Shamrock: Hazard Detection for Lunar Landing

Why Terrain Relative Navigation?

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Introduction

Say we are flying a drone and we know the area which the drone is flying over. Given an image taken by the drone, how do we figure out the drone's specific location? The answer is simple, Terrain Relative Navigation (TRN). The primary idea of TRN is to take advantage of landmarks on the surface of the known landing site in order to orient the drone in space at a given point in time. In order to do this, we need a few pieces of information. We need a map of the total landing site, referred to as a global map. Additionally, we need an image taken by the drone at a given point in time, the local map. Lastly, we need data from an inertial measurement unit (IMU), which gives information about the orientation of the drone at that moment in time.

Background

TRN has in the past decade become a major area of research because, when combined with hazard avoidance algorithms, it allows rovers to autonomously land with extreme precision at a desired landing site. An example of a flight where TRN would have been useful was on the Apollo 11 mission, the first manned landing on the Moon. In this mission, it was necessary for an astronaut onboard the spacecraft to navigate toward a safe touchdown on the surface. This safe landing is a difficult maneuver and if done incorrectly will cause great danger to both the humans onboard and the spacecraft [7]. Thus, there is a clear need for autonomous landings in order to ensure safety.

Additionally, TRN has been particularly useful in scientific research applications. On September 8th, 2016, NASA launched a rover, Osirix-Rex, into space designed to land on a near-Earth asteroid named Bennu [3]. The purpose of this mission was for the rover to collect rocks from the surface of Bennu and bring back to Earth asteroid and space matter for further scientific research. The rover is planned to return back to Earth in 2023. Although this asteroid was chosen because it is close enough to Earth, the mission is still planned to take 7 years from the rover take-off into space to the landing back on Earth [3]. In this mission, it is crucial that the rover lands close enough to the desired landing site on the surface of Bennu, within a certain error tolerance. This will allow for the rover to collect rocks safely from the asteroid before returning to Earth. The worst-case scenario would be if the rover landed on a boulder or a steep slope and tipped over making it impossible for this mission to be completed. The foreseeable issues that may arise at the time of landing can be avoided by the use of TRN and Hazard Avoidance technologies. This type of analysis must be done when the rover is close enough to the landing surface to get detailed images of the terrain. Thus, these algorithms must be performed in real time, onboard the rover during its landing process, just a few meters above the landing site [8]. If the TRN algorithms onboard the rover had failed to perform as they were intended to, the 7 year long mission to Bennu would have been an extreme waste of much of NASA's time, money, and resources. These applications were the motivation for Team Shamrock's design project.

Image 1: Global Map Used in Team Shamrock's Project

Team Project

The goal of Team Shamrock's project is to design the navigation and hazard detection algorithms to identify either one or many safe landing sites on the surface made to look like an asteroid's. The final goal of Team Shamrock's design project is to create a surface that resembles the surface of an asteroid, which can be imaged with a drone. The drone is equipped with a camera, an IMU, and a Light Detection and Ranging (LIDAR) sensor. Throughout the course of the flight, the drone will take images and collect data. Then, post flight processing will be done to determine the optimal landing site for the rover. The real time, onboard image processing used to land a rover is a problem that NASA has been working on. Therefore, this is out of the scope of the team's year long design project. The major technical components of the team's project will be the Kalman Filter giving a position and velocity estimate of the drone, the image processing of camera images and LIDAR data to detect the hazards on the landing surface, and the hazard detection algorithm to make the final decision about the safest place to land.

The IMU measurements drift quite significantly during flight. Therefore, the role of TRN in this project is to assist the Kalman Filter's position estimate by correcting for the drift of the measurements collected by the IMU. The TRN algorithm is able to match the current image taken by the drone, the local map, to the image of the entire landing site, the global map. By detecting features from the local map, the algorithm is able to place the local map on the corresponding section of the global map. In real world space applications, the global map will be accessible due to the imaging of space that exists due to satellites in orbit. In the context of this project, the global map will be an image of the entire landing surface that the team builds. However, it is a reasonable assumption that this global map will be accessible if this project was to be extended to a full integrated, live time asteroid landing system.

The TRN algorithm that is implemented, takes in the two images, the local map and the global map. Correlating the local map at each location on the global map, we are able to place the local map on the global map by finding the greatest correlation [2]. Once this match is made, the task now becomes generating the coordinates of the drone at the point in time that the image was taken. Using a 3-dimensional perspective projection, the drone can be projected onto the map to determine its location at the time of imaging. The IMU will supply the projection algorithm with the roll, pitch, and yaw of the drone, corresponding to the angle of the camera in 3-dimensional space. Additionally, the IMU will supply the altitude measurement at that point in time to determine the correct projection of the drone onto the landing site. Using this projection, the exact coordinates of the drone can be determined. For this project, any coordinate system can be used as long as it is uniform among the algorithms for the purpose of integration. The simplest coordinate system for this application is a "room-centric" coordinate system. Choosing one corner of the landing site as the origin of the coordinate system and mapping each degree to a given number of meters, the area in space can be translated into the coordinates of the drone at the time of imaging. This information can then be fed into the Kalman filter to help correct for the drift in the IMU. In turn, this will help provide for a much more accurate position measurement of the drone.

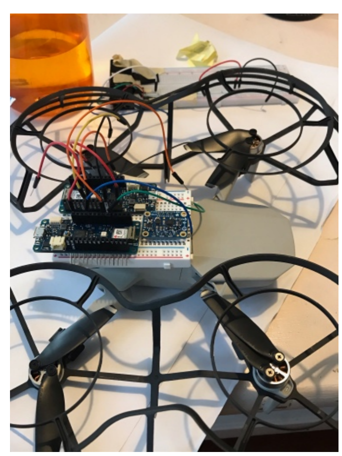

Image 2. Drone to be Used to Collect Images, IMU Data, and LIDAR Data

Conclusion

TRN has great applications in the latest space exploration missions. Without TRN algorithms on board, the rover would not achieve the required level of precision landing accuracy that is necessary for missions such as NASA's Osiris-Rex mission to land on the asteroid Bennu [8]. In Team Shamrock's design project, the TRN algorithm is able to orient the drone in space and correct for the error in the IMU measurements that is being used to estimate the drone's current position. This algorithm is crucial to this project in locating the drone in space. Additionally, in NASA's Osiris-Rex mission to Bennu, TRN has even larger applications in real time image processing where millions of dollars, time, and resources have been allocated toward the project [3].

References

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