CubeSat Constellation Flight Using Optical Tracking and Visual Structure from Motion

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Abstract

CubeSats are small satellites of roughly 10cm in three dimensions. They are deployed for tasks such as technology demonstration and scientific research. In our group, CubeSats implement and simulate the spacecraft that are used for Quantum Space Applications. An associated challenge is precision Rendezvous and Proximity Operations, Docking, Undocking (RPODU). Computer vision techniques such as Optical Tracking and Visual Structure from Motion (vSfM) can be used for such procedures like formation flying of spacecraft in a constellation.

Introduction

-RPODU: Refers to two (or more) spacecraft approaching in orbit for assembly, communication, and scientific collaboration.

-Quantum Space Science: Area of study that encompasses and integrates concepts from quantum mechanics, photonics, and space.

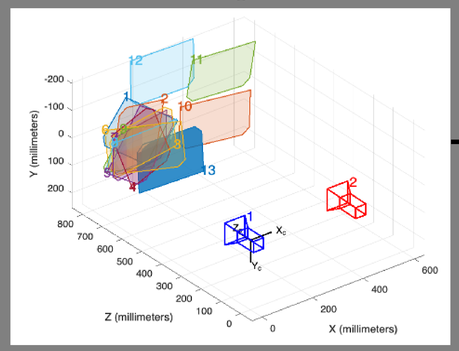
-Optical Tracking: Following a particular object and determining its position.

-vSfM: Computer vision technique that estimates the 3D structure of a scene from a set of 2D images.

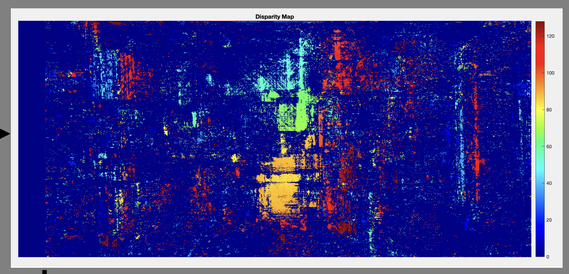
Our group's "Flight Tech Demo" project includes a 1U CubeSat named CuBEE, containing onboard cameras and LiDAR. CuBEE is mounted on a gimbal and CNC platform to simulate 6-degrees of flight. Optical tracking is performed and external cameras are used to implement vSfM to aid in RPODU.

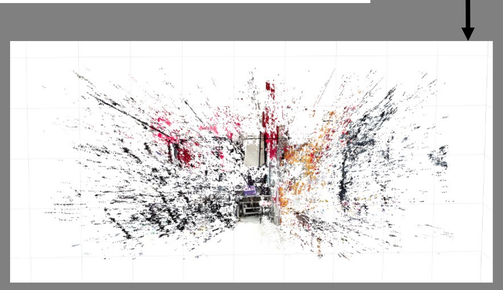
Workflow

Camera calibration is performed to estimate the intrinsics, extrinsics, and distortion coefficients of the lenses and image sensors.



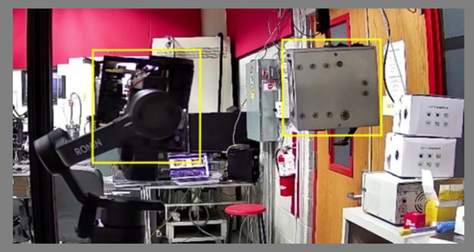
The video frames are inputted, rectified, and the disparity between the stereo cameras is computed.

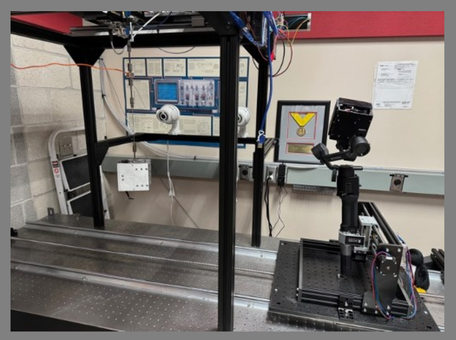




A 3D point cloud viewer can be used to see the model that is generated after performing the 3D reconstruction from the information above. The world pixels correspond to physical units like millimeters.

Tracking can be performed through the external or internal cameras





Tests are performed using the setup pictured. CuBEE attempts to dock with another CubeSat suspended by a microgravity platform to replicate impact dynamics in space. The docking simulates precision spacecraft RPODU.

Results

CuBEE successfully tracks the target CubeSat and docks. Analysis was performed comparing the RPODU procedures with and without the external cameras feeding CuBEE data derived from vSfM. For the optical tracking to work, the target must be in focus, which can be a challenge if the distance between CubeSats is under 6.5". The target must also be in the field of view, which also relies on enough separation. The data collected through vSfM remedies these, and also provides objective measurement of speed, distances, and monitoring of the area to calculate the most optimal trajectory. The development, testing, and execution of RPODU are enhanced and guaranteed using our method.

Conclusion

The project makes possible Quantum Space Science missions that implement concepts that rely on precision RPODU for tasks such as assembly, orientation, and tracking.

An example includes the Laser Interferometer Space Antenna (LISA), which is designed to detect gravitational waves.

Formation flight of three spacecraft in a constellation has never been demonstrated in practice, but can now be implemented. The hardware and software were chosen to be NASA flight compliant. The project aligns with NASA Mission Directorate research priorities including ARMD, ESDMD and SOMD, SMD, STMD, and NASA Centers including AMES.