The planar extraction in image-based 3D point cloud photogrammetry for as-built Building Information Modelling

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Abstract

The current process of creating Building Information Model (BIM) for existing structures or as-built models is generally involved creating a geometric model from a 3D point cloud, commonly obtained from a laser scan. The laser scanning techniques, however, can be expensive and difficult to apply, unlike the image-based techniques. In this paper, the automated planar extraction of point cloud obtained from an image-based technique and from a laser scanner are compared using a commercial software package. The extracted planes from both techniques are compared against the planes extracted manually, which is used as a benchmark. The sample data used in the study was obtained from a civil engineering laboratory which contained 3D points lying on planes (i.e. walls and floors) and a large number of non-planar 3D points from the scene clutter. It was demonstrated that the laser scanning point cloud delivered a better result in the plane extraction than the image-based point cloud, although it still cannot provide a result that is sufficiently accurate for automatically creating a BIM model.

Keywords: Planar Extraction, Structure from Motion, Laser Scan, Building Information Modelling, Photogrammetry

1. Introduction

Building Information Modelling (BIM) has become a standard in the construction industry (Shanbari et al., 2016) in managing buildings. In BIM modelling, each element of a building is represented as a set of geometrical primitives and its associated attributes which provide the semantic information of structural elements. Existing structures are often lack up-to-date geometrical models and therefore, a laser scanner has become a standard tool that are used to create buildings' geometrical models. Typically, a point cloud is obtained by a laser scanner and is then converted to geometrical primitive models by manual methods or by automatic algorithms. The implementation such as PCL (Point Cloud library), which is an open source library for processing 3D points, can help to manage and improve the quality of point clouds as a pre-processor from laser scanners or from image-based techniques. However, this method is unable to create geometrical models for BIM (Radu and Steve, 2011). Currently, commercial software packages can use point clouds from laser scanners to automatically detect and convert the point clouds to BIM with some degree of accuracy, although much work is still required for complete automation as concluded in Thomson and Boehm (2015). However, obtaining the point cloud from the laser scanning techniques is still expensive and required expertise to operate the scanners (Gao et al., 2012), which is one of the major drawbacks in using laser scanners for creating BIM models.

A 3D point cloud can also be obtained from images using the Structure from Motion (SFM) technology. The image-based point cloud may not be as accurate as the laser scanning point cloud, but the SFM technology is cheaper and easier to use. In this paper, the comparison of planar extraction from point clouds obtain from the laser scanning and image-based techniques are compared. The software package used for planar extraction is called, which is a plug-in of Revit, and the results are compared against manually extracted planes. The contribution of this work is to demonstrate that point cloud from the image-based technique can be used to create a geometric model for BIM without the need of a laser scanner.

2. Related Work

2.1 3D Modelling in BIM

Point cloud data captured by a laser scanners are normally used as a reference for the construction of as-is BIMs (Gao et al., 2012). Gao et al. (2012), proposed multiple laser scans for constructing as-is BIMs to capture the geometric information by performing multiple laser scans of a research lab during the renovation process at different phases. The laser scan data can be used to generate the geometric model of the facility. Multiple visible components such as ceilings, wall and floors, and non-visible components such as water pipes hidden behind the finished surfaces and airducts were created with geometric models. Viorica et al., (2015) proposed a general framework in creating as-built models. The author discussed various research works that tried to solve challenging tasks associated with as-built BIM generation for infrastructure. The authors emphasized that accurate geometrical models are important for BIM and there is no current automatic methods to create BIM models for existing buildings. The author proposed that current techniques should be incorporated with object detection techniques in order to obtain accurate as-built BIM models. Thomson and Boehm (2015) proposed automatic geometry generation from laser scanning point cloud for BIM. The authors proposed to automatically reconstruct basic Industry Foundation Classes (IFC) geometries from points clouds and then verify by creating point cloud from the constructed IFC geometries. They used the PCL implementation of RANSAC algorithm to detect the horizontal and vertical planes to build the IFC geometries. Additionally, the geometric models were also used to create points cloud data from IFC components for verification. The authors did not generate the BIM models automatically as there were no available tools available.

2.2 Automatic Planar Extraction from Point Cloud

As stated in Viorica et al. (2015), a point cloud is normally acquired by a laser scanner, and then manually extracting planes or other geometries from the point cloud requires considerable effort to create geometrical models. Thomson and Boehm (2015) applied the RANSAC algorithm implemented in PCL to detect horizontal planes such as floors and ceilings and vertical planes (e.g. walls) from a laser scan point cloud. Pang et al. (2015) created an algorithm to segment point cloud into different components of rooms such as floors, planes and pipes by applying classification algorithms. The authors used Support Vector Machine (SVM) with Fast Point Feature Histogram (FPFH) to classify each area of a sampled point cloud data. This method still faced with many problems such as noise in the sampled point cloud, although the authors were able to demonstrate the ability to classify planes, pipes and other components for creating 3D BIM models. Xu et al. (2017) applied the voxel and graph based segmentation (VGS) to improve geometric primitive recognition from point cloud to classify planes and cylinders from a point cloud. From previous research, it is cleared that segmenting geometries from a point cloud data is important for automatic generation of BIM models. Therefore, this paper demonstrated the use of an image-based 3D point cloud for planar extraction, which will be used to create BIM models in the final steps. The image-based point cloud is a much cheaper option than the point cloud from laser scanners.

3. Methodology

This article is a comparative study of the planar extraction from point clouds obtained from the image-based and laser scanning techniques. Two sets of point cloud data were acquired, one from a laser scanner and the other is from image-based technique. The data sets were taken from a civil engineering laboratory at King Mongkut's University of Technology Thonburi. The two data sets were registered together using the Iterative Closest Point (ICP) algorithm in order to make the point clouds to have identical reference coordinates. Then, the point clouds from both sets of data were used in plane extraction using a commercial software package called Imaginit.

3.1 Iterative Closest Point Algorithm

ICP has become the most used method for registering 3D shapes. This algorithm estimates the rigid motion parameters between two 3D shapes by assuming that the two shapes are partially overlapping, i.e. a set of N points in the first shape are supposed to have correspondences in the second shape, they are approximately aligned i.e. a rough estimate of the initial transformation is known (Sébastien et al., 2006).

The ICP algorithm is composed of two steps, the first step is to generate temporary correspondences, and the second step is to estimate the relative rigid-body transformation.

Consider two points clouds $\{p_i\}$ (cloud 1) and $\{p_i'\}$ (cloud 2) issued from the measurement of an object by a 3D sensor, from two different viewpoints. From a geometric point of view, we can consider that the corresponding point p_i of p_i', i.e. its closest point in $\{p_i\}$, can be defined as

$$p_i = \arg\left[\min_{p_j \in \{p_i\}} \left\| p_j - p_i' \right\|\right] \quad (1)$$

For every pair of corresponding points p_i and p_i' we want to find the rotation (3x3) matrix R and the translation (3x1) vector t so that

$$p_i = Rp_i' + t \quad (2)$$

where p is coordinate $(x, y, z)^T$, R is Rotation matrix (3x3), t is translation vector.

For convenience, the homogeneous coordinate transformation T is used, T has six free motion parameters (3 angles and 3 translation components), which can be defined as

$$T(p) = Rp + t \quad (3)$$

So, we write (2) as

$$p_i = T(p_i') \quad (4)$$

Theoretically, three point pairs (p_i, p_i'), are necessary to identify a unique transform T. However, due to the different noise sources (sensor measurements, image segmentation, point matching), the transformation estimated from three arbitrary point pairs is not generally the best one. Estimating the best motion parameters requires using an error minimization technique such as searching a least square solution to the over-determined system of equations (4). For a set of N matches, the criterion to be minimized is

$$\varepsilon = \frac{1}{N}\sum_{i=1}^{N} \left\| p_i - Tp_i' \right\|^2 \quad (5)$$

where ε is criteria used for data or threshold compatibility considerations.

This two steps procedure must be iterated to reach the convergence of the computed transformation, *i.e.* when the change in mean square error falls below a threshold, then the transformation T is found.

3.2 Commercial Software

Figure 4 shows the pipeline of the work carried out in the commercial software package. The sample data was taken from a civil engineering laboratory from King Mongkut's University of Technology Thonburi, as show in Figure 1. There are three major steps in the experiments conducted in this study.

Step 1, a set of images were taken from the laboratory, which was converted to a 3D point cloud using a program called Agisoft, as shown in Figure 2 (top). (Agisoft, 2016). Another 3D point cloud was also obtained from the laboratory using a laser scan (Figure 2 (bottom)).

Step 2, the two models were then imported to Cloud Compare so that the 3D point clouds were registered together via an Iterative Closest Point algorithm to have an identical reference world coordinate as shown in Figure 3. (Sébastien et al., 2006).

Step 3, the 3D point clouds were then imported into Revit and an automatic plane extraction algorithm was applied to both point clouds using a plug-in called Imaginit. The extracted planes are compared against the manually extracted planes to qualitatively measure their accuracy.

Figure 1 253 Images were collected from King Mongkut's University.

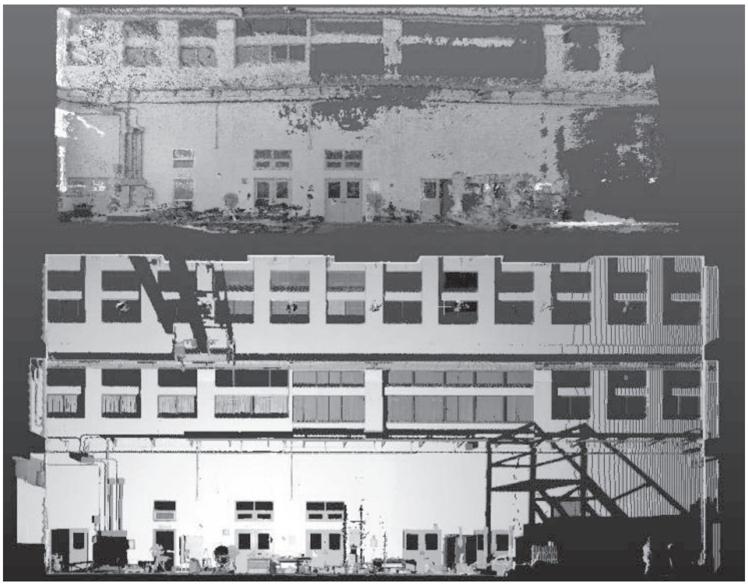

Figure 2 (Top) the point cloud from the image-based technique, (bottom) the point cloud from a laser scanner

4. Results and Discussion

4.1 Results from Iterative Closet Point (ICP)

Iterative Closest Point (ICP) method was used to register the point clouds from the laser scanner and from the image-based technique via the software package called CloudCompare. The program reports the cloud-to-cloud distance as shown in Equation (1) by the nearest neighbour algorithm. As shown in Figure 5 and Table 1, the point cloud from both method can be aligned well and the cloud-to-cloud distance is 0.1967. From the results, this means that average distance between the two point clouds is around 0.1967 m or 19.67 cm. The results are quite high, this may be caused by the difference in the point clouds as some regions were missing in the image-based based point cloud. Nevertheless, the two point clouds can be registered to have identical world coordinates.

4.2 Results from Commercial Software

As shown in Table 2 and Figure 6, 36 planes are extracted from the 3D laser scan point cloud. All planes have the same normal vectors as the planes extracted by the manual method. Most detected planes are small and overlapped, which contradicts with the manual extracted planes. From these results, the planes on the windows and doors are not be detected by the commercial software because commercial software only concerned with the density of point cloud and did not consider the semantic information about the point cloud. Figure 7 shows the results from plane extraction using the image-based point cloud, 8 planes are extracted, and the normal vectors were identical to the manually extracted planes.

All detected planes have the same normal vectors as the manual planes, although the detected planes only cover a small area of the wall. The 3D point cloud from the image-based technique is noisier than the laser scanner, which results in fewer detected planes. Another reason is that the density of point cloud from the image-based technique is less than the laser scan method, therefore, fewer planes are detected.

However, it can be said that the point cloud from an image-based technique can be used for planar extraction using the commercial software package. Nevertheless, the results from both the image-based and laser scanning techniques are still not good enough for complete automation for creating a geometrical model for BIM.

Table 1 The algorithm shows the cloud-to-cloud distance from Iterativa Closest point algorithm

Data Registration	Cloud-to-cloud distance
Laser Scan and Image-based	0.1967

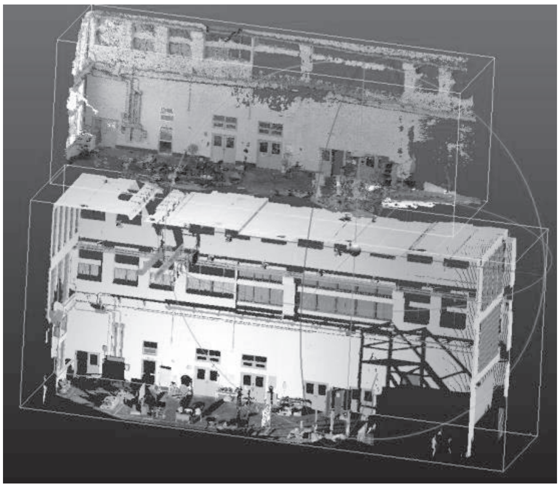

Figure 3 3D registration of point clouds from the laser scanner and the image-based technique in CloudCompare

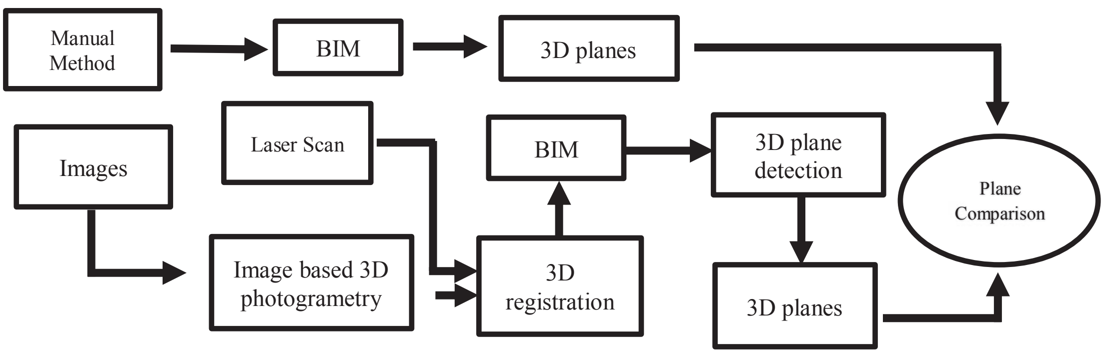

Figure 4 Framework for commercial software

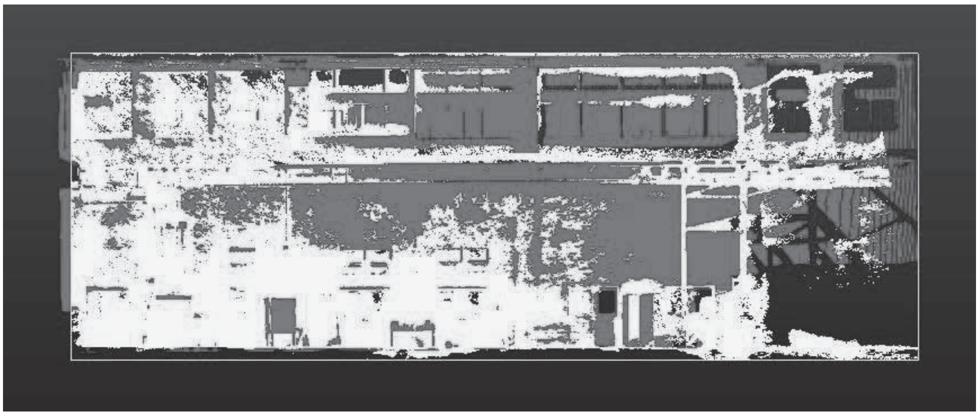

Figure 5 Registration between two the point clouds from the laser scanner and image-based method using Iterative Closest Point algorithm

5. Conclusions

From the results, it can be concluded that the point cloud from the image-based technique can be used for planar extraction by the commercial algorithm. The extracted planes can then be used to construct planes in as-built BIM models.

In this paper, automated planar detection from point cloud using a commercial software package was applied to the point cloud obtained from the images-based and laser scanning techniques. The laser scanned and images-based point clouds were imported to CloudCompare to register the clouds together via an Iterative Closest Point (ICP) algorithm to allow the point cloud to have the same world coordinates. It was observed that the cloud-to-cloud distance between the two point clouds was approximately 19.67 cm. Although the number may be high, visually, the two point clouds can be registered together well and sufficient for the next stage of processing.

The results from commercial software by using image-based and laser scanning point clouds are still not good enough for complete automation for creating a geometrical model for BIM. This is caused by an algorithm in the commercial software package, which requires orderly point clouds and sufficient density to find planes.

However, the image-based technique is cheaper than laser scanning technique and can be deployed faster. The image-based technique can also be used with a drone that can collect data from a location, where human cannot access. This is one of the main advantage of the image-based method as it uses image data which can be collected much easier, whereas the laser scanner cannot be collected from high altitude.

The experimental results of this paper are also the prototype of using image-based technique to bulild an as-built BIM model. The image-based technique can save time for modelling existing structures.

For further study, this article only detected the planar geometry. Other shapes such as cylinders (e.g. pipes) are also required to be detected as structural components. The algorithm from the commercial software package used in this paper only used 3D point cloud for segmenting planes. However, algorithms such as object detection algorithms can be used to help in detecting geometries as the algorithm can provide semantic information about the point cloud. Therefore, with object detection algorithm, walls and floors can be identified.

6. Acknowledgments

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Table 2 Summarizes the total number of detected planes from the point clouds from the laser scanner and image-based technique

Data type	Plane Detected
Laser Scan / Automatic detection	36
Image-based / Automatic detection	8

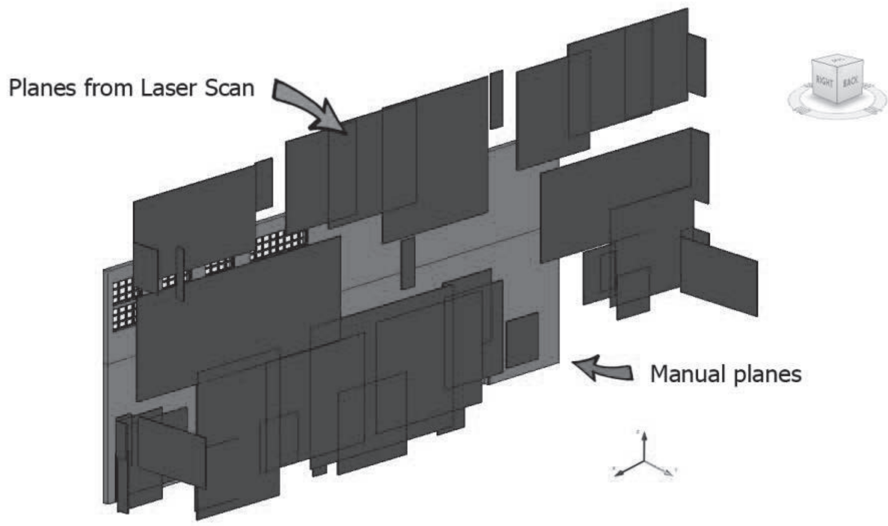

Figure 6 The results from the manual method and from the laser scanner

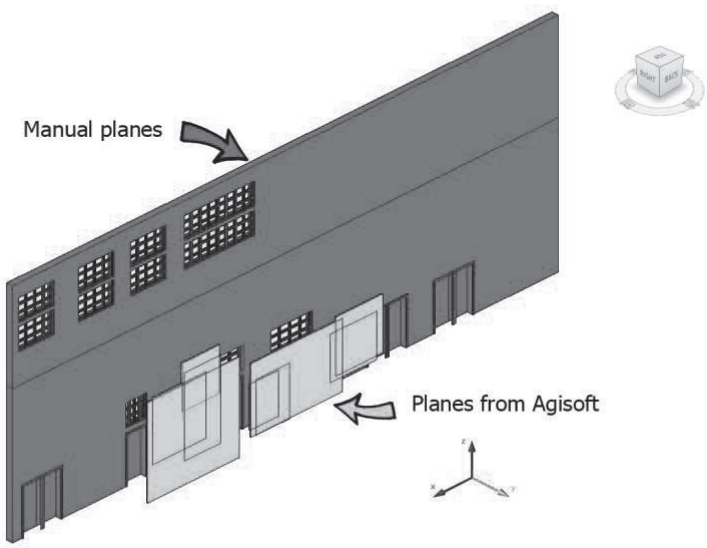

Figure 7 The results from the manual method and from Agisoft.

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