National Aeronautics and Space Administration

FY23 Strategic University Research Partnership (SURP)

# Robust Machine Learning for Autonomous Visual Navigation Under Variable Illumination Conditions

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**Objectives:** The objective is to demonstrate the use of machine learning to improve terrain relative navigation invariance to illumination changes during planetary entry, descent, and landing. A secondary objective is to apply the same techniques to multi-modal matching (e.g., visible to SAR) for terrain relative navigation on bodies with dense atmospheres.

**Background:** Visual navigation is the process by which a spacecraft uses optical sensors to survey its surroundings and estimate its position. Visual navigation is a powerful tool but is limited, in part, by its sensitivity to large illumination changes. Feature-based visual navigation, where areas of interest in sequential images are identified and used to estimate the spacecraft's position over time, has been successfully used at JPL, for example on Mars 2020. However, large variations in illumination conditions in the set of images used by a spacecraft for position estimation can complicate the process of identifying reliable landmarks between images, and in some cases, can cause visual navigation to fail.

**Approach and Results:** (1) Collect existing imagery for the Moon, Mars, Venus and Titan. Results: Initial data sets from Moon and Mars have been collected. Simulation has been developed to generate lunar imagery under variable illumination. Hardware testbed for collecting imagery in a lab environment has been developed.
(2) Develop a neural network to pre-process optical, infrared, and synthetic aperture radar images with illumination changes to bring them into an illumination-invariant image space. Results: Two learning approaches have been applied to the collected imagery. Fragoso et al.'s approach was applied to simulated lunar terrain images. Since the position of the craters do not change with varying illumination, this approach enabled matching of the corresponding craters across small illumination differences and showed an example of 'constellation-based' feature matching. These initial results indicated that the geometric relationship of visual features is important to matching across variable illumination conditions and this led the research to consider "transformer" based approaches because they have recently found success mapping global spatial relationships by utilizing dense pixel matches. The LOFTR approach of Sun et al., using its existing pre-trained model, was applied to lunar imagery under varying illumination conditions and initial results are quite encouraging. This method shows potential to be illumination-invariant, and performance would be improved from training on a custom terrain dataset.

(3) Guaranteeing robustness of the machine learning approach will be investigated in second year.

**Significance/Benefits to JPL and NASA:** JPL's expertise in visual navigation will be leveraged with MIT knowledge of space-based machine learning applications to create a network that can be used on future planetary or small body vision-based navigation missions. The machine learning will expand the applicability of vision-based navigation to problems with changes in illumination (e.g., landing in the morning or late afternoon for Mars Sample Retrieval Lander; Venus or Titan landing with different modalities; and autonomous navigation/exploration missions to small bodies). Additionally, this is only the first foray into combining machine learning with vision for landing. There will be numerous future applications where learning can expand the tasks possible with vision (e.g., using machine learning to identify scientifically interesting geolocations in an image and then targeting the region of interest for landing) and the overall autonomy of spacecraft.

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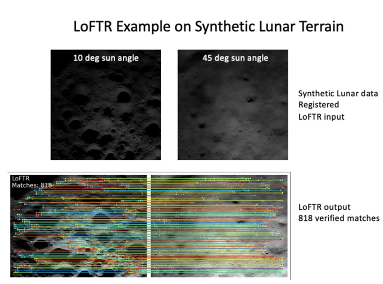
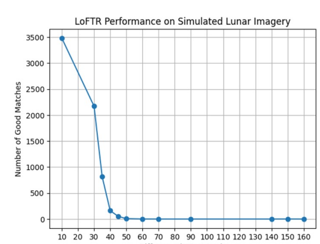



*Example of LOFTR global matching on simulated lunar imagery.*




*Number of correct matches in off the shelf LOFTR network as a function of illumination elevation angle difference.*