Lab Assignments – 2025/2026/02

Algorithm development and implementation for computer vision and graphics applications

I. Targetless Multi-Sensor Extrinsic Calibration

Develop an algorithm to determine the spatial transformation between a 3D Lidar and an RGB-D camera without using specialized calibration targets. The approach utilizes "features of opportunity" such as building edges or lamp posts and motion-based trajectory alignment to synchronize coordinate systems. By matching the visual trajectory from the camera with the point cloud motion from the Lidar, the system can self-calibrate during active movement. The research focuses on the minimum motion diversity required for convergence and whether temporal synchronization lag significantly degrades extrinsic estimation compared to static methods.

Software: OpenCV (feature extraction), Ceres Solver (factor graph optimization), and Open3D (point cloud registration).

II. Comparative Photogrammetric and Lidar Mapping

Conduct a large-scale 3D reconstruction of an environment using high-resolution RGB frames processed through the COLMAP Structure-from-Motion (SfM) pipeline. This dense photogrammetric point cloud is compared directly against a ground-truth point cloud generated by a 3D Lidar to evaluate geometric accuracy. The project aims to identify the strengths of passive vision versus active laser sensing in diverse lighting and structural conditions.

The research focuses on "geometric fidelity," specifically analyzing which modality better captures high-frequency details like thin wires or foliage and how COLMAP handles monocular scale ambiguity.

Software: COLMAP, Open3D or PCL (point cloud processing), and CloudCompare (mesh-to-mesh distance analysis).

III. Lidar-based SLAM in Unstructured Terrain

Deploy Simultaneous Localization and Mapping (SLAM) in outdoor environments characterized by steep slopes and uneven ground using only 3D Lidar data. Without an IMU to provide orientation priors, the system must rely on advanced scan-to-map matching and ground-plane extraction to compensate for the sensor’s pitch and roll. The objective is to maintain a globally consistent 3D map by identifying stable geometric primitives in unstructured areas where traditional planar surfaces (like walls) are absent.

The research focuses on "Motion Distortion Compensation" and "Geometric Degeneracy," investigating how pure Lidar odometry handles rapid angular changes and whether the absence of inertial data leads to significant "z-drift" or vertical misalignment in non-flat terrains.

IV. Algorithm development for minimal fitting of a torus

Similarly to the minimal fitting of a sphere **[1]**, one topic is to analyze the torus fitting problem in 3D. The motivation comes from signed distance function research in computer graphics. The important beneficial property of a torus is that this is the simplest second-order surface with an exact signed distance function.

Besides the 3D coordinates, normal vectors of the points are also provided as an input of the algorithm. The initial task is to implement the method of Eberley **[2]** for the overdetermined case. However, we would like to replace the algebraic approach with a geometric one. Therefore, we attempt to find other minimal geometric fitting methods both for 3D position-based and for 3D position and normal vector-based problems. We also have to define the minimum number of inputs for both cases.

[1] Tóth et al.: Automatic LiDAR-Camera Calibration of Extrinsic Parameters Using a Spherical Target, IEEE International Conference on Robotics and Automation (ICRA), 2020

[2] David Eberly: Fitting 3D Data with a Torus, 2018