CHANGE DETECTION ALGORITHM OF 3D LIDAR POINT CLOUDS CAPTURED BY UNMANNED AERIAL SYSTEMS

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Abstract

Three-dimensional LiDAR-Based Point cloud map (3D map) is widely used in varieties of application. In the inspection and survey applications, LiDAR equipment is attached to unmanned aerial system (UAS) for additional perspective of 3D map. Due to the plenteous information and details provided by 3D map, human could find it complicated when comparing between two 3D maps that collected with UAS at the exact location but different in time collected. This paper provides the details of the UAS and LiDAR setup to generate 3D point clouds. Moreover, the object detection algorithm is presented step by step for the obtained point clouds. The experimental results show that the proposed detection algorithm can differentiate the object with the dimension of 2x2x2 meter from two 3D maps successfully while the aircraft flying at the altitude up to 50 meters.

Keywords: *LiDAR, Object Detection, Point Clouds, Three-Dimensional Map*

1. Introduction

Three-dimensional map (3D map) is an powerful tool to capture and identify the details of area and object. Previously, 3D map is generated by using the technique of photogrammetry where multiple two-dimensional pictures are processed. However, photogrammetry technique does not use the actual distance of the object to the capturing device such as camera, therefore, the error of the 3D map is still existed and can cause an inaccurate analysis after all. To overcome the mentioned issue, the technology called Light Detection and Ranging (LiDAR) is introduced where its fundamental is to emit pulse and receive its reflection to identify the distance to the object [1]. LiDAR sensor uses the time it took to calculate the distance repeat this process millions of times to create a point clouds. As mentioned, LiDAR sensor does not capture all surface area of objects but only certain area of objects. Accuracy of LiDAR sensor and positioning system (GNSS) may affect the location coordinates of points acquired but is not the main reason. LiDAR sensor does not design to acquired exactly same location coordinates of points from two different point clouds map captured. Moreover, to obtain the broad perspective of the 3D map, LiDAR sensor has been used by equipped with unmanned aerial system (UAS) in order to capture and create bird-eye view 3D map of the interested area. This concept can be seen in various applications such as environment reconstruction [2], bridge defects inspection [3], and building information modelling [4]. These examples show the popularity of using UAS equipped with LiDAR to generate 3D map and make use it for several analysis such as change detection of the monitored area for the safety and improvement purposes.

Change detection can be considered as very useful analysis tool. Formerly, comparing between two different point clouds will be done by overlapping point clouds. Human visualization is in need to perform identification of the two-point clouds. Dyeing each point clouds in different color may reduce the complicates of identification but still can't be considered as an effective solution. Computation power of computer tremendously increased in recent years. Utilizing it efficiently will result in possibility to remove all human load to perform the identification. Furthermore, using only computer to process the tasks the data size could be fed to system would increase many folds from using human to identify changed and could process continuously without tiredness. Comparing two similar point clouds is a complicated task due to points data stores in each point clouds have slight difference location coordinates (XYZ). Point in the same area does not have the exact same location coordinates.

The algorithm of change detection from the point clouds is the crucial research topic recently. Xiao et al. [5] initiated change detection project with two different methods which has an objective to test the change detection of a road environment, people movement and parking cars**.** The 3D map change detection methods include Bottom-up and Top-down algorithm. Bottom-up method analyzes low level changed detection, which is pixel reference, to use in preprocess or data-cleansing. This method is suitable for a short term to search temporary object and no changing in long term to search permanent object. On the other hand, Top-down method analyzes high level where the data processing needs to be done before object separation**.** Both principles have advantage and disadvantage. For example, Bottom-up can process raw data but detection may have mistaken from closed data. Top-down will have an accurate detection if there is a precise data processing. Liu et al. [6] studied change detection in 3D map with point-to-point comparison, which refers to nearby points between two comparison maps. Defining threshold to determine range is the key component which changes the density of 3D map before proceeding to the change detection analysis,

Objective of this paper[1] aims to identify changed in point clouds by utilizing tremendous amounts of computation power. Furthermore, reduce the role of human in the process. Designing algorithm that could separate between significant changes and noises is focused. The research mainly targets on identifying objects that presented or disappeared in different

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time aspects. The algorithm would be testing through scenarios which suspicious car presented in an open area. This scenario included certain noises such as trees and grasses. The wind blow causes tree branches to move and leaf to fall which result a change of point clouds. The following sections include methodology where steps to obtain the change detection from point clouds are explained. After that, the experimental setup and results are presented. Lastly, the experimental results from different scenario are discussed and summarized.

2. Methodology

This section explains the method to obtain the change in the 3D point clouds of two different map step by step including data collection, data merging, and change detection algorithm. Figure 1 illustrates process to obtain 3D map.

Data Collection

The 3D map data collection is done by using Light Detection and Ranging (LiDAR) sensor attached on the Unmanned Aerial Vehicle that flies in a survey grid flight path. Data quality, point cloud density, and accuracy are depended on a sensor quality, flight altitude, data overlapping, and flight path directions [7]. These configuration parameters are crucial for the precision of the detection algorithm.

The Unmanned Aerial Vehicle that used in a data collection process is a modified Agricultural Hexa-Rotor with a customized open-source flight controller module and attached with the data collection sensor. The aircraft is able to perform up to 30 minutes flight time and 1 square kilometer of map coverage area per flight. The aircraft support hot swapping process so it can continue collecting data mission without rebooting the entire system.

The data collection sensor used in the research is Geosun GS-100M. The sensor consists of LiDAR Unit (Livox Avia) and position system (IMU and GNSS). All units operate simultaneously while UAV airborne collecting 3D point clouds, attitudes, and positions. In addition, GNSS base station collects ground reference data in order to perform Post-Processed Kinematic (PPK) high precision GNSS data correction process used to improve the positioning data up to centimeter level. Although, small distance between strips and cross grid flight path decreases data blind spot and increases data density due to the multi direction flight of the grid and more overlapping area of data, it takes more time to collect data than linear grid due to the additional strips. Because of the small distance between strips and the flight path, multi-rotor UAS is more suitable for the task due to its maneuverability.

Data Merging

The software provided with the Lidar sensor module are Shuttle and gAirhawk used in the data merging process. Shuttle software is used to correct GNSS data from the rover GNSS unit (Lidar positioning unit) with base station unit in PPK process. After that extracted data is processed into text file format. Then gAirhawk software merges the extracted data and Lidar RAW files in to processed files (.las) [8]. The las file is now containing 3D point clouds with three-dimensional coordinate of each point.

Change Detection Algorithm

The following are steps of the change detection algorithm for two 3D point clouds maps. Ultimately, the algorithm starts from removing unwanted components and ends with the difference of two maps.

- *Ground removing*: First, the algorithm removes ground from both maps by fitting a plane to a point cloud with three constraints; maximum allowable distance from inlier point to the plane, additional orientation constraints specified by reference vector declared as positive z axis (0, 0, 1) and maximum angular distance. Point clouds that defined as ground can be consider as a tremendously meaningless data, removing these data can dramatically reduce computation power needed in change detection algorithm.
- *Similar points elimination*: Concept of the processes is to remove all of the related objects and point clouds in both reference map and comparison map. What we are left is the points which is different in both maps. The points can be either Appearing and Missing change of the map depending on which is the minuend and subtrahend map. Both Appearing and Missing use the same methods and algorithms but switching between minuend map and subtrahend map. Appearing change map obtained by using reference map as minuend and comparison map as subtrahend. In the same way Missing change map obtained by using reference map as subtrahend and comparison map as minuend. It seems to be simple, but the problem occurs in actuality despite the fact that point clouds in both maps are identical but the coordinates of them are inequivalent. Subtracting or Removing Point Clouds need an exact coordinate to specify points to be remove from the map. The problem resolved by finding a neighbour points within a radius of a query points in the minuend map from subtrahend point cloud. The process amount of time and computational power required depends on the radius size of neighbour's point wanted and number of point clouds in both maps.
- *Point cloud noise removing*: After eliminating all identical point clouds, the remaining point clouds still contain noise data from the sensor. The noise needed to be removed to decrease unnecessary data to detect object. Estimated mean average distance between all neighbour point clouds and threshold deviation distance were declared in order to filter out noise data. These two parameters may vary depends on sensor performance, captured area and terrain type.
- *Segment and Fit cuboid processed point clouds*: Segments are a process of turning point clouds into clusters by calculating Euclidean distance between points. Point clouds which exceed defined threshold Euclidean distance will be considered as different clusters. Furthermore, fitting cuboid to segmented point cloud clusters output Cuboid Model which store cuboid corner points [9].
- *Filter out unmet condition clusters*: Since we use dimension and volume as condition to filter out unwanted clusters, 4 corner points which store in Cuboid Model are therefore necessary. By calculating distance between points to obtain length, width and height. From the resulting dimension, we can calculate volume. For example, in testing scenarios we declared car as our target thus any point cloud clusters smaller than 2 cubic meters or larger than 7 cubic meter will be filtered out.

3. Experimental Setup

There are two scenarios to test all steps mentioned in the methodology section to ensure the consistency of the results obtained especially the object detection algorithm. The data collection is implemented by using the unmanned aerial system equipped with LiDAR system as shown in Figure 1.

Figure 1. UAS equipped with LiDAR System

The proper flight path for data collection needs to have approximately 7 meters separation between each path with the flight altitude of 15 meters. With this configuration, there will be about 70 degree field of view and 21 meter radius coverage which will provide appropriate overlapping of collecting data and point density. Moreover, the flying path will look similar to chess table in order to reduce the blind spot and increase the clarity of the resulting map. A car is placed on both areas to test the object detection algorithm. The flight plannings of both tests are illustrated in Figures 2 and 3, respectively. The flight time for both cases took about 20 minutes.

Figure 2. Flight planning for testing I

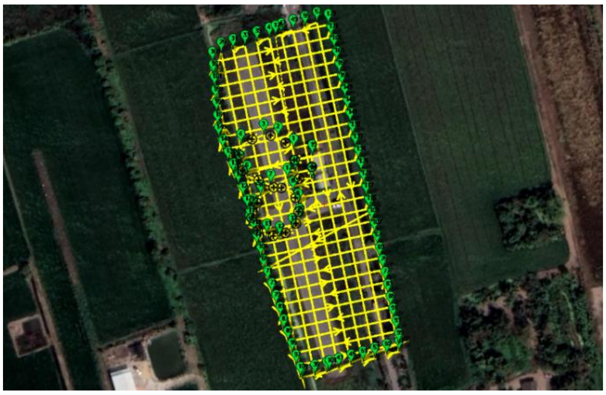

Figure 3. Flight planning for testing II

When the LIDAR system is installed on the aircraft and collects data from the light sensor in point cloud format to create a 3D map. Merged point cloud is conducted in two different areas, which each data set is collected at heights from 15 meters to 50 meters increments in 5 mm steps and point cloud overlap in each flight path from 20% to 50% increments in 10 % steps. Each area, when compilation of the specified dataset is completed, is collected one more set but add objects (a car) to conduct change detection experiment. For test area I, a car is placed outdoor in the middle of the area. On the other hand, a car is paced underneath the canvas shade.

4. Experimental Results

The processed 3D point cloud maps of the test area I are shown in Figures 4 and 5. The detected car obviously appears in the latter figure even not applying the detection algorithm. However, to test the proposed algorithm, the algorithm is applied to the 3D point cloud. The result after applying the algorithm looks similar to Figure 5. The processed area for the algorithm covers 10,000 square meter and takes 15 hours to finish the process. Therefore, the authors segment the processed area into 20 pieces before running the process. The process time reduces to 7 hours.

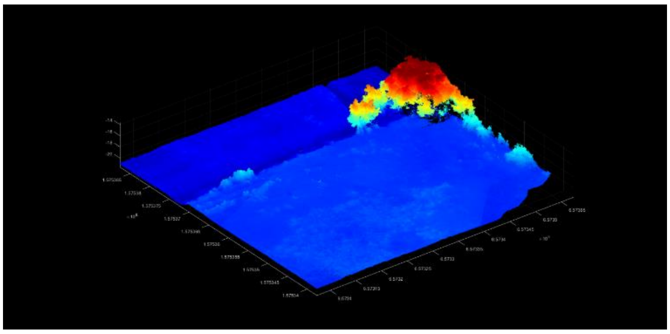

Figure 4. 3D point cloud map of testing area I

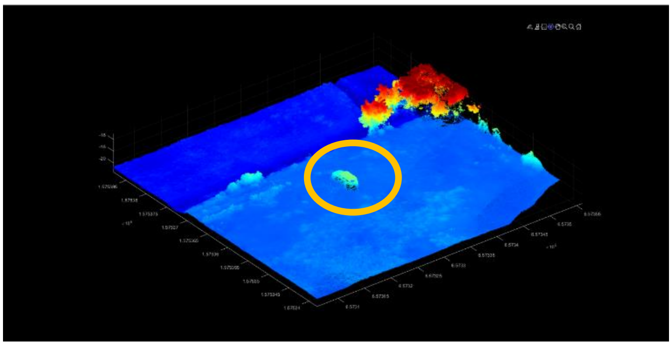

Figure 5. Object detection result of testing area I

For the testing area II where the car is paced underneath the canvas shade and in the proximity of other objects such as building, trees, and electricity poles. The resulting 3D point clouds map is illustrated in Figure 6. The car is placed in the circled area. After that, the object detection process is applied to the 3D point clouds map of both cases (with and without a car in the area). The comparison of both cases after applying the algorithm can be noticed in Figures 7 and 8, respectively.

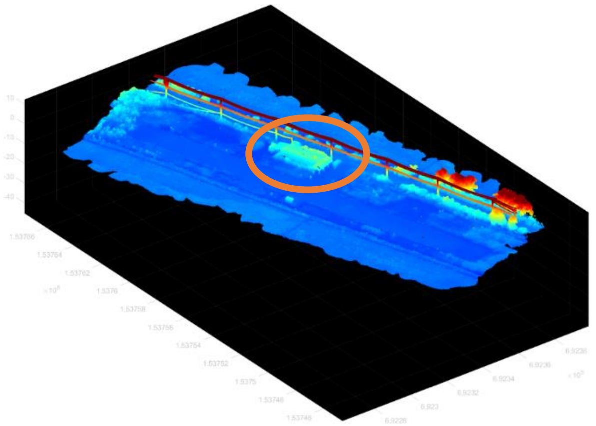

Figure 6. 3D point cloud map of testing area II

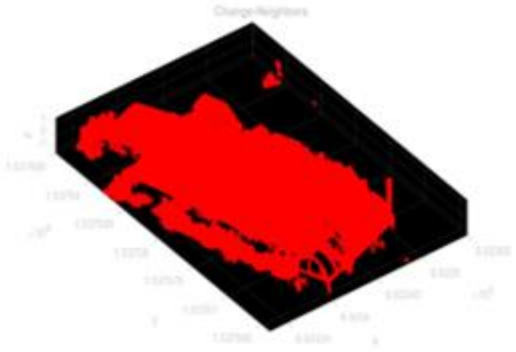

Figure 7. Object detection result of testing area II (area without a car)

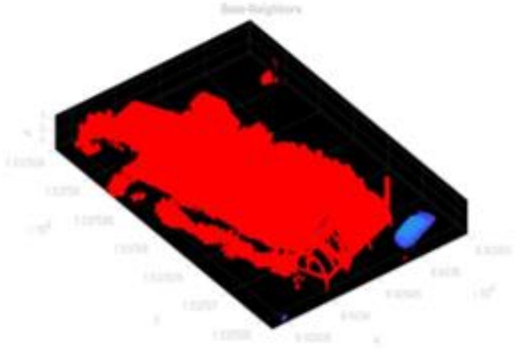

Figure 8. Object detection result of testing area II (area with a car)

As shown in Figure 8, the car is detected on the bottom right of the figure (in blue). Even the car is under the shade but the car can still be detected from the 3D point clouds since the LiDAR sensor has a multiple return property so that the information of both shade and car are appeared on the 3D map. Furthermore, after applying to the obtained 3D point clouds map, the algorithm is able to find the difference of both maps as well as calculate the volume and dimension of the detected difference. Figure 9 shows the calculated volume of the detected object which is approximately 7.4 cubic meter.

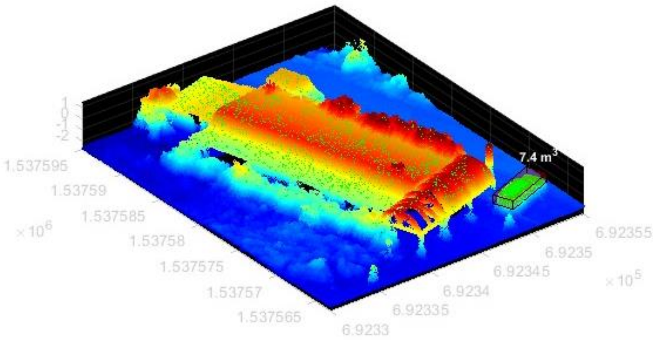

Figure 9. Object detection result of testing area II with calculated volume of detected object.

5. Discussion

From the experimental results, if small objects detection are required, a flight path must operate in an altitude between 15 to 20 meters and sensor’s exposure angle should be at least 70 degree. The overlap distance between each line of scanning must be greater than 50%. This is a reason why aircraft has many frequent routes and takes a lot of time to store data.

After applying the detection algorithm to several data sets, there are two conditions to consider in object detection: the perpendicular size of the object from the ground must be greater than 0.5 m and the volume of the object must be greater than 1 cubic meter in order to achieve accurate detection. If the object passes conditions, the program will detect objects in the area very well. For example, a power line with a of height 15 meter above the ground and diameter less than 30 centimeter can be detected very well.

The advantage of the data collected from the unmanned aerial system is that it can provide more perspective and coverage than the ground system. For instance, the car in the testing area II may not be able to detect because of the obstacles in the proximity area whereas the bird-eye view and the multiple return property of the LiDAR system provide more details of the object in the area. This is also to confirm that the information from the 3D point clouds can be more accurate comparing to 2D photo when using with an appropriate object detection algorithm.

6. Conclusion

This paper success in creating algorithm to detect significance between two point clouds based on mean average distance between neighbour point clouds and Cuboid Model. There still are a lot of room for improvement left. Currently the algorithm created are unable to detect small dimensions change effectively and need to perform in open field scenarios. Computation time in each task consumes enormous amount of time due to single core computation. To sum up the algorithm has lot of potential in it but necessary to take more time to develop and optimize. This paper only shows proof of concepts in change detection with computer computation power. In addition, to increase the ability to detect more details in the specified area, a higher performance of LiDAR system could be considered. Also, to increase a time to scan the area for collecting data, different type of unmanned aerial vehicle could be determined.

This work could be very useful for the search and rescue in the area that is difficult to access. Moreover, the usage of unmanned aerial system can reduce the time of operation as well as avoid the risk of the dangerous area for human that might need to involve in the activity.

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