Real-Time Registration of Point Clouds from LiDAR Integrated UAV for Indoor Environment Reconstruction

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Abstract

3D mapping and modeling of indoor environments is a popular topic in 3D navigation research and applications. We proposed an integration of a navigation sensor module, including laser scanner, camera and an inertial sensor in an Unmanned Aerial Vehicle (UAV) for indoor environment reconstruction. The presented design for a new indoor mapping system is based on LOAM (Laser Odometry and Mapping) method. It performs scan matching to estimate motion of the LiDAR sensor in 6-DOF and mapping in real-time. The rotating LiDAR sensor is mounted on a moving UAV in order to acquire data with a balanced time, completeness and accuracy ensuring the reduced cause of mis-registration of the resulting point cloud data. We evaluate the mapping and registration of point cloud data of an indoor corridor of a building from an integrated navigation sensor in an UAV.

Keyword : Indoor scene reconstruction, Point cloud processing, Automatic registration, Mapping, Drones, UAV, Laser scanner, LiDAR

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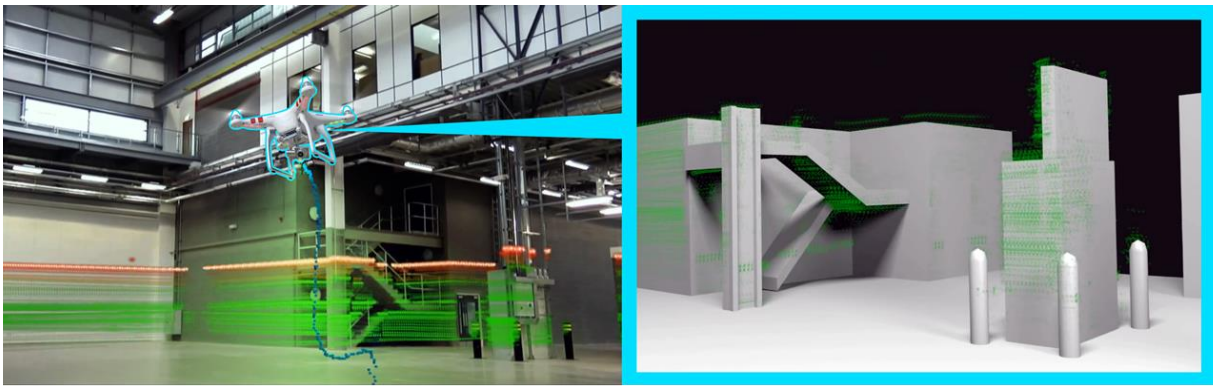
1. Introduction

Drones, also known as Unmanned Aerial Vehicle (UAV) are flying machines nowadays they are valuable source of data for inspection, surveillance, mapping and 3D modeling issues [1, 2]. UAV are currently used for outdoor applications, and, apart from the user interaction, their guidance is GPS-based. Since they are naturally much smaller than regular UAV, mini UAV are more likely to be used in indoor applications [3] (see Fig. 1). Since, the GPS signal cannot be efficiently used inside buildings, and so, UAV must permanently be remotely controlled, which strongly helps in indoor environment reconstruction.

As the sensor technology development, multiple data sources acquired by different sensors platform and different views have provided the great advantages for the desired result achievement. The advantages of UAV lie in its rapid, accurate and high resolution 3D data acquisition, especially for indoor environment modeling. For detailed indoor modeling from wearable LiDAR sensors, one of the challenges is the data completeness. For example, when a person wearing LiDAR sensor moves along an indoor environment, only the objects closing to person can be clearly acquired, whereas the sides or position himself standing are missing from the laser point cloud. However, the use of low cost UAV offers an alternative complementary for the disadvantageous of scanning using wearable LiDAR method [4].



(a) UAV + Navigation sensor + Scanned area (b) Point cloud data + 3D Model

Fig. 1. Example of an indoor environment scanning and 3D reconstruction

3D laser scanners provide automation with the ability to extract 3D dimensional information about their surroundings, detect obstacles in all directions, build 3D maps, and localize. The acquired point clouds show the particular characteristic of having non-uniform point densities: usually a high density within each scan line. The resulting non-uniform point densities affect neighborhood searches and cause problems in local feature estimation and registration when keeping track of the UAV movement and building 3D maps. In this paper, we present a complete processing pipeline for building globally consistent 3D maps with this sensor on a flying UAV.

2. UAV Based position tracking and scanning

UAVs are the promising platforms for acquiring 3D point cloud data and spatial information in any environment. Typically these devices are equipped with optical sensors to support navigation of the platform or to transmit observations to the operator and a camera. By collecting the data and processing captured images, an unknown indoor environment can be explored and reconstructed effectively.

2.1 LiDAR Odometry

3D point clouds data can be produced by laser scanning technology. The laser scanning technology offers fast and accurate way to collect 3D data. These laser scanners can be used for both indoor and outdoor data capture. LiDAR which stands for *"Light Detecting and Ranging"* is a remote sensing method that uses light in the form of a pulsed laser to measure ranges (variable distance) to the earth. Here we assume that the LiDAR is pre-calibrated. We also assume that the angular and linear velocities of the LiDAR are smooth and continuous over the time, without abrupt changes [5].

We start extracting feature points from the LiDAR cloud, P_k. The LiDAR naturally generates unevenly distributed points in P_k. The returns from the laser scanner have a resolution of 0.25^0 within a scan. These points are located on a scan plane. However, as the laser scanner rotates at an angular speed of 180^0/s and generates scans at 40Hz, the resolution in the perpendicular direction to the scan plane is $180^0 /40 = 4.5^0$. Considering the feature points are extracted from P_k using only information from individual scans, with co-planar geometric relationship.

$$c = \frac{1}{|s|.\| X^L_{(k,i)} \|} \| \sum_{j \in S, j \neq i} (X^L_{(k,i)} - X^L_{(k,i)}) \| \tag{1}$$

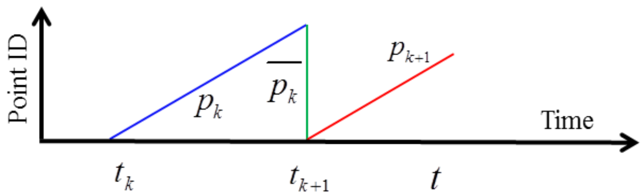


Fig. 2. Reprojecting point cloud to the end of a sweep

Let i be a point in P_k, $i \in P_k$ and let S be the set of consecutive points of i returned by the laser scanner in the same scan. The points in the scans are sorted based on the c values, then feature points are selected with the maximum c's, namely edge points, and the minimum c's, namely planar points. Finally, the feature points are selected as edge points starting from maximum c value, and planar points starting from the minimum c value, and if a point is selected, Then the number of selected edge points or planar points cannot exceed the maximum of the sub region and none of its surrounding point already selected, and it cannot be on a surface patch is roughly parallel to the laser beam, or an boundary of an occluded region. The odometry algorithm estimates motion of the LiDAR with in a sweep. Let t_k be the starting time of a sweep k. At the end of each sweep, the point cloud perceived during the sweep, P_k, is reprojected to time stamp t_{k+1}, illustrated in Fig. 2. During the next sweep $k+1$, P_k is used together with the newly received point cloud, P_{k+1}, to estimate the motion of the LiDAR.

2.2 LiDAR Mapping:

LiDAR mapping algorithm runs at a lower frequency than the odometry algorithm, and is called only once per sweep. At the end of sweep $k+1$, the LiDAR odometry generates a undistorted point cloud, P_{k+1}, and simultaneously a pose transform, T_{k+1}^{L} containing the LiDAr motion during the sweep, between [t_{k+1}, t_{k+2}]. The mapping algorithm matches and registers P_{k+1} in the world coordinates as illustrated in the Fig. 3.

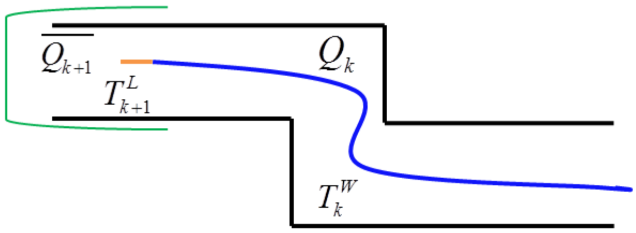


Fig. 3. Illustration of Mapping Process

The blue colored line represents the pose output from the LiDAR mapping, T_k^{w} generated once per sweep. The orange colored region represents the transform output from the LiDAR odometry, T_{k+1}^{L} at a frequency round $10H_z$. The LiDAR pose with respect to the map is the combination of the two transforms, at the same frequency as the LiDAR odometry [6].

3. Registration of point clouds

The registration of point cloud is one of the important step in processing data from 3D laser scanners. Registration of multiple scanned point clouds are performed with a standard Iterative Closest Point (ICP) algorithm [7] by using the CloudCompare software [8]. The ICP algorithm is a reliable and popular method for point cloud registration. Iterative registration algorithms align pairs of 3D point clouds by alternately searching for corresponding points between the clouds and minimizing the distances between matches. The ICP algorithm is briefly described and result of registration with multiple scans of LiDAR data is shown in Fig. 4.

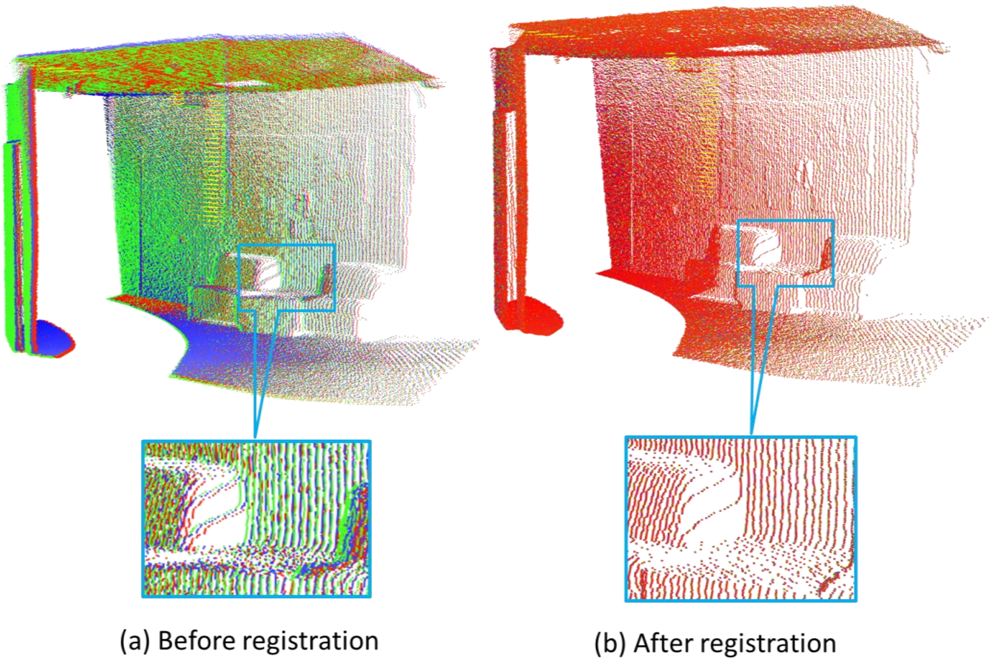


Fig. 4. Real-time registration of a building's indoor corridor

In order to align a point cloud *A* with point cloud *B*, is search for closest neighbors in *B* for point's $a_i \in$ A and minimizes the point-to-point distances $d_i^{(T)} = b_i - T_{ai}$ of found correspondences:

$$T = \arg\min_T \sum_i \| d_i^{(T)} \|^2 \tag{2}$$

As a result, points in *A* are dragged onto their corresponding points in *B*. Assuming correct correspondences, the ICP algorithm can reliably register regular uniform density point clouds (if the initial alignment is not considerably off). In case of our non-uniform density point clouds, closest points do not correspond to the same physical point in the measured environment and the point-to-point error metric leads to dragging the high-density 2D scan lines onto another-instead of correctly aligning the aggregated 3D scans. Since the ICP is based only on a local search algorithm to recover correspondence between two point clouds and it minimises the sum of square distances between possible corresponding points, it converges slowly sometimes and tends to fall into local minima.

4. Conclusions

The system described in this paper enables autonomous Unmanned Aerial Vehicle (UAV) navigate and acquire 3D point cloud data in indoor environments. In a real-world experiment, we have shown that, we can build a globally consistent 3D mapping out of sparse point clouds with a flying UAV (in GPS denied environments). Towards the end, we present a system for registration of point clouds by using a standard Iterative Closest Point (ICP) algorithm for acquired point cloud data from a laser scanner in indoor environments.

Our future work includes the indoor 3D modeling and visualization system, which automatically reconstructs the model from the laser scanned points. We also focus on construction of geometric primitive type to more shapes, such as cylinders or spheres.

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