DESIGN AND PERFORMANCE OF A WEARABLE GEOSPATIAL DATA ACQUISITION SYSTEM

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ABSTRACT: Recently, the number of researches about multi-sensor system is increased, because this kind of system can provide us a lot of useful information for 3D reconstruction purpose. A multi-sensor system can base on various platforms such as robot, backpack, drone, etc. to become portable and acquire data efficiently. This paper introduces the design and performance of a geospatial data acquisition system; especially, backpack system, including two fisheye lens cameras, two LiDAR sensors and GNSS-INS. At the stage of system design, the sensors are allocated to maximize the overlapping of data acquisition areas and to minimize the occlusions among the sensors. After the backpack system is built up, several critical processes should be carried out to acquire precise geospatial data from the system. On the first step, sensor self-calibration process of the optical camera is carried out. A fisheye lens camera follows different physical model compared to the regular optical cameras. Thus, specifically designed test beds and calibration approach for the fisheye lens camera are applied for this step. The second step is system calibration, which expresses the geometric relationship between sensors (e.g., 3-translations and 3-rotations). One issue of matching problem has arisen in the process of system calibration between the LiDAR sensors and fisheye lens cameras. In this process, the point-to-plane approach was applied to overcome the limitations of the traditional point-to-point approach. After system calibration, positional and semantic information were acquired from the backpack system for data fusion. The experimental results using real datasets showed high accuracy of data fusion. Subsequently, georeferencing process should be carried out for integrating the datasets acquired from different epochs while the backpack system is moving. Visual Odometry (VO) and Iterative Closest Point (ICP) methods were compared to each other. The results show that the VO method reduces the effect of the error propagation problem coming from ICP when the backpack system is moving. The future works will focus on the Simultaneous Localization and Mapping (SLAM) method in georeferencing process. In this experiment, the proposed backpack system was used to test with real dataset and verified the accuracy.

1. INTRODUCTION

Multi-sensor system (MSS) has been widely used for indoor geospatial data collection purpose, especially in 3D model reconstruction (Bosse et al., 2012; Wen et al., 2016; Blaser et al., 2018). In this case, a MSS can include optical cameras, laser scanners for positional and semantic information, with additional GPS/INS. Afterwards, these datasets are combined to get 3D information of environment and position of system. Between different types of multi-sensor systems, wearable system has many benefits for using. Firstly, this system can be moved easily by human with its reasonable weight, to survey in a long trajectory. Secondly, in case of rugged terrain or complicated area, a permanent geospatial system or drone can not get in and survey completely. By contrast, a person can wear a MSS and directly measure in a flexible way. In this paper, a backpack system is introduced with several specific sensors: 2 fish-eye lens cameras and 2 LiDAR sensors. These sensors are arranged in different positions and directions to ensure that not only the surrounding environment is fully surveyed, but also the overlapping data areas between sensors are maximized.

After building the backpack system, there are some steps to be taken. The first step is sensor self-calibration. More detail, sensor self-calibration is the process to determine the interior orientation parameters (IOPs) including focal length, coordinates of principal point, and distortion parameters. IOPs express the characteristics of each sensor, the fish-eye lens camera and LiDAR sensor in this case. On the other hand, system calibration is the process of finding the relationships between sensors in a whole geospatial data acquisition system (Zhang and Huang, 2006). This relationship can be express by the relative orientation parameters (ROPs), including 3 translations and 3 rotations. However, it is hard to find conjugate points between optical cameras and LiDAR sensor. Thus, the traditional point-to-point registration approach (Besl and McKay, 1992) is not applicable for the accurate system calibration procedure. Instead, this paper used the point-to-plane registration method to overcomes the limitations of point-to-point approach. The original idea of this method was proposed by Habib et al. (2005) and Ghanma (2006) for the georeferencing between aerial photos and LiDAR data. This method is based on the constraint that all the pixels representing a specific plane should be located in the corresponding plane patch which acquired from LiDAR data.

Finally, using IOPs from sensor self-calibration process, ROPs from system calibration process and Collinearity equations, RGB-D data can be calculated in data fusion procedure. However, when the backpack system is moving, each RGB-D data acquired from sensors belong to an independent coordinate system of each epoch. Because of that reason, georeferencing process is needed to combine all the data into the same coordinate system. In general, georeferencing includes 3 approaches: direct georeferencing, indirect georeferencing and data-driven georeferencing (Schuhmacher and Böhm, 2005). In direct georeferencing, position and orientation of multi-sensor system can be calculated directly using additional sensors such as a GNSS Athena, IMU, total station, etc. in case the environment is suitable for these sensors to acquire accurate results. By contrast, the indirect georeferencing approach do not use precise information from additional sensors. It is based on matching features between images taken from optical cameras and point cloud data from LiDAR sensor. This approach requires high-quality or high-resolution images and the improvement of matching process between images. The Visual Odometry (VO) method is a case of indirect georeferencing. The final approach, data-driven georeferencing, is based on reference datasets that have already been georeferenced such as digital surface models or virtual city models. However, these initial datasets will affect the georeferencing results considerably. The algorithm considered for this approach is the Iterative Closest Point (ICP) proposed by Besl and McKay (1992), or Simultaneous Localization and Mapping (SLAM) method (Durrant-Whyte and Bailey, 2006).

2. DESIGN OF BACKPACK SYSTEM

In this paper, the wearable geospatial data acquisition system will be introduced as a multi-sensor system with the combination of 2 fish-eye lens cameras and 2 LiDAR sensors. All sensors are attached onto a platform which has a shape of a backpack so that the whole system can be worn by human. In the body of system's platform, all sensors are fixed tightly when the system is moving or shaking. Two fish-eye lens cameras are allocated on two sides of the top of the backpack system in two opposite directions. One LiDAR sensor lies among three cameras on the top and the other one lies on the back and locates in inclined direction. Design of backpack system and positions of all sensors are expressed in Figure 1.

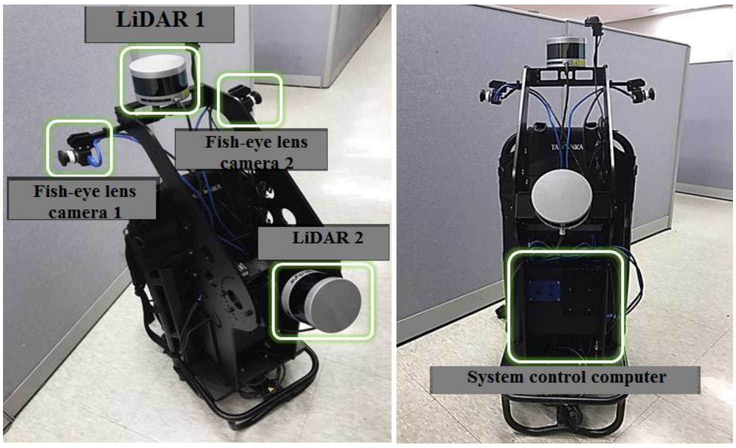

Figure 1: Design of the backpack system

A fish-eye lens camera has a different projection model from a general optical camera. Therefore, it is necessary to identify the characteristics of fish-eye lens camera to ensure the accuracy of calibration process. Table 1 shows the specifications of the cameras used in the proposed backpack system.

Table 1: Specification of fish-eye lens camera

	Fisheye-lens	Camera
Model name	Sunnex DSL315	Chameleon3 5.0 MP Color USB3 Vision
Projection	Isometric projection (equisolid angle projection)	
Resolution (pixel)	2448×2048	
Pixel size (mm)	0.00345	

Focal length (mm / nominal value)	2.67

Two LiDAR sensors are placed vertically and horizontally in order to scan the surrounding environment completely and avoid direct contact between the beams of light from two sensors. The characteristics of LiDAR sensor are illustrated in Table 2. With the proposed design, the backpack system can acquire information of environment from all directions with the overlapping areas to remain the accuracy. Figure 2 show the fields of view of each sensor when surveying.

Table 2: Specifications of LiDAR sensor

Model name	Velodyne HDL-16E	
Number of channels	16	
Field of View	Horizontal	360°
	Vertical	30° (±15°)
Resolution	Horizontal	0.1°(5Hz) 0.2°(10Hz) 0.4°(20Hz)
	Vertical	2°
Range	Up to 100 m	
Accuracy (nominal)	± 3 cm	
Size	104 mm × 72 mm	
Weight	0.83 kg	

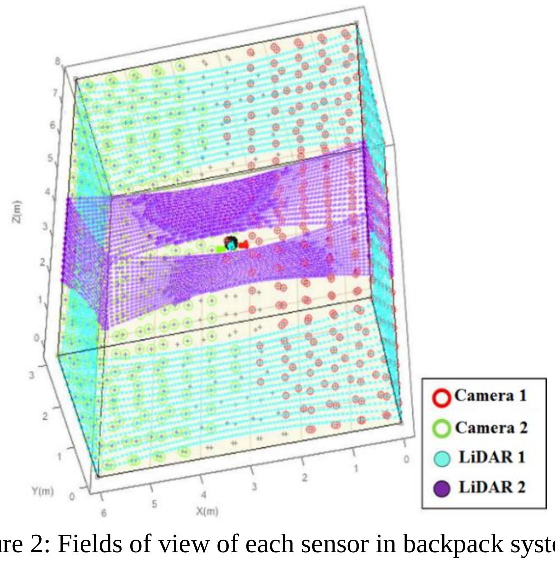

Figure 2: Fields of view of each sensor in backpack system

3. PERFORMANCE OF BACKPACK SYSTEM

3.1 Sensor self-calibration

In the multi-sensor system, the first process should be carried out is the self-calibration procedure of each sensor. The basic concept is determining the characteristics of sensor to accurately represent the mathematical model of sensor. With an optical camera sensor, it is considered calibrated if IOPs (principal point, focal length and distortion parameters) are known. The general method using in self-calibration is least square estimation method – bundle block adjustment (Fraser, 1997; Remondino and Fraser, 2006). However, the fish-eye lens camera exhibited a correlation between orientation parameters, which was different from general optical camera. In this case, the correlation between orientation parameters of fish-eye lens camera has to be analyzed. After that, several testbeds (with black and white patterns) are designed for simulation. Finally, the self-calibration process will be done using the algorithms base on general camera model with bundle adjustment procedure.

3.2 System calibration

After calibrating two camera sensors, the system calibration process, which express the geometric relationship between cameras and LiDAR sensors, is proposed. In this paper, point-to-plane registration method is used, because it overcomes the limitations of traditional point-to-plane registration method. In general case of point-to-point approach, the relative locations (without the scale factor) between optical images from cameras are calculated using tie points, which simultaneously appears on multiple images. Afterwards, by using the LiDAR points ad Ground Control Points (GCPs), the scale factor can be calculated, and Exterior Orientation Parameters (EOPs) of all images are expressed in the coordinate system of LiDAR sensor. Nevertheless, it is hard to determine the exact locations of GCPs from LiDAR sensor because of its inherent and random characteristics. Instead, the point-to-plane approach does not require the exact locations of GCPs, only tie points on the plane and the corresponding plane patch which is acquired from LiDAR sensor are used. Designed testbeds are also used to create simulated data for system calibration process. The concept of the point-to-plane approach in system calibration is express in Figure 3.

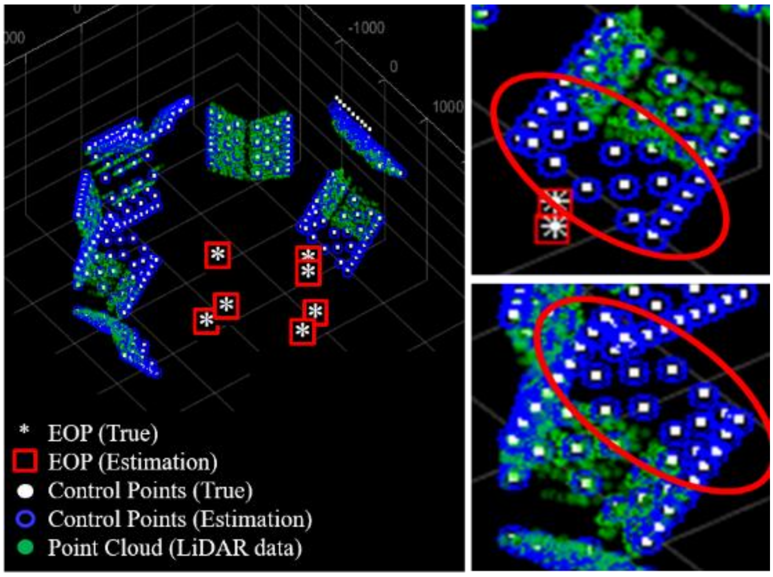

Figure 3: Point-to-plane method in system calibration

3.3 Data fusion

In a multi-sensor system, data fusion is the process of integrating multiple datasets from different kinds of sensors to produce more accurate and useful data than could be achieved by the use of a single sensor alone (Hall and Llinas, 1997). Relative orientation parameters, which are calculated from system calibration process, will be used to transform the coordinates of LiDAR point cloud into the same coordinate system of fish-eye lens camera by the Collinearity equations (1), (2) (Choi et al., 2018)

$$\mathrm{x} = x_p - \mathrm{f}\frac{m11(X - X0) + m12(Y - Y0) + m13(Z - Z0)}{m31(X - X0) + m32(Y - Y0) + m33(Z - Z0)} + \Delta x \tag{1}$$

$$\mathrm{y} = \mathrm{y_p} - \mathrm{f}\frac{\mathrm{m21(X - X0) + m22(Y - Y0) + m23(Z - Z0)}}{\mathrm{m31(X - X0) + m32(Y - Y0) + m33(Z - Z0)}} + \Delta y \tag{2}$$

$$\text{Rotation matrix } \mathrm{M}(\omega, \varphi, \kappa) = \begin{bmatrix} \mathrm{m11} & \mathrm{m12} & \mathrm{m13} \\ \mathrm{m21} & \mathrm{m22} & \mathrm{m23} \\ \mathrm{m31} & \mathrm{m32} & \mathrm{m33} \end{bmatrix}$$

In the equations, x and y are the coordinates of image point from fish-eye lens camera. Δx and Δy are the distortion parameters of camera. x_p and y_p are the coordinates of principle point and f is focal length. ω, φ, κ are the primary rotation angles along X-axis, Y-axis and Z-axis, and the value from m11 to m33 can be extracted from the rotation matrix. X, Y, Z are the coordinates of Ground control point, and $X0, Y0, Z0$ are the figures for the sensor position in ground coordinate system.

4. GEOREFERENCING

4.1 Iterative Closest Point (ICP) method

Iterative Closest Point (ICP) is the method to minimize the difference between two point clouds, is proposed by Besl and McKay (1992). The concept of this method is to iteratively find the shortest distance between one point of the source point cloud to a fixed point cloud, calculate the transformation and apply to the source point cloud until the solution is converged. In the case of using backpack system, ICP method is used to match two LiDAR point clouds that have the overlapping area when the system is moving. The final result will be the transformation between each pair of point clouds to covert all LiDAR data into the same coordinate system. However, ICP is widely used for data registration, but less popular in georeferencing, because the overlapping point areas among LiDAR point clouds can change continuously (Fan et al., 2015). The matching process of images taken by cameras at each stop when the system is moving will give us higher accuracy results. In more detail, the indirect georeferencing process using images will overcome the disadvantages of ICP. A method called Visual Odometry method will be proposed when using the backpack system.

4.2 Visual Odometry (VO) method

Visual Odometry (VO) is the process of estimating the motion of a vehicle using images from cameras attached to it (Scaramuzza and Fraundorfer, 2011). In the backpack system, monocular VO is applied, with the use of only one fish-eye lens camera on each side when the system is worn and moving. For georeferencing, this is the indirect process based on matching point features between images taken from fish-eye lens cameras. This approach requires high-quality or high-resolution images and the improvement of matching process between images. With the high-quality images data, VO method will show precise results. This procedure needs the control points at the beginning (the first epoch) to be the initial value from an additional sensor such as a total station, GNSS or IMU. After this procedure, we can get the geometric relationship between cameras and the ground coordinate system. We can combine this relationship with ROPs of cameras and LiDAR sensors to relate the LiDAR point's coordinates to the ground coordinate system and transform each point cloud from each epoch.

5. EXPERIMENTS

The real dataset is collected using the backpack system in a corridor of engineering building at Myongji University, Korea. This is an indoor environment including many closed doors and one way in the center which leads to the stair. From one side of the corridor, to start the experiment, the backpack system is worn and moved straight ahead to the other side of the way. After each 1m, the system is stopped and acquire precise images and point cloud data. On the first position of the experiment, several control points are generated and measured using a total station, in order to make the initial data for matching process in VO method. Total station is an accurate sensor can be used in case of indoor environment with a good line of sight and simple structure without complex elements. After data acquirement process, the backpack system will be connected with a monitor to access the dataset and save all image data and LiDAR point data by an USB port.

Figure 4: Experiment place for using backpack system

Before doing the georeferencing process, all raw data have to be analyzed by the data pre-processing approach. With ICP method, all LiDAR data will be transformed to 36 datasets acquired from each time the backpack system is stopped. Image data is also chosen which is corresponding to the LiDAR data for the VO method. After that, all data will be used for the georeferencing process to calculate the final results which is the geometric relationship (three translations and three rotations) between point cloud's coordinate and the ground coordinate system. Finally, accuracies are calculated to compare between two method.

6. RESULTS AND DISCUSSION

Figure 5 shows the final point cloud after using ICP method to find the relationship between LiDAR point cloud and the Ground coordinate system, and apply all the transformation to the point data of each epoch:

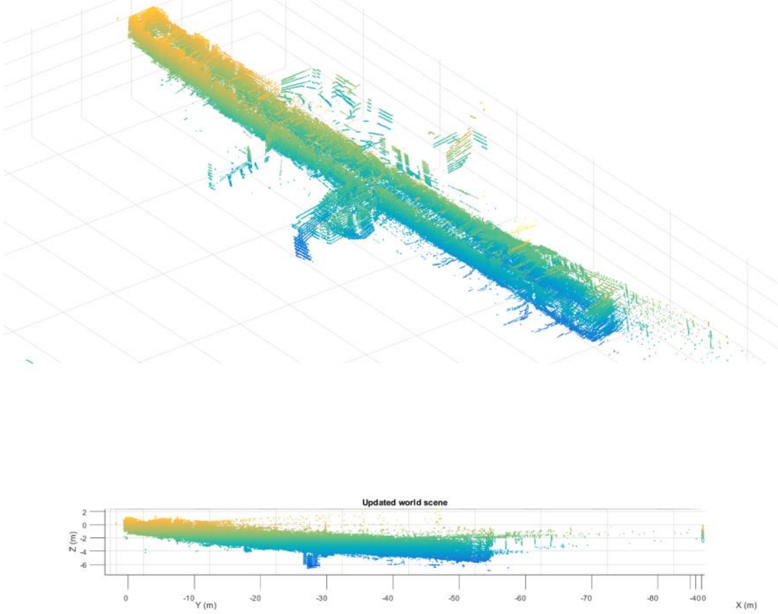

Figure 5: Point cloud data using ICP method

Visually, the result of ICP method shows that when the backpack system is moving further to the other side of the corridor, the position of point cloud has bigger errors, especially in Y-Z plane, the corridor looks like skewed down .It is called the error propagation. To improve the error, VO method is tested to see the result of point cloud data after the georeferencing process.

7. CONCLUSION

This paper performs a wearable geospatial data acquisition system- a backpack system, including two fish-eye lens cameras and two LiDAR sensors. Design and performance of the backpack system is design, with several critical steps: sensor self-calibration, system calibration, data fusion and georeferencing. With the georeferencing procedure, ICP method and VO method are described and compared to each other to show the effectiveness of image data and LiDAR point data. In the experiment, the backpack system is used to acquired real dataset and then the accuracies of two methods are considered. It can be seen that the VO method shows the higher accuracy and the final point cloud of the test area looks better. In the future, SLAM method or the integration of image and point data will be focused to improve the result achieved from the backpack system.

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