TECHNISCHE UNIVERSITÄT DRESDEN

Fakultät Elektrotechnik und Informationstechnik ● Institut für Automatisierungstechnik

THESEN ZUR DISSERTATION:

State Estimation and Mapping for Exploration on Asteroid Surfaces

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1. For in-situ exploration on asteroid terrain surface, a flash LiDAR-aided inertial navigation system with a minimum sensor setup (an IMU and a flash LiDAR sensor) is capable of performing spacecraft state estimation and terrain map generation.

2. When only relative state measurements are available, global state estimation is subject to error accumulation and global mapping suffers from accumulated mapping errors. The relative navigation framework that estimates local system states and builds local map is more suitable than the global navigation framework in terms of accuracy of state estimation and mapping.

3. In comparison with the filtering-based local relative navigation, optimization-based local relative navigation using sliding window estimator requires long computational time but achieves little accuracy enhancement in the test scenarios. The filtering-based method is preferred.

4. The iterative closest point (ICP) method computes accurately relative state observation by registering directly a point cloud to another one by solving iteratively a linear equation system. The point-to-plane error metric is suitable for terrain-based point clouds.

5. In the scan-to-map matching (S2M), abstracting point clouds with surfels removes high frequency information in the raw point clouds, resulting in less registration accuracy than the ICP. Indirect formulation of the error metric as negative log likelihood and solving a nonlinear least squares problem lead further to less registration accuracy in the S2M.

6. In comparison with the ICP, the S2M requires no additional storage of the previous point cloud for the registration. The surfel grid map (SGM) is directly available in the mapping and has less data amount than the point cloud.

7. Compared with the extended digital elevation map, the surfel grid map (SGM) provides directly surface properties (such as roughness and inclination) that are beneficial for further analysis and processing of the terrain map. The SGM with surfels requires lower resolution and less memory space.

8. Four factors (surface roughness, flight height, flash LiDAR inclination and field of view) affect the texture (information of high frequency, size of surface area, ground sampling distance,

valid point measurements) of the point cloud measurements. This texture of point clouds and the different formulation of the registration in the ICP and S2M lead to different navigation behaviors and performances.

9. Higher surface roughness leads to smaller errors in horizontal position estimation. Surface roughness shows little influence on attitude estimation.

10. Both ICP and S2M show an optimal flight height (around 16 meters) with minimal registration errors for the investigated reference exploration scenarios.

11. A maximum pitch angle (flash LiDAR inclination) exists in pitching manoeuvre of the spacecraft, beyond which the ICP has relatively larger registration error and the S2M diverges.

12. Larger flash LiDAR field of view (FoV) leads to more accurate state estimation in the pitching manoeuvre of the spacecraft before the maximum pitch angle is reached. For the S2M, larger flash LiDAR FoV results in larger maximum pitch angle, while there is no clear relation between the flash LiDAR FoV and the maximum pitch angle for the ICP.

13. For the ICP, less number/ratio of valid flash LiDAR range measurements leads to larger registration errors. For the S2M, larger ground sampling distance leads to larger registration errors.

14. The flash-LiDAR-sensor-based extraction of rock point clouds is efficient due to direct mapping between pixels in the flash LiDAR focal plane array (FPA) and their point measurements. The projected contour histogram (PCH) descriptor encodes geometric contours of each rock point cloud from different viewpoints in a form of histogram, leading to simple and yet unique description of each of them.

15. The terrain-based surfel grid map A* path planning utilizes surface properties provided by the SGM. Parametrization of the cost function in the path planner tailors and optimizes the path to application-specific terrain requirements.

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