A Monocular SLAM method for point cloud geolocation in GPS-Denied Environments using UASs

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Abstract

GNSS positioning accuracy in urban canyons or forest areas is degraded, since satellite signals are obstructed by buildings and vegetation. In these GPS-Denied environments, this study proposes the use of an Unmanned Aerial System (UAS) for autonomous mapping, that resolves the problem of localization for the drone itself by acquiring location information of characteristic points on the ground in a local coordinate system in real time. At the same time, applying this method using visual identifiers as control points in the mapping environment, it is possible to provide coordinates in a global coordinate system. We present a prototype drone equipped with a monocular camera and an embedded computing system capable of monitoring an area to produce a local map of its surroundings. The resulting point cloud is readily measurable with an implemented visualizer for extracting and interpreting geometric information from the area of interest.

Keywords: GPS-Denied environments, Visual SLAM, Point Cloud, UAS

1 Introduction

The aim of this work is to develop a methodology for localizing arbitrary marks in a real world scene when GNSS (Global Navigation Satellite System) signals fail to provide coverage. Typical scenes with GNSS signal interference include both urban areas with tall buildings, or forest trees that block the satellite's signal line of sight. This work covers two alternative solution approaches: Firstly, a GNSS equipped drone estimates its location by flying over the signal-denied area, while acquiring accurate GNSS measurements in the starting and ending flight positions. In the second case, the UAS does not depend on starting/ending positions but it autonomously identifies, within the signal-loss area, a ground control point of known coordinates, and transfers this information to other nearby unknown points.

The contributions of the present study are threefold: First, a simulation environment is implemented for experimenting with various drone configurations. Second, a method that utilizes efficient SLAM (Simultaneous Localization And Mapping) algorithm (ORB-SLAM2 [1]) is demonstrated for transferring accurate GNSS signals from a point of the scene to the drone as well to the points of interest. Third, a visualization environment is implemented to illustrate the drone flight paths along with sparse point clouds with the enhanced functionality to derive geodetic coordinates and basic measurable geometries to user-selected points of interest.

2 Relevant Work

There has been substantive work in the literature relating to GNSS-denied environments. In [2] the authors propose a method for indoor navigation based on fiducial markers whereas in [3], radio-frequency identification tags for autonomous navigation are proposed. The latter seems to be more challenging in GNSS-denied environments. The review paper [4] introduces multiple ways to ameliorate lack of GNSS signals, mainly with EKF (Extended Kalman Filters) and visual based methods, including SLAM. This work includes autonomous navigation for assigning GNSS coordinates to areas that have not been previously mapped within the GNSS-Denied zones. To the best of our knowledge, there exists no method that combines visual SLAM with transference of GNSS coordinates from one location to another based only on camera sensors.

3 Implementation

A simulation environment is implemented, where a drone scans the area and the ORB-SLAM2 algorithm [1] is applied for obtaining a sparse point cloud.

For this work, the assumption of a monocular camera attached to a UAS was made along with the existence of two identifiable landmarks to be used as Ground Control Points within the scene. These landmarks are identified as ArUco markers [5].

An rgb video feed is processed by ORB-SLAM2 algorithm, to localize the UAS and map the scene at hand. A sparse point cloud is estimated along with the UAS trajectory versus time. In parallel, ArUco marker recognition is performed. For each video frame where trajectory information exists for both the camera location and the identifiable marker, re-projection of the estimated marker positions is carried out by combining ArUco detection with orb-slam2 localization.

Within the visualization software, the trajectory and point cloud information are imported directly. The problem with the monocular approach for SLAM methods is that there is no way to determine the absolute scale of the area surveyed, without reference to some external measurements. In our approach, the scale of the ArUco markers is estimated with respect to the scale of the point-cloud and the UAS trajectory. This is accomplished by comparing the distances between successful detections of the same ArUco marker. By minimizing the distance between all ArUco markers, we can approximately estimate their scale and use its real world size to effectively create an absolute metric between all points in the 3d scene.

As a final step, a selection process has been implemented at the visualization tool to permit the user to manually select points from the point cloud and identify their positions within orb-slam2's coordinate system. A relative to absolute scale conversion is finally carried out and the geodetic coordinates for all selected points are obtained.

A limitation of the above pipeline is that monocular SLAM scale estimation tends to accumulate errors (scale drift), which is partially corrected by revisiting already seen places in the scene (loop closure).

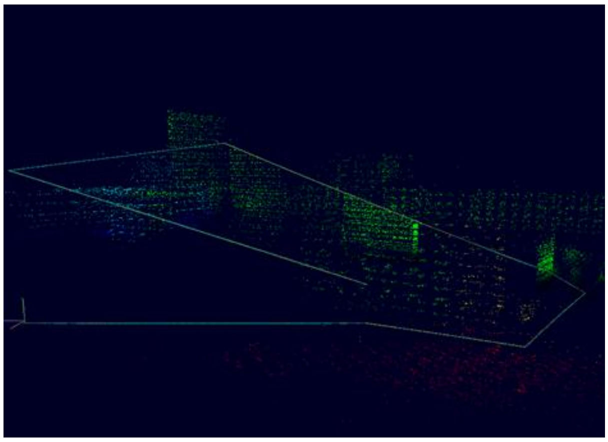

Figure 1: Visualization tool for trajectory and point cloud detection for a sample trajectory

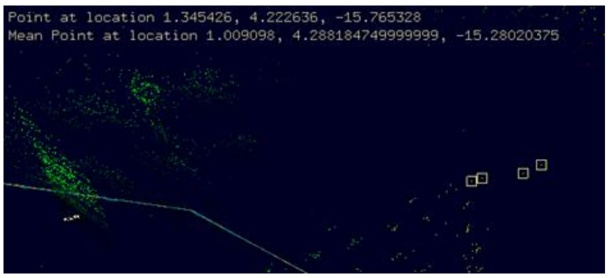

Figure 2: Visualization tool, with data point selection

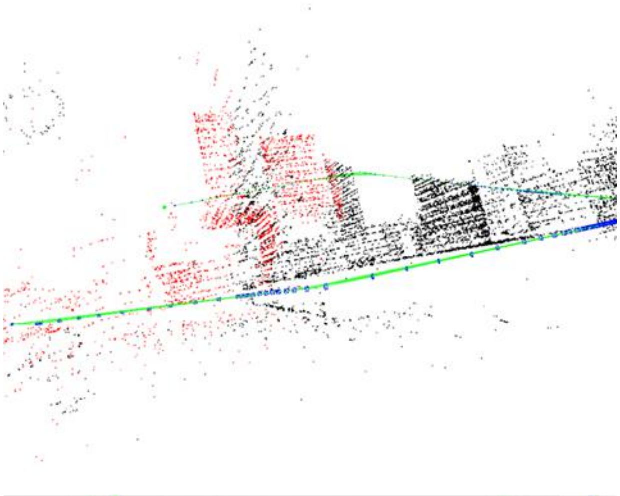

Figure 3: Orb-Slam2 localization and mapping on custom made city model

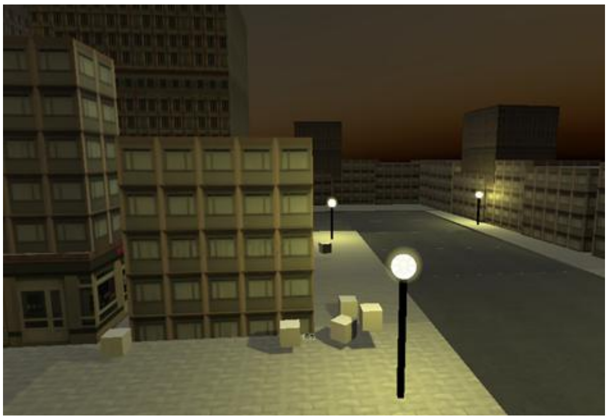

Figure 4: Unity3d custom-made city model for experiments (invisible cubes function as waypoints for automated flights for repeatability)

4 Results

The ultimate goal of this project is to estimate the location of an unknown ArUco marker when the coordinates of another one are known. Specific trajectories for the UAS to follow have been defined by normalizing the flight paths to ensure repeatability. Apparently extensive testing in multiple situations is required to secure robustness over scale estimation although this is not always possible under the assumption of a single monocular camera. The final offset error in the marker's position can be made arbitrarily high, depending on the flight path length as well as the ArUco marker size estimation error. Within the orb-slam2 coordinate system the drone localization error varied as expected based on the error estimates presented in [6]. ArUco marker estimation introduced additional errors in translating to real world coordinates, which did not allow accurate estimation of final error rates. An estimation of the offset error based on preliminary experiments is within the range of a few meters for flight paths averaging thirty to sixty meters, after loop closure. We converted the arbitrary ORB-SLAM2 units based on the size of the city-model and ArUco marker intended sizes.

5 Conclusion

We have presented our methodology for extracting positional and GNSS-related information from scene landmarks using a camera-equipped drone. The first findings of the defined methodology provide low accuracy within the point cloud, yet, the real time point cloud reconstruction is quite optimistic. The use of stereo camera should compensate for most described errors.

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6 References

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