POINT CLOUD REGISTRATION AND ACCURACY FOR 3D MODELLING - A REVIEW

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Abstract:
Geoinformation is a surveying and mapping field where topography and details on the ground are spatially mapped. The point cloud is one of the data types that is used for measurement and visualisation of Earth features mapping. Point cloud could come from a different source such as terrestrial laser scanned or photogrammetry. The concepts of terrestrial laser scanning and photogrammetry surveying are elaborated in this paper. This paper also presents the method used for point cloud registration; Iterative Closest Point (ICP) and Feature Extraction and Matching (FEM) and the accuracy of laser scanned, and photogrammetric point cloud based on the previous experiments. Experimental analysis conducted in the previous study shows an impressive result on laser scanned point cloud with very minimum errors compared to photogrammetric point cloud.

Keywords:
Terrestrial Laser Scanning, Photogrammetry, 3D Modelling, Point Cloud

Introduction
Generally, the method of obtaining spatial information and geometry primitives are the advantage of point cloud. Point cloud is a spatial representation of geometry and surface that appear in digital visualisation.

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This paper presents about the conceptual idea and advancement of geospatial technologies and 3D modelling to enhance 3D data acquisition assessment. Table 1 shows the 3D acquisition system involved in geoinformation field.

| Acquisition system | 3D acquisition and modelling |
|--------------------|-----------------------------|
| Range-based        | Mobile Laser Scanning System |
|                    | Terrestrial Laser Scanning  |
| Image-based        | Close-range photogrammetry   |
|                    | Spherical photogrammetry     |
| Systems range or   | Remotely Piloted Aircraft Systems (RPAS) |
| image-based        | Unmanned ground vehicle (UGV) system |

(Ancona et al., 2015)

Geoinformation Method

Terrestrial Laser Scanning

Terrestrial laser scanning is a method of capturing virtual reality of ground scene through laser emission. The equipment, known as terrestrial laser scanner (TLS) is actually a ground-based version of airborne light detection and ranging (LiDAR). LiDAR sensor, installed in an airborne is frequently used for topography and terrain mapping. Meanwhile TLS, is practically used for capturing as-built or structure on the ground such as roads, buildings, dams, bridges and many more. TLS works without additional personnel to hold a ranging pole or to place targets since it works as an active remote sensing system (Zakaria et al., 2019). This was also supported by (Mettenleiter, 2004).

This can be seen as an advantage for TLS if there is hazardous area such as landfall site becomes the site of interest (Zakaria et al., 2019). Figure 1 shows example of indoor point cloud model. Other than that, TLS has better accuracy and precision, no interference with operations and construction activities and the equipment operating and data processing are also simple (Thomson & Boehm, 2014). The emitted laser signal is received by the sensor system producing distance, triangulation and coordinate positioning of the targeted point. However, the signal emission can be refracted or interrupted if the scanned surface is wet or shiny. Figure 2 shows the transmission and receiving of pulse of light where the time-of-flight measurement takes place.
Photogrammetry
Point cloud data captured by camera in photogrammetry surveying is applicable for 3D modelling that is practical for presenting as-built details. The use of SfM software provide an advantage of developing 3D geospatial information of a scene or object as shown in Figure 5. The output from SfM is more than just orthophotos, where point cloud and meshes are the benefit for 3D geometry and 3D data extraction.
Phogrammetry has geometry and spatial primitives which leads to safe, fast and accurate for elaborative detailing (Ahmet & Yakar, 2018). In addition, 3D reconstruction representing shapes and 3D geometry of architecture details can be generated by photogrammetry with the combination of other geodetic tools (Croce, Caroti, Piemonte, & Bevilacqua, 2019).

**3D Data Presentation**

Laser scanning technology offers relevant and reliable data representation of Earth features and infrastructures on the ground. Table 2 shows the impact of using laser scanning for spatial modelling. The practice of laser scanning for as built infrastructure is compatibly well functioning if this technique is optimized for cleaned and well-defined 3D model Figure 4 shows wireframe 3D model before translated into semantic model.

| Table 2 | Laser Scanning for 3D Modelling |
|---------|-------------------------------|
| **Acquisition system** | **3D acquisition and modelling** |
| 1 Data presentation | 3D data consists of 3D coordinates positioning and/or spatial data. (Cantoni & Vassena, 2019; Sethurasamayraja & Mangalapallil, 2014) |
| 2 Data storage | Digital (Maietti, Ferrari, Medici, & Balzani, 2016) |
| 3 Attribute | Dimensional measurement with geometrical primitives scanned data. (Stančić, Roić, Mader, & Vidović, 2014a) |
| 4 Details monitoring | Improve decision making (Volk, Stengel, & Schultmann, 2014) |
| 5 Location | Scanned data can be overlaid on a map with local coordinate system. (Sethurasamayraja & Mangalapallil, 2014) |
| 6 Filing system | Asset data are stored and presented in GIS or database (Maietti et al., 2016) |

![Figure 4](Image)

**Figure 4** Wireframe 3D Model (Left) and Rendered 3D Model (Right)

Source: (Stančić, Roić, Mader, & Vidović, 2014b)

**Point Cloud Registration**

Point cloud registration is the process of points alignment through a rigid body transformation algorithm. Equation 1 shows the basic alignment formula that ICP uses to find rigid body transformation (Stachniss, 2021).

\[
\sum_{(i,j) \in C} \| y_i - R x_j - t \|^2 \rightarrow \text{min}
\]
where,
Y = Point cloud (source)
X = Point cloud (target)
R = Rotation matrix
T = Translation vector

Assuming coordinates of P and Q:
Y = \{y_i | i = 1,2,3 ...\}
X = \{x_i | i = 1,2,3 ...\}
with correspondences \(C = \{(i,j)\}\)

ICP uses two sets of data to iteratively refine the transform by repeatedly constructing pairs of related points on the surface and minimizing an error metric (Fujimoto, Kimura, Beniyama, Moriya, & Nakayama, 2009). Meanwhile, Li, Wang, Wang, and Tao (2020) define ICP as the creation of rigorous transformation matrix by iteratively aligning two datasets and searches for point-to-point correspondence.

There is one modern method of point cloud registration known as feature extraction and matching method (FEM). FEM is an improvement method of ICP where it eliminates noise error during the registration process as demonstrated by Liu, Kong, Zhao, Gong, and Han (2018). From a point cloud collection, FEM finds concave or convex points. Any surface with convex or concave points is considered a feature point. Equation 2 shows the determination of concave and convex point (Liu et al., 2018).

Let a point cloud dataset, P;

\[
S(p) = \frac{1}{2} - \frac{1}{\pi} \arctan \frac{k_1(p) + k_2(p)}{k_1(p) - k_2(p)}
\]

which,

\(p_i\) is a local convex point: \(S(p_i) > \max(S(p_{i1}), S(p_{i2}), ..., S(p_{ik}))\)
\(p_i\) is a local concave point: \(S(p_i) < \min(S(p_{i1}), S(p_{i2}), ..., S(p_{ik}))\)

\(S(p_{i1}), S(p_{i2}), ..., S(p_{ik}) = S(p)\) value of the point \(p_i\) neighbourhood points.

**Measurement and Accuracy**
Koivumäki, Steinböck, and Haneda (2021) demonstrate an experiment for point cloud accuracy analysis, identifying the effect of processed point cloud and raw point cloud in defining measurement. They discovered that processed point cloud with de-noising processing is accurate compared to raw point cloud which it incapable to reproduce corrected multipath in the measurement, creating spurious reflection that does not exist in the reality. Figure 5 shows the processed point cloud and the raw point clouds.
Petschnigg, Spitzner, Weitzendorf, and Pilz (2021) emphasize that integration of scanning method improves point cloud accuracy where number of holes can be reduced and increases the point cloud density. They presented the effect of different point cloud data source; laser scanning and photogrammetry in car factory details representation. The result was surprising where photogrammetry with wide-angle imaging produced 854-point density, the highest number compared to six-scans laser scanning dataset which was only 146.7-point density. However, in terms of accuracy, it was found that the six-scans laser scanning achieved the highest accuracy with ±4.8 mm compared photogrammetry with around ±6 to ±8 mm.

Conclusion
As concluded, spatial information together with accurate model and mapping can be digitally recorded through point cloud scanning by using several geoinformation method such as terrestrial laser scanning and photogrammetry. The assessment of point cloud registration shall be focused on which method would be the most accurate to solve the rigid body transformation. Experimental analysis conducted in the previous study demonstrated in earlier section shows an impressive result on laser scanned point cloud with very minimum errors compared to photogrammetric point cloud.

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**Figure 5** Denoised and Bing Cluster Populated Point Clouds (left) and Pre-Processed Raw Point Clouds

Source: (Koivumäki et al., 2021)
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