power supply Printed Circuit Board, and the Intel NUC [4] on-board computer were all selected as the systems required to achieve its goal of fully autonomous regolith mining. A diagram of all these systems and how they interact can be seen below.

The autonomous systems and ROS software packages were implemented using four sensor systems: A Intel RealSense 3D IR camera [5], a RPulidar 2D Laser Scanner [6], a Phidgets IMU [7], and motor and linear actuator encoder feedback. All of these systems fed data into RTABMap [8], a Robot Simultaneous Localization and Mapping (SLAM) framework. Path-finding was then done on the SLAM output, to enable fully autonomous control. A diagram of the ROS nodes, and how they communicate can be seen below.

3. Results and Discussion

Results:
The Autonomous systems did not perform adequately to receive points for autonomous runs during the 2016 NASA competition. The problems with the autonomous systems stemmed mostly from issues the teams used.

The IMU on-board the robot was not accurate enough to provide odometry data to the SLAM system. Because of this, any movement of the robot would be inaccurately represented without other odometry sources to augment the IMU data. The first two images on the left show the odometry output using solely the IMU.

The Realense 3D IR camera [5] effectively creates 3D point clouds of the environment around the robot, however the data is prone to non-deterministic outliers, which are too frequent to filter out using Voxel grid methods. Because of this, the camera could not be used for its primary purpose of obstacle avoidance. Finally, the LiDAR was very good at scanning the environment around the robot and detecting obstacles, but due to NASA rules [2] it could not be used to augment the robot odometry and therefore was unusable. Because of these reasons a reliable, fully functioning, autonomous system could not be created using these sensors.

Discussion:
Although data from the autonomous sensors was collected, there were implementable solutions to solve some of the problems without needing sensors. One solution is implementation Kalman filtering [9] on the wheel odometry, and to implement LiDAR optical flow [10] odometry. This lead to the robot being able to navigate through environments, because localization on the map was functioning; however it still posed problems like what can be seen in the image captioned “Optical Flow Odometry Failure”

Selecting new sensors to use with the same autonomy algorithms is the best way to improve autonomy for future research, instead of a 3D IR sensor, a 3D Stereoscopic camera could be used. This sensor won’t be prone to IR interference from the sun, and is more accurate due to the higher resolution cameras.

A better IMU can be used to remove the requirement to have multiple odometry sources, and would improve robot localization.

Finally, assistive localization beacons using scanning LiDAR can be placed in an environment to give coordinates from a fixed point to the robot.

4. Conclusion

Fully autonomous robotic systems are well within the realm of possibility for many applications. With the latest sensor technology decreasing in price and increasing in accuracy and reliability, it is only a matter of time when fully autonomous robots (including self-driving cars) become common place in society. The features of ROS remove complexity from the process of creating autonomous systems, and makes it possible for a small team to build a robotic system and make it function autonomously. With slightly better sensors, the software systems in place on this robot would need no other modifications to make the robot operate fully autonomously.

5. Future Work

The next step for the autonomous systems research is to use the same autonomous system nodes (RTABMap, Move_base) with better odometry and vision sensor data. Additionally, the navigation goal setting and competition digging/dumping/navigating procedures should be refined with more redundancies and error checking.

Using the sensor changes suggested in the discussion section above, major improvements could be seen, enough to enable fully autonomous operation of the robot during the entire NASA competition round.

Other than autonomy, the largest problem for the NASA competition was weight. For every 1lb of weight sent into space, it costs NASA roughly $10,000 [11]. Because of this, an 80kg robot, although within requirements, is too heavy to win the competition. A new mechanical design, which is spec’d to weigh less than half of the current robot is depicted to the right.

6. Ethics & Sustainability

Autonomous robots have the potential to make many dangerous jobs safer by removing the human component. In 2015, Rio Tinto Kennecott sponsored this research with the specific goal to help develop autonomous mining operations. Autonomous mining would make coal mines, open pit mines, and other mining operations safer for humans, and more profitable for companies by only requiring one person to operate multiple machines from a safe control room.

Additionally, when it comes to ethics and robots that are functioning autonomously, Isaac Asimov’s three laws of robotics [12] very succinctly sum up what robots should be allowed to do.

7. References