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ADAPTION OF INVARIANT FEATURES IN IMAGE FOR POINT CLOUDS REGISTRATION

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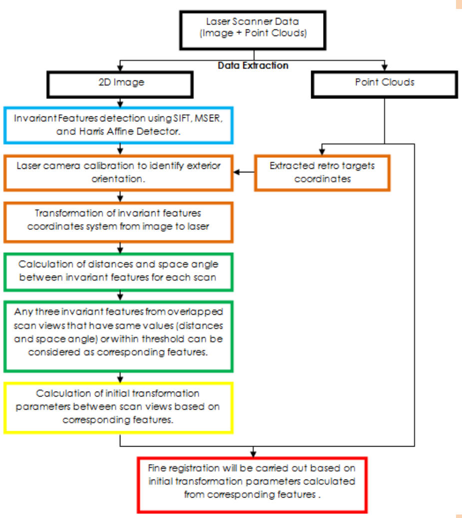
Graphical abstract



Abstract

Currently, coarse registration methods for scanner are required heavy operator intervention either before or after scanning process. There also have an automatic registration method but only applicable to a limited class of objects (e.g. straight lines and flat surfaces). This study is devoted to a search of a computationally feasible automatic coarse registration method with a broad range of applicability. Nowadays, most laser scanner systems are supplied with a camera, such that the scanned data can also be photographed. The proposed approach will exploit the invariant features detected from image to associate point cloud registration. Three types of detectors are included: scale invariant feature transform (SIFT), 2) Harris affine, and 3) maximally stable extremal regions (MSER). All detected features will transform into the laser scanner coordinate system, and their performance is measured based on the number of corresponding points. Several objects with different observation techniques were performed to evaluate the capability of proposed approach and also to evaluate the performance of selected detectors.

Keywords: Laser scanner, photogrammetry, registration, invariant features detector

Abstrak

Pada masa ini, kaedah pendaftaran kasar bagi pengimbas memerlukan bantuan yang banyak dari operator samada sebelum atau selepas proses imbasan. Terdapat juga kaedah pendaftaran automatik tetapi hanya sesuai untuk kelas dan objek tertentu (e.g. garis lurus dan permukaan rata). Kajian ini bertujuan mencari kaedah pendaftaran kasar yang automatik sesuai dengan pelbagai aplikasi. Kini, kebanyakan sistem pengimbas laser dibekalkan dengan kamera, oleh itu data imbasan juga mempunyai imej. Pendekatan yang dicadangkan akan menggunakan ciri tidak berubah yang dikesan pada imej untuk membantu pendaftaran titik awan. Tiga jenis pengesan yang digunakan: 1) *scale invariant feature transform* (SIFT), 2) *Harris affine,* dan 3) *maximally stable extremal regions* (MSER). Semua ciri yang dikesan akan ditukarkan ke sistem koordinat pengimbas laser, dan prestasi pengesan diukur berdasarkan bilangan titik (ciri) sama yang dikesan. Beberapa objek dengan menggunakan teknik cerapan berbeza telah dilaksanakan untuk menganalisis kemampuan pendekatan yang dicadang dan juga untuk menilai prestasi pengesan yang dipilih.

Kata kunci: Pengimbas laser, fotogrammetri, pendaftaran, pengesan ciri tidak berubah

1.0 INTRODUCTION

Capability of the laser scanner in providing high density and fast 3D data has made it applicable in various applications such as reverse engineering, construction design, historical modeling, accident investigation and structural deformation monitoring. From 3D data (point clouds) into the final 3D model, there are several processing stages should be carried out as follows [1-3]: 1) scanned data from multiple views, 2) registration, 3) triangulation and data sampling, 4) shape identification (primitive or free-form), 5) segmentation, 6) surface fitting, 7) building 3D model, and 8) texturing. However, there also has different approach such as by Tahir [4], which performed the modeling part at the beginning stage in order to employ a model based registration. One of the crucial part in the processing stage is known as registration. It's often occurred either by using tacheometry, photogrammetry or laser scanning measurement, single station cannot afford to provide 3D data that cover the whole object surface. Thus, multiple station is required during scanning process (Figure 1), and this will result in each scanned data are acquired with local coordinate systems defined by the laser scanner. For visualization and further processing, all scan data need to be orientate into one common coordinate system.

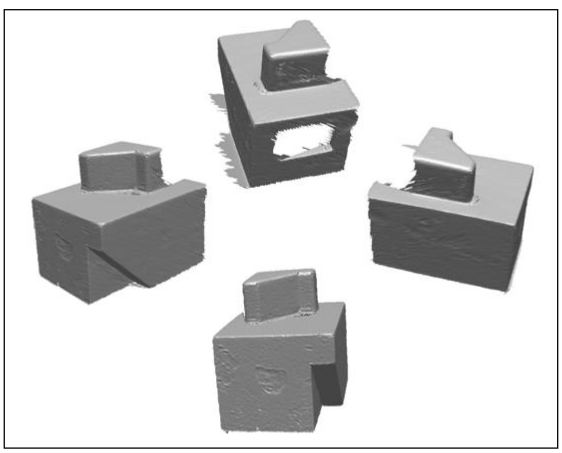


Figure 1 Data acquisition from different view points

Registration process can be divided into two main phase, which are course registration and fine registration. Course registration is applied to identify the approximate transformation parameters. In order to achieve that, corresponding points or features between overlapped scans data should be recognised. Based on the information from course registration, cost function for corresponding will be minimised using fine registration methods. The most popular algorithm to performed registration process is known as Iterative Closest Point (ICP) by Besl & McKay [5]. However, there is one fundamental limitation of the ICP that it requires a good initial registration (course registration) as a starting point to maximize the probability of converging to a correct registration [6]. To improve the limitation of ICP, there are several variations have been formulated [7-10]. This limitation also has made most of the commercial software as well have provided manual registration function that enabled an operator to manually mark at least three corresponding points (Figure 2) that appeared on the 3D surfaces in triangle form [11].

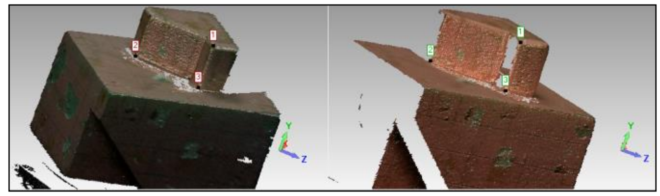


Figure 2 Manual registration using Geomagic software

Other solutions have also been considered by laser scanner manufacturer and researchers by producing an artificial registration targets [12-13]. However, artificial target needs operator intervention and in some cases targets installation can be cumbersome and restricted. There are many study have been done to solve and improve the registration issues, especially for target less and automatic registration. But, the main problem is most of the method that have been published can only deploy with limited class of objects. For instance, model based registration required object that has certain geometric features (e.g. straight lines, flat surfaces). Nowadays, most of the laser scanner are coming with the inbuilt or attached camera. Image can provide colour and texture information, which can be useful for human interpretation and photo-realistic visualization. Moreover, information from images also can be used to detect invariant features. These invariants from image can be exploited for point clouds registration. In order, to verify the capability of proposed approach, analysis will be performed by identify the number of corresponding invariant feature in the laser scanner coordinate system.

2.0 RELATED WORK

Point clouds registration approaches should be initiated with Iterative Closest Point algorithm (Besl & McKay, 1992). This method performed by searching pairs of nearest points in the adjacent scan data. Those pairs then are used to estimate the rigid transformation to align them. Transformation parameter is applied to one of the scan data, and the procedure is iterated until convergence. As discuss in previous chapter, ICP has a limitation that requires a good initial registration to approximate transformation parameters. Even so, generally, there is no information about initial registration. As a result, ICP algorithm is applied for fine registration to improve precision [14]. In addition, several variations have been formulated to improve the limitation of ICP, Chen & Medioni [7] have used difference strategy for points selection and for finding correspondence points, their algorithm began with by selecting initial points on a regular grid, and computes the local curvature of selected points. Zhang (1994) has introduced a method for searching correspondence points based on the distance between the pair. Masuda & Yokoya [9] proposed robust method, especially with noise and outliers by performed random sampling during ICP calculation. Instead of using only point clouds data, Johnson & Kang [10] have introduced colour ICP, which also used colour information with point clouds for registration purpose. Akca [13] have generalized Least Squares image matching method for point clouds registration. The proposed method known as Least Square 3D Surface Matching (LS3D), matches one or more correspondence surfaces by minimizing the sum of squares of the Euclidean distance between the surfaces.

In order to produce an automatic method during processing, some manufacturer and researcher have associate artificial target during scanning process. This approach used special target that can be recognized by laser scanner or digital camera such as a spheres, reflective target, planar target, black and white plane target and coded target. Those artificial targets will be distributing at the site and at least three targets should be invisible from adjacent scan stations. Those targets then will be used as correspondence points to orientate scan data into a common coordinate system. For instance, Leica Geosystem has introduced three types of planar target (Figure 3). By using Cyclone software, those targets can be identified and extract automatically. Akca [13] also has used artificial target known as a black and white plane target in his research for full automatic registration. Coded targets that are commonly deployed in photogrammetry method as well has been adopted for point cloud registration. Al-Manasir [15] have proposed a method known as Image Based Registration (IBR). This method transformed photogrammetric orientation from a digital camera mounted on the laser scanner to all scanned data into a common coordinate system. In order to solve a limitation of ICP method to register craniofacial spatial data, Zulkepli et, al. [11] also have used photogrammetric targets. Using Photo-Laser Control Frame attached with the coded target, the result shows the increasing of accuracy, and the object also has been registered perfectly.

Figure 3 Artificial targets from Leica Geosystem [12]

Registration based on natural target used the features from the objects. This approach assumed that dense and accurate 3D point clouds can provide enough geometric information such as line, curvature, planes, spheres, cylinder and torus. Rather than register the scan data before modelling, this approach has inverse the procedure. The corresponding models then will be used for registration purpose. Stamos & Leordeanu [16] used line and plane pairs as correspondence feature to register multiple scan's data. Tahir [4] has adopted Hough transform in his method for automatic planes, spheres, cylinders and tori detection, and those features will be used for registration. The method has been divided into two stages, first stage known as Indirect method for course registration and follow with Direct method for fine registration. On the other hand, Roth (1999) has used intensity information to find point of interest in each range data. 3D triangulations are constructed based on 2D interest points and all possible pairs between 3D triangulation are then matched.

There are many research have been carried out to improve registration part, the lack of ICP algorithm has split this process into two stages, coarse and fine registration. Coarse registration is currently an active area of research, especially to make it fully automatic or less operator intervention either before and after scanning process. Begin with manual marking of at least three corresponding points, research on this topic has moved one stage forward with an automatic recognition capability by using artificial target. It's not only automatic but also offer less operator intervention, when the natural target can also be used for course registration. However, there are still having limitations in these current methods that can be improved. For instance, the used of artificial target are applicable to any types of objects, but it's needed operator intervention during data collection for distribute the targets. This problem has been solved by natural target method, but the limitation still existed when it's only applicable to object that has certain geometric features (e.g. straight lines, flat surfaces). Thus, this study will try to search for a method that used natural features from the scanned data that applicable to any types of objects. As discussed in the previous chapter, current laser scanner also provided coloured image. And research on image is very established, especially on invariant features detection. Therefore, this study will search any possibility of exploiting invariant features from image for point clouds registration.

3.0 PROPOSED METHOD

The method is divided into four stages (Figure 4), begin with invariant features detection using three different methods. After that all features will be transformed into the laser scanner coordinate system based on space relation of the camera and laser scanner. Then, correspondence between invariant features will be search using space angle and distances. Course registration will be carried out using vector calculated from matched invariant features. Finally, fine registration for the point clouds will be performed using ICP method. Two types of analysis will be carried out in this study, first to identify the capability of detector to produce corresponding features. Second is to evaluate the performance of proposed method.

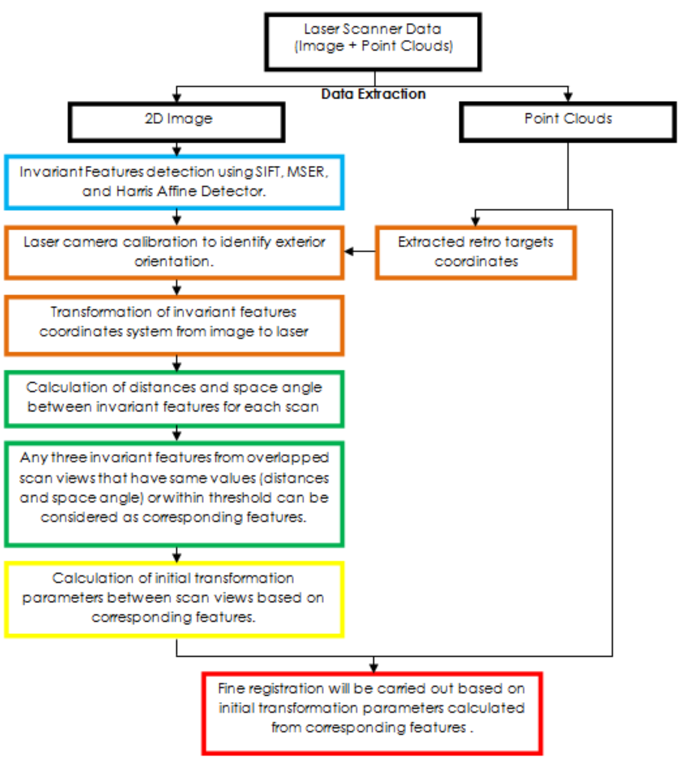


Figure 4 Proposed method for point clouds registration using invariant feature from image

3.1 Invariant Features Detector

Features in the image can be points, edges or small image patches. They can be considering invariant when an image property such as intensity, colour and texture does not change when a rotation, translation, scale and illumination applied to the image. With this attribute, invariant features can be used for matching the images.

This section gives a brief description of the three region detectors used in the proposed method. Section 3.1.1 describes about Scale Invariant Feature Transform (SIFT) detector, follow with Harris Affine in sections 3.1.2 and finally, Maximally Stable Extremal Region Detector (MSER) in section 3.1.3.

3.1.1 Scale Invariant Features Transform

Detector developed by Lowe [17] extracting invariant features from images that can be used to perform reliable matching between different views of an object or scene. The features are invariant to image scale and rotation, and are shown to provide robust matching across a substantial range of affine distortion, change in 3D viewpoint, addition of noise, and change in illumination. The features are highly distinctive, in the sense that a single feature can be correctly matched with high probability against a large database of features from many images.

The recognition proceeds by matching individual features to a database of features from known objects using a fast nearest-neighbor algorithm, followed by a Hough transform to identify clusters belonging to a single object, and finally performing verification through least-squares solution for consistent pose parameters. This approach to recognition can robustly identify objects among clutter and occlusion while achieving near real-time performance.

3.1.2 Harris Affine

Mikolajczyk and Schmid [18] have produced a method to detect interest points in scale-space, and then determine an elliptical region for each point. Interest points are detected with the Harris detector. Scale-selection is based on the Laplacian, and the shape of the elliptical region is determined with the second moment matrix of the intensity gradient.

The second moment matrix, also called the autocorrelation matrix, is often used for feature detection or for describing local image structures. Here, it is used both in the Harris detector and the elliptical shape estimation. The local images derivatives are computed with Gaussian kernels of scale. The derivatives are then averaged in the neighborhood of the point by smoothing with a Gaussian window of scale. The eigenvalues of this matrix represent two principal signal changes in a neighborhood of the point. This property enables the extraction of points, for which both curvatures are significant, that is the signal change is significant in orthogonal directions. Such points are stable in arbitrary lighting conditions and are representative of an image.

3.1.3 Maximally Stable Extremal Region

A Maximally Stable Extremal Region [19] is a connected component of an appropriately thresholded image. The word 'extremal' refers to the property that all pixels inside the MSER have either higher (bright extremal regions) or lower (dark extremal regions) intensity than all the pixels on its outer boundary. The 'maximally stable' in MSER describes the property optimized in the threshold selection process.

The set of extremal regions, for instance, the set of all connected components obtained by thresholding, has a number of desirable properties. Firstly, a monotonic change of image intensities leaves the regions unchanged, since it depends only on the ordering of pixel intensities, which is preserved under monotonic transformation. This ensures that common photometric changes modelled locally as linear or affine leave the regions unaffected, even if the camera is non-linear (gamma-corrected). Secondly, continuous geometric transformations preserve topology–pixels from a single connected component are transformed to a single connected component. Thus after a geometric change locally approximated by an affine transform, homography or even continuous non-linear warping, a matching extremal region will be in the transformed set. Finally, there are no more extremal regions than there are pixels in the image. So a set of regions was defined that is preserved under a broad class of geometric and photometric changes and yet has the same cardinality as the set of fixed-sized square windows commonly used in narrow-baseline matching.

3.2 Space Relation for the Camera and Laser Scanner

The determination of the relative position and orientation of the camera with respect to the TLS has been described by Al-Manasir [15] and here only a short summary of the process is presented. Following a separate camera calibration process, spatial resection from selected image-identifiable scan points is employed to determine the required rotation angles and 3-axis translations (also known as exterior orientation). Based on Al-Manasir [15], minimum of three object points is necessary for the spatial resection, but 10 or so well distributed points would be recommended for accuracy and reliability reasons. For this study, as shown in Figure 5, 3D calibration frame which consist with 43 points (35 points using 10mm diameter targets and the rest is 6mm diameter) have been used in order to determine spatial relation between camera and laser scanner.

Data collection process has been carried out using 5 scanning station (Figure 6) and one of the station was pointing perpendicularly to the calibration field. Laser scan coordinates of this station was extracted as reference coordinates for bundle adjustment. This yielded exterior orientation elements for the camera to a 0.001 sigma accuracy.

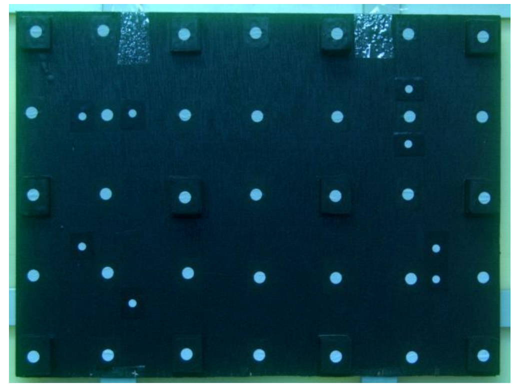


Figure 5 3D calibration frame

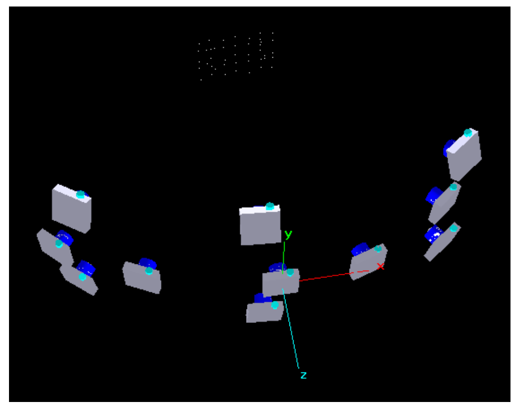


Figure 6 Camera network

With the camera exterior orientation determined with respect to the TLS, transformation between the two Cartesian coordinate systems (object and image space) can be expressed as follows which based on collinearity equations:

$$\begin{pmatrix} x \\ y \\ -c \end{pmatrix} = \lambda \begin{pmatrix} m_{11} & m_{12} & m_{13} \\ m_{21} & m_{22} & m_{23} \\ m_{31} & m_{32} & m_{33} \end{pmatrix} \begin{pmatrix} X - T_x \\ Y - T_y \\ Z - T_z \end{pmatrix} \quad (1)$$

where X, Y, Z and x, y are the laser scanner and camera coordinate system respectively; c represent the principal distance; T_x, T_y and T_z expresses the position of the camera with respect to the origin of the TLS coordinate system; λ is a scale factor; and the rotation matrix (m_{11}, m_{12}, m_{13} and ...) expresses the relative alignment between the axes of the two systems as follows (Wolf & Dewitt, 2000):

$$m_{11} = \cos\phi \cos\kappa$$
$$m_{12} = \sin\omega \sin\phi \cos\kappa + \cos\omega \sin\kappa$$
$$m_{13} = -\cos\omega \sin\phi \cos\kappa + \sin\omega \cos\kappa$$
$$m_{21} = -\cos\phi \sin\kappa$$
$$m_{22} = -\sin\omega \sin\phi \sin\kappa + \cos\omega \sin\kappa$$
$$m_{23} = \cos\omega \sin\phi \sin\kappa + \sin\omega \cos\kappa$$
$$m_{31} = \sin\phi$$

$m_{32} = -\sin\omega\cos\phi$
$m_{33} = \cos\omega\cos\phi$

Based on Al-Manasir [15], the reverse transformation from image to laser scanner coordinate system is:

$$X = X_o + \lambda^{-1}R^T x \qquad (2)$$

Which in matrix notation is

$$\begin{pmatrix} X \\ Y \\ Z \end{pmatrix} = \begin{pmatrix} T_x \\ T_y \\ T_z \end{pmatrix} + \lambda^{-1}\begin{pmatrix} m_{11} & m_{12} & m_{13} \\ m_{21} & m_{22} & m_{23} \\ m_{31} & m_{32} & m_{33} \end{pmatrix}^T \begin{pmatrix} x \\ y \\ -c \end{pmatrix} \qquad (3)$$

3.3 Invariant Features Matching

This study has exploited the space angle and the distances from invariant features as matching tools. The space angles and the distances among a given set of points are translation and rotation invariant parameters among the different laser scanner viewpoints [13]. These two certain conditions can be used both to identify corresponding features and to eliminate other features that have no pairs. With the aid of Figure 7, below is a formula used to calculate the distance and space angle:

$$3D\ Distance = \sqrt{(X_2 - X_1) + (Y_2 - Y_1) + (Z_2 - Z_1)} \qquad (4)$$

$$Angle = \cos^{-1}\left(\frac{{d_1}^2 + {d_2}^2 - {d_3}^2}{2d_1d_2}\right) \qquad (5)$$

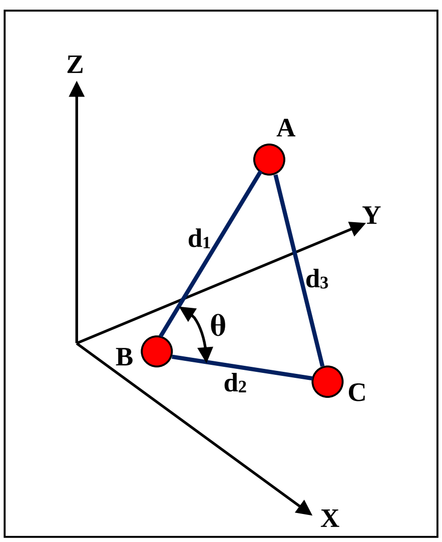


Figure 7 Space angle and distances between three points

Distances between three features are calculated first to generate a triangle as shown in Figure 7. Then, by using cosine and sine rules, space angle is determined between the vectors. Consider we have two scanned data, first scan is a reference, thus, all invariant features from second scan will be matched to the features from first scan. Based on that consideration, every space angle (θ) and two distances (d_1, d_2) combinations for each invariant features in the second scan list are searched in the first scan list in a predefined angle and distance tolerance values (for angle <0.3°, for distance <30mm). Three of the angle and distance elements, in which at least one of them must be distance, can exactly define a triangle. Therefore, the presented search scheme is same as to find the equal 3-D triangles in the both point sets. If a point does not has a compatible 3-D triangle in the ground control points list, this point does not has a corresponding features and must be discarded from the list.

4.0 EXPERIMENTAL

For this experiment, non-contact 3D digitizer Vivid 910 (Figure 8) is used for data collection. This close-range laser scanner can provide 3D point clouds measured using triangulation method and 0.3 MegaPixel (640 x 480) color image. The CCD camera and the laser scanner are fixed in one box with the camera mounted on top of the laser scanner. There are three types of lens comes with this scanner, and this study is used middle lens. The object with high illumination effected has been chosen for this experiment (Figure 9).

Figure 8 Non-contact 3D Digitizer Vivid 910

Figure 9 Scanned object, vase

In this study, discussion is focuses on the strategy to employ the invariant features extracted using selected detector to assist the laser scanner coarse registration procedure.

5.0 RESULTS AND DISCUSSION

A data set consisted of three difference scanning approaches, containing with point clouds and images. All images collected in this experiment will then be processed using three methods as discussed in section 3.1 to identify invariant features. Figure 10 below shows invariant regions detected from the vase using SIFT, Harris and MSER.

(a) (b) (c)

Figure 10 Invariant features detection (a) Scale Invariant Feature Transform (b) Harris Affine (c) Maximally Stable Extremal Region Detector

In order to apply all invariant features for coarse registration, collinearity equation is employed using exterior orientation parameters from previous calibration. As a result, all features from image now are in the 3D laser scanner coordinate system (Figure 11).

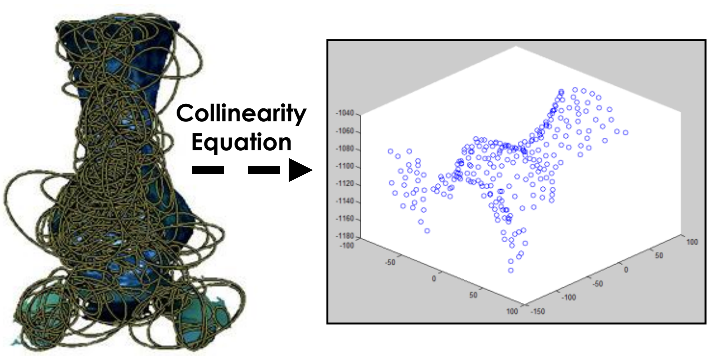


Figure 11 Invariant features coordinate transformation from image to laser scanner coordinate system

To ensure invariant features from image are reliable for point clouds registration, space angle and distances between features are calculated (Figure 12). These data then are used for matching the features between overlapped scan views. Tolerance as discussed in section 3.3 will be applied during searching process.

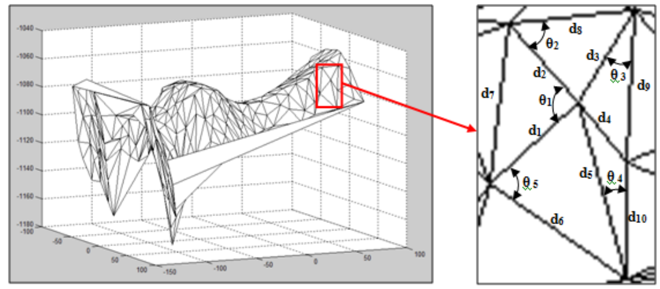


Figure 12 Calculation of space angle and distances

Compared to the most of papers (Mikolajczyk and Schmid, 2002) regarding invariant features detector, the evaluation process is performed based on image matching method. This study will applied different, instead of using photogrammetric approach, performance of invariance features detector will be evaluated based on laser scanning approach. This will be achieve by identify number of corresponding features of each detector in point clouds data.

6.0 CONCLUSION

In this paper, we have proposed a point clouds registration method that uses the invariant features from image to handle the course registration problem. The method integrates both laser scanner and image data and does not require any initial transformation parameters for point cloud registration. Finding of this study will indicate reliability of proposed method and also present the performance of selected detector in order to carry out coarse registration. Furthermore, it's also will produce a natural registration method which applicable to most of objects and can reduce operator intervention during data collection and processing.

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