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Graph-based SLAM (Simultaneous Localization And Mapping) for Bridge Inspection Using UAV (Unmanned Aerial Vehicle)

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ABSTRACT

The manual bridge inspection requires the hard work of the surveyor. A robot such as UAV (Unmanned Aerial Vehicle) can be used to avoid boring and dangerous works and replace humans. The field of research for bridge inspection using UAV has gradually been developed to meet human needs. However, UAV's GPS (Global Positioning System) receiver cannot receive GPS signals under the bridge. This is because the satellite signal is blocked by the bridge structure. The purpose of this paper is to propose a localization method for bridge inspection using a UAV in the lower part of the bridge. Our localization method is a graph-based SLAM (Simultaneous Localization And Mapping) approach using a 3D LiDAR and a mono camera. VO (Visual Odometry) from the camera and the ICP (Iterative Closest Point) algorithm using a 3D LiDAR provide nodes and constraints for the graph structure. Experiments were conducted in a bridge environment and our method was compared with the ground truth obtained from an RTK (Real Time Kinematic) GPS.

1. INTRODUCTION

As the development of UAV has been advanced in a decade, the application using UAV grow up radically. The bridge inspection using UAV is also in a large part of UAV application. Traditionally bridge inspection was done by manual. However, human bridge inspection is dangerous and takes a lot of time (Murphy 2011, Jung 2016, Song 2016).

In order to inspect the bridge using the UAV, the pose of the UAV should be determined. Generally, the pose of the UAV is acquired via the GPS. However, in the lower part of the bridge, the satellite signals are blocked by the bridge and GPS is unusable. Therefore, the robust localization method is required even under the bridge.

In this paper, we propose a localization method for bridge inspection using a UAV

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under the bridge. For a robust localization, the graph-based SLAM (Jung 2016, Lee 2014, Kaess 2008) using a single camera, 3D LiDAR, GPS, and IMU are leveraged. The initial pose is determined from the IMU and the pose results from the single camera, 3D LiDAR and GPS provide nodes and constraints of the graph structure. The pose information from each sensor is fused using the graph structure. Therefore, in case that the GPS signal is blocked such as under the bridge, it is possible to localize UAV.

The remainder of this paper is organized as follows. The system overview of proposed method is explained in Section 2. In order to prove the localization performance of proposed method, experimental results are presented in Section 3. In Section 4, conclusions of our work and future works are described.

2. UAV POSE ESTIMATION USING GRAPH-BASED SLAM

2.1 System Overview

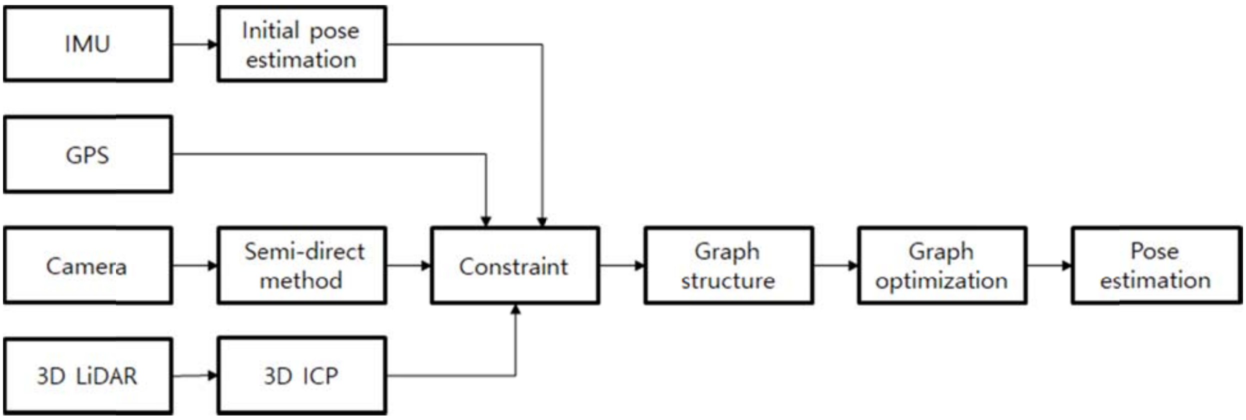

Fig. 1 Overall flow diagram of the proposed method.

The overall flow diagram of the proposed method is shown in Fig. 1. The proposed method leverages the graph-based SLAM. The graph structure is composed a node and a constraint. The node of the graph structure is the UAV pose and the constraint of graph structure mean the relative pose between the node and the covariance. The graph structure makes it possible to determine the pose fusing the pose results of each sensor. In this way, localization is performed by fusing the pose information acquired from each sensor, so that it is possible to robust localization even in a region where the GPS signal is not received, such as the bridge.

As input data, IMU (Inertial Measurement Unit) data, GPS pose information, the camera image stream, and 3D points of 3D LiDAR are acquired from the UAV system. First, the initial pose is estimated using the IMU (Inertial Measurement Unit) data. The pose from the IMU accumulates the pose error for a long term. Therefore, only relative pose information for a short term is used to calculate the pose information. The GPS provides the pose information and reliability. Thus, the GPS data is directly leveraged for the graph structure. In order to determine the pose from the camera images, the semi-direct method is used. The semi-direct method is presented in the next part. The

3D ICP makes use of the 3D points obtained from 3D Lidar. The 3D ICP algorithm of the proposed method is also described in the next part.

The final pose is estimated from the graph optimization process. In the proposed method, sparse linear algebra method (Kaess 2008) is used for graph optimization of the constructed graph structure.

2.2 Semi-direct method

Semi-direct method (Forster 2014) is a technique composed a feature-based method and direct method. The feature-based method has the computation burden occurs when feature extraction process. However, feature-based method robustly operates for camera motion estimation. The pixel information of the camera image which is the intensity gradient direction and magnitude is directly used in the direct method. The direct method has an advantage the computation time compared to feature-based method since direct method uses the raw pixels directly without extracting the feature extraction. The semi-direct method has a 3D map composed of features and the feature extraction process is only leveraged when the number of the corresponding features is low between the current image and 3D map. For the camera motion estimation, basically the direct method is used in the semi-direct method. Also, in order to take the computation advantage, the subpixel-based direct method is conducted.

2.3 3D ICP with normal vector

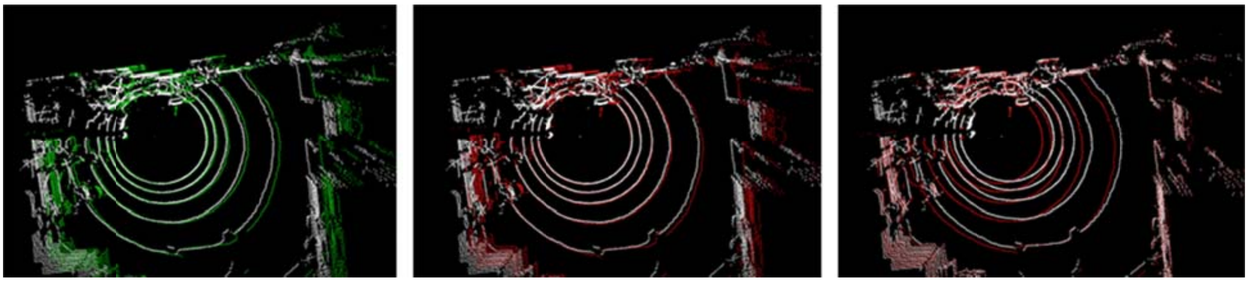

Fig. 2 ICP results. White points of all images are original points and green and red points are target points. The left is the before the ICP algorithm. The middle is the results of the ICP algorithm without normal vector. The right is the results of the ICP algorithm considering the normal vector.

In order to acquire the relative pose information of the 3D points from the 3D LiDAR, the ICP algorithm is used. The ICP algorithm finds the corresponding points between the original and target points. However, simple point to point ICP algorithm does not guarantee the pose accuracy, since the position of scan data is not always same. The ICP algorithm considering the normal vector increases the accuracy of the pose. The ICP algorithm with normal vector is not point to point matching. The compared ICP results are shown in Fig 2. The right of the Fig 2 is the ICP method in proposed method. It is confirmed that the white and red points are correctly aligned when compared with the middle of the Fig 2.

3. EXPERIMENTS

3.1 Experiment setup

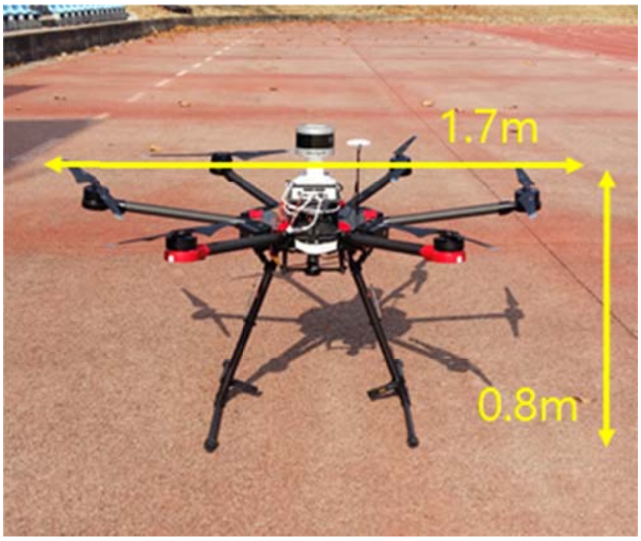

Fig. 3 UAV sensor system. It is composed the UAV, single camera, 3D Lidar, RTK-GPS and mini PC.

The Fig. 3 illustrates our UAV sensor system. UAV platform (DJI Matrix 600), RGB camera (Point Grey Flea3), 3D LiDAR (Velodyne VLP-16), RTK-GPS (DJI RTK-B), and mini PC (Intel NUC) are used. The RTK-GPS is just used for ground truth. The experiment environment is shown in Fig 4.

Experimental site is Korea science museum monorail. The flight time and distance are about 90 second and about 70 meters respectively.

In order to evaluate the proposed method, RTK-GPS data as a ground truth should be acquired. Therefore, the UAV flight next to the bridge. It makes RTK-GPS inoperative the under the bridge since the satellite signal is blocked by the bridge structure.

Fig. 4 Experiment environment

3.*2 Experimental Results*

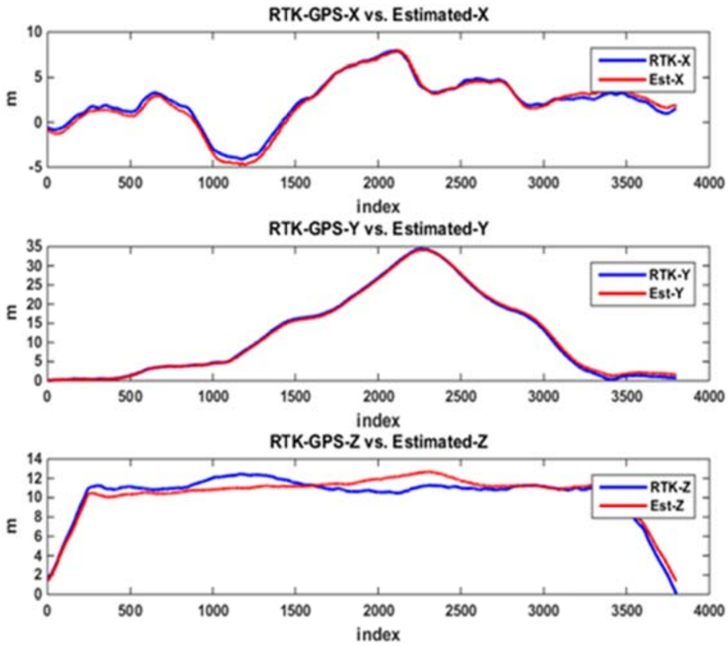

Fig. 5 Localization results. The red solid line indicates the estimated pose and the blue solid line is ground truth. The x and y axis of all figure is time index and meter respectively.

The graphical results are shown in Fig 5. The red solid line indicates the estimated pose results and the blue solid line is the RTK-GPS pose. The X and Y-axis of all figure is time index and meter respectively. Table 1 presents the RMSE (Root Mean Square Error). It can be confirmed that the RMSE values of proposed method of the Z-axis are larger than the X and Y-axis. However, the RMSE values of each axis are within 0.7 meters.

Table 1 RMSE results.

	X	**Y**	**Z**
RMSE error (m)	**0.416**	**0.423**	**0.630**

4. CONCLUSIONS AND FUTURE WORKS

In this paper, we proposed the graph-based SLAM method for bridge inspection UAV localization. In order to acquire the 3D pose results from the 3D LiDAR, the ICP algorithm considering the normal vector was used. The semi-direct method was leveraged for localization using the single camera. The estimated poses from each sensor are fused using the graph structure. Therefore, it is possible to estimate the pose where the GPS signal is blocked. To prove the robustness of proposed method, the experiment was conducted in outdoor environments. The RTK-GPS is used for just ground truth. The RMSE value of the proposed method is within 0.7 meters.

For the future works, we will boost the computation time using the GPU (Graphic Processing Unit) for the ICP algorithm.

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