AUTOMATIC CO-REGISTRATION OF TERRESTRIAL LASER SCANNING DATA AND 2D FLOOR PLAN

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ABSTRACT:

Nowadays, with the rapid development of 3D building model based applications, there is an urgent demand to develop automatic techniques for integrating 3D outdoor building models with 2D and 3D indoor information to produce semantically, geometrically and topologically correct 3D building models. 3D terrestrial laser scanning (TLS) data provides the accurate 3D geometric information, whereas 2D floor plan has useful semantic facade and indoor information about a building. Therefore, the two datasets are complementary and the integration of these two datasets not only could provide a way to integrate 2D and 3D CAD and GIS data, but also can resolve many practical problems in 3D building modeling. As a first step, this paper presents a semantic and geometric information integrated point matching based method for automatic co-registration of 3D TLS points and 2D floor plans. In order to find the correspondences between the two datasets, the 3D-to-2D registration problem is converted to point matching by coding the invariant geometric and semantic context information into a sequence of points using a defined shape description. Then a similarity score formula is proposed to find the initial matching points and after iterative refinement, all the potential corresponding points are found and used to calculate the transformation. The method was tested using real datasets and produced successful results with high accuracy, which demonstrates the feasibility to register 2D floor plan with 3D TLS data.

1. INTRODUCTION

1.1 Motivation

In recent years, with the rapid development of systems and applications for 3D surveillance and 3D outdoor and indoor navigation, there is an urgent demand to develop automatic techniques for integrating 3D outdoor building models with indoor information. As the fundamental part, the underlying 3D building models have to be semantically, geometrically, and topologically correct with both indoor and outdoor structure and information. It has been recognized that it will be of great benefit if 2D and 3D data from GIS, CAD, and BIM (Building Information Models) can be integrated into a single framework so as to provide up-to-date and precise geometry, topology, and thematic contents (Hagedorn et al, 2009). To achieve above goals, the first step is to geometrically and semantically co-register 2D CAD data and 3D GIS data with high accuracy. 2D architectural floor plan and 3D TLS data are the two data sources perfect for this task.

It can be seen that the two datasets are complementary: the shortcomings of one dataset can be overcome by using the other dataset. Floor plan can provide semantic information and accurate feature outlines for 3D façade reconstruction, especially for occluded areas. Using 2D floor plans for reconstruction of 3D indoor building models is a practical way compared to other methods. (Yin et al, 2009) provides a survey of building model generation from paper and CAD-based architectural drawing. TLS data has been proven to be a valuable source for building façade reconstruction (Pu et al, 2009). In particular, 3D TLS data can provide accurate 3D geographic information to assist the reconstruction of 3D indoor models. Therefore, the integration of these two datasets could resolve many practical problems in 3D building modelling and create an opportunity to reconstruct integrated 3D indoor and façade models with high geographic accuracy and rich semantic information.

According to the author's literature review, researches on the registration of TLS data and floor plan can hardly be seen. One more or less related is (Khoshelham et al., 2009), in which a method for automated point cloud-to-map registration using a plane matching technique is presented to georeference the 3D point clouds using 2D maps. The reason could be because the two datasets are compiled separately from two different industries and there is a gap in the data fusion between architectural engineering and construction community and GIS and geomatics engineering industry. To bridge the gap, first the two datasets need to be matched and registered into the same coordinate system.

In this paper, we present a new method for automatic co-registration of 3D TLS points and 2D floor plans with the objective to get these two datasets co-registered and ready for the further integration towards 2D CAD data and 3D GIS data integration and automatic integrated 3D indoor and façade modeling. Meantime, the feasibility of the registration is demonstrated.

1.2 Problem Analysis

Problems in co-registration of 3D TLS points and 2D floor plans lie in the dimensional difference and the uncertainties or ambiguities intrinsic to the two datasets.

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First, a 2D floor plan has no fixed location in the real 3D world, that is, there is no specific elevation to locate it. Therefore, the registration is a horizontal registration with floor plans matching to their respect storeys. One good idea is to project 3D TLS points to 2D. But still we need to find a way to make them comparable. Second, both points belong to the building and those do not belong to the building will have a negative influence on the matching results. Moreover, both the data structure of the 2D floor plan and the facade structure of a building could be very complicated. Invariant characteristics need to be extracted for achieving a successful matching. Third, it's very hard for laser scanning to cover everywhere on the facade. There are always occluded areas or no-data areas. Sometimes important features like windows could be missing. Therefore, an automated registration method should be able to deal with those uncertainties and produce correct matching results by using as much information as possible. Since 2D floor plans have rich semantic information, how to make good use of this semantic information in matching and registration process is a problem needs to be solved. Besides, individual floor plans of the same building may have different origins, sizes, and structures. These factors also need to be taken into account.

1.3 Proposed Approach

Based on the problem analysis, we propose an approach for the co-registration of 3D TLS points and 2D floor plan based on semantic and geometric information integrated point matching. Figure 1 shows an overview of the workflow, which mainly consists of three stages: 1) outline extraction, in which 2D outlines are extracted from 3D TLS points and 2D floor plans and are named as 2D line chains and 2D line strings respectively; 2)semantic and geometric parsing, in which line chains and line strings are semantically, geographically, and topographically parsed into two series of points using a proposed shape description; 3) semantic and geometric information integrated point matching, in which the best matching between line chains and line strings are found by using a proposed point matching algorithm and then the transformation is determined.

The input of 3D TLS points is not necessarily to be geo-referenced, but it will be more meaningful if the data is geo-referenced. There are many kinds of 2D floor plans in paper format and digital formats, and paper drawings can be digitized and converted to CAD files. To make it general, in our approach, we use digital 2D CAD-based architectural floor plans.

First, to make the two datasets comparable, 3D TLS points are cut into a series of section strips using horizontal section planes every certain height and the points of each strip are projected onto their corresponding section planes. 2D outmost lines are extracted from floor plans and projected TLS points respectively. Then invariant semantic information about the characteristic features like walls, windows, and doors and geometric information such as lengths, directions, and topology of these features are coded as a sequence of points using a defined shape description. The registration is then converted to a point matching problem, where the correct corresponding points need to be found to estimate an accurate transformation between the two datasets. A general semantic and geometric information integrated matching algorithm is proposed to solve the point matching problem, in which we introduce a new similarity measure of point pairs using geometric difference and quantified semantic difference. To improve the matching results, an iterative matching refinement is also employed.

A more detailed description of the processes is presented in the following chapters. Concluding remarks are given in the final chapter.

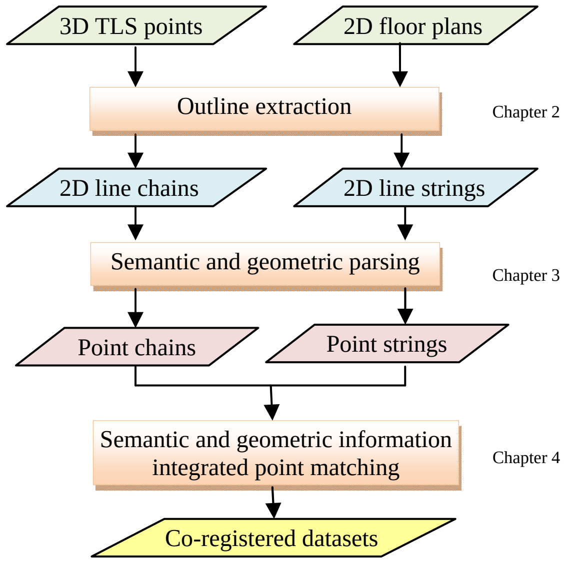


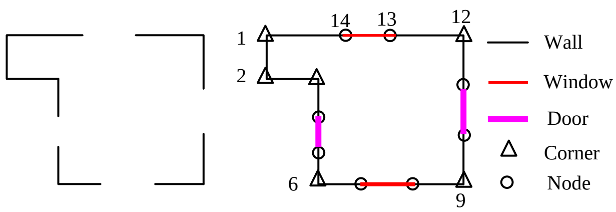
Figure 1. Proposed approach for co-registration of 3D TLS points and 2D floor plans

2. OUTMOST LINE EXTRACTION

The common part between 3D TLS points and floor plans is the outmost wall. The goal of this step is to extract the comparable 2D wall outlines from 2D floor plans and 3D TLS points. To distinguish them, we name them as line strings and line chains respectively.

2.1 Extraction of Line Strings from Floor Plans

Usually, there are many kinds of contents in a floor plan drawing. In our case, we only need the outmost lines of walls because they are just the common part of the two datasets. One problem is that the floor plans from different companies may have different contents in different formats and floor plans may also have various levels of details. It's hard to make a method suitable for all cases. In this paper, we introduce the basic processing algorithm based on an example. In practice, this process can be done automatically or semi-automatically according to the real data.



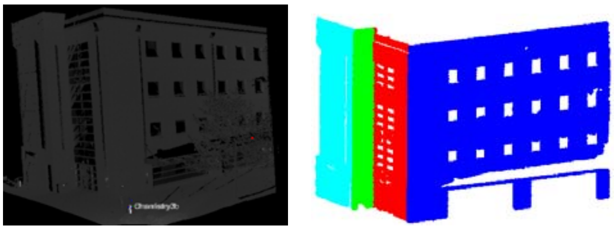
(a) Outmost wall outline (b) Numbering and parsing

Figure 2. Extraction of line string

The exterior outline can be extracted by two steps. First, the outmost wall outline is extracted as shown in Figure 2(a). Then, small recesses and extrusions less than a threshold, for example 0.5 meter, will be ignored in order to simplify the registration.

2.2 Extraction of Line Chains from 3D TLS points

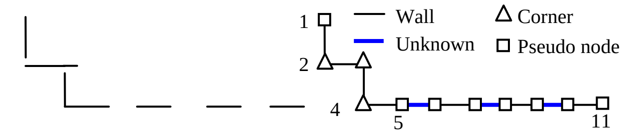
2.2.1 Segmentation and Non Wall Points Removal The objective of this step is to remove non wall points and obtain the base elevation of the building. First, the 3D TLS points are segmented using the algorithm described in (Rabbani et al, 2006). Based on the nature of the building facades and ground, points on walls and ground can be easily distinguished according to the size of the segments and the surface normal. Figure 3 shows an example of the original TLS points and corresponding segmented points with only wall points. The lowest elevation of the facade points will be used as the base elevation of the building.



(a) Original TLS points (b) Points on facades

Figure 3. Segmentation and removal of non-facade points

2.2.2 Section Cut and Best Line Fitting The wall points are cut into a series of equal-height section strips by using level section planes from the base to the top of the facades. The height is adjustable and will be determined according to the real situation. Then all the points are projected onto their corresponding section planes. From the projected 2D points, best fitting lines can be estimated using least squares fitting. Figure 4(a) shows an example of best fitting lines estimated from projected 2D TLS points.



(a) An example of best fitting lines (b) Numbering and parsing

Figure 4. Extraction of line chain

2.2.3 Line Linking The gaps between the line segments in Figure 4(a) may mainly have three causes: the existence of windows or doors, undershot and no-data due to occlusion. The line segments are linked by: 1) intersecting two neighbouring lines when they are not in the same direction to make a corner; 2) merging two neighbouring lines into one line if they are in the same direction and the gap is less than a threshold, for example 0.5 meter; 3) removing overshot and dangling lines.

3. SEMANTIC AND GEOMETRIC PARSING

3.1 Numbering and Semantic Parsing

A program will be run on the extracted line strings and line chains to remove extra vertices in each line segment, sort the order of all line segments in anticlockwise direction, and number all inner points using unique and consecutive numbers from 1 in anticlockwise direction.

For line strings, all line segments extracted directly from wall outlines are attributed as walls. Then the gaps will be filled by lines connecting the two ends of the neighbouring wall lines as shown in Figure 2(b). These lines are attributed as windows or doors respectively based on the 2D floor plan. Then all inner points are classified into two categories: corners and nodes as illustrated in Figure 2(b). Corners are intersection points of two lines in different directions. Nodes are connection points of two lines in the same direction but having different attributes.

For line chains, one difference is: in a line string, each line has a specific attribute; whereas in a line chain, only lines derived from the line fitting have the wall attributes. All the linking lines have the same unknown attribute as shown in Figure 4(b). Inner points are classified as corners and pseudo nodes. A pseudo point is similar with a node. The only difference is that a pseudo point always connects a line with wall attribute and a line with unknown attribute.

3.2 Shape Description

In order to solve for correspondences between line strings and line chains, we define a shape description by using the invariant geometric and semantic context information of the inner points to present the line strings and line chains. The shape description of is defined as below:

```
L = [   int ID,  // Point number
        string Class   // Corner , node or pseudo node
        single Angle,  // Inner Angle
        string Ratio   // Ratio of right line and left line
        string LA   // Attribute of left line
        string RA   // Attribute of right line
        double X    // X coordinates
        double Y    // Y coordinates      ]
```

Because line segments are sorted, we call the line ahead of an inner point right line and the other is left line. The angle is defined as the angle from right line to left line anticlockwise. Using this definition, line strings and line chains can be semantically, geometrically, and topographically parsed. It can be seen that all the geometric and semantic information used in the definition are invariant to scaling, rotation, translation of the datasets and therefore can facilitate accurate and fast matching.

4. SEMANTIC AND GEOMETRIC INFORMATION INTEGRATED POINT MATCHING

The co-registration is to find the transformation between 3D TLS points and 2D floor plans, that is, to calculate rotations, translations, and scales between the two datasets. After line extraction and semantic and geometric parsing, the problem is formulated to point-to-point matching problem. The transformation is now a 2D conformal transformation or nonreflective similarity transformation between two point datasets, which can be presented as:

$$X_2 = sRX_1 + T \tag{1}$$

or

$$Y = MX \tag{2}$$

where X_1 = points in line strings

X_2 = points in line chains
s = scale
R = rotation matrix
T = translation matrix
X = homogeneous coordinates of points in line strings
Y = homogeneous coordinates of points in line chains
M = transformation matrix

To solve for the transformation, at least two corresponding point pairs are required and a more accurate solution can be achieved using least squares estimation if more point pairs are used. Therefore, the main problem for the registration is to find as many corresponding points as possible. But because of the uncertainty caused by occlusion and missing data, some points may have no corresponding points and the shapes of some corresponding parts of the two line datasets could be dissimilar. The matching algorithm has to be able to deal with these situations.

Many shape matching algorithms have been proposed. Among them, relaxation labelling processes are techniques that can reduce or eliminate local ambiguity. (Lee et al, 1989) presents a 2D shape matching algorithm based on the relaxation concept, which uses inangle and exangle as invariants and can match partially occluded polygons well. But one problem in our case is that all the line segments in the line chain can be in the same direction when we just have TLS data of one facade. This algorithm cannot deal with this situation. But the relaxation concept will be adopted in our algorithm, which means we can just find some real matching point pairs to calculate an initial transformation and then the transformation can be further refined by finding more corresponding points.

4.1 Similarity Measure of Point Pairs

In order to obtain reliable matching results, all the invariants like angle, ratio, and semantic attribute should be taken into account when we compare point pairs. In Chapter 3.2, we have defined a rich description of the line strings and line chains. By defining the shape description of the inner points using the context information, the point matching problem is then equivalent to finding for each point on line chain the corresponding point on the line string that has the most similar shape definition. Therefore, first a similarity measure between two points is required.

Suppose there are N points in the line string and M points in the line chain. We propose an equation to calculate the similarity score of point pairs as

$$S(i,j) = \frac{1}{1 + A(i,j) + |1 - Ri/Rj| + C(i,j) + LA(i,j) + RA(i,j)} \quad (3)$$

where i = 1,2,…,M
j = 1,2,…,N
A (i, j) = absolute angle difference in radian
C (i, j) = absolute class difference
Ri, Rj = ratio
LA (i, j) = absolute attribute difference of left lines
RA(i, j) = absolute attribute difference of right lines

Both invariant geometric and semantic information are incorporated into the equation. For quantifying point class difference, we assign 1 to corner and 0 to node and pseudo node. Following the same idea, for line attribute we assign 1 to wall and 0 to window, door, and unknown. Then the similarity of point pairs should be between 0 and 1. If two points have the same point class, inner angle, attributes of left and right line, and there is also no difference in ratio, then the similarity score of the point pair is 1, which means they are completely similar. Two points are considered to be matched if the similarity score of the point pair is greater than 0.9. Every point in the line string will be compared to each point in the line chain and in the end a list of matched point pairs can be obtained.

4.2 Removal of Mismatched Point Pairs

Although we try to use all the invariant geometric and semantic information for the point matching, there may be still some point pairs that could be mismatched. To achieve a most accurate transformation, the list of matched point pairs needs to be verified. Wrongly matched point pairs should be removed and multiple matched point pairs need to be checked and confirmed.

4.2.1 Multiple Matches Multiple matches will occur if a building has symmetric window structures or similar facade structures. In this case, one point in the line chain will have two or more matching points in the line string. First, we select and sort all the points in the line chain that have multiple matching points in anticlockwise order. From the first point, the order of its matching candidate points in the line string will also be sorted anticlockwise. We assume that the first one is the corresponding point and remove it from the candidate lists of the other multiple matched points. Then using the same rule, the corresponding points of other points will also be designated. The list of matched points will be updated and now it has only singular matches.

4.2.2 Spurious Matches Because line strings and line chains are ordered in the same direction, this topological structure can be used to remove some of the spurious matches. Since the order of points in the line chain is in anticlockwise order, their corresponding matching points found in the line string should also in the same order. Points that do not meet this rule will be removed from the list.

4.3 Calculation of Initial Transformation

After refinement, an initial transformation will be calculated first using the point pairs in the current list. Then the points from the line string in the list are transformed to the coordinate system of the line chain. The errors and the standard deviation can be calculated. If the standard deviation is smaller enough than a given threshold, all the point pairs in the list are correctly matched. The transformation will be used as the initial transformation for further process. If the standard deviation is larger than the threshold, we will randomly and iteratively select three point pairs from the list to recalculate the transformation until the standard deviation is less than the threshold. Then the transformation will be used as the initial transformation.

4.4 Iterative Refinement of Transformation

In order to achieve the best accuracy, all potential point pairs should be used for the transformation calculation. We propose an iterative method to find as many matching points as possible. The iterative refinement algorithm follows these steps:

1. Set the point set of the line chain C.
2. Set the initial transformation matrix M and the initial matching point pair list L.
3. Transform all points in the line string to the coordinate system of the line chain using M and get point set S.
4. For every point c in C, find the nearest point s in S and the distance d using K-NN algorithm.
5. Update point pair list L using the point pairs whose corresponding d value less than a given error limit.
6. If there is no change of the size of L then exit iterative.
7. Recalculate M according to updated point pair list L and go to step 3.

4.5 Determination of the Best Matching

Because there is no specific elevation for a floor plan, our objective is to obtain the best horizontal position by finding the best matching between the line strings with the line chains from TLS points. A line string will be compared with every line chains from bottom up. When a line string and a line chain have the most corresponding point pairs and the standard deviation is less than an error limit or a threshold after iterative refinement, we define and identify it as the best matching. In case that the facade structures of some of the storeys of a building are the same, the line string of a floor plan could have multiple best matches. Because normally we know which storey a floor plan belongs to, the multiple best matches can be distinguished by arranging the floor plans in the bottom-up order. The final transformation will be calculated base on the best matching.

5. TEST RESULTS

5.1 Test Data

The proposed method is tested with a real set of TLS data and 2D architectural floor plans of the Chemistry Building on Keele campus of York University. The building is a big four-storey building with two wings. We scanned the north-west part of the building using Riegl-Z390i as shown in Figure 3(a). The angular resolution of the scan was set to 0.05 degree. As shown in Figure 3, from the second floor to the fourth floor the facade structures are the same. The ground floor has a different structure. To make it easy to manipulate, we cut the floor plans of the west wing out. Figure 5 shows a part of the floor plan of the second storey in AutoCAD format. The TLS points were not directly georeferenced using well-defined control points since ground coordinates have no effect on the registration results. We georeferenced the TLS points by: 1) segmenting the TLS points and extracting the biggest facade plane; 2) using the normal of the plane to calculating the rotation angles; 3) rotating TLS points to make walls vertical; 4) moving the TLS points to the real world location based on the coordinates of the building map in a GIS database.

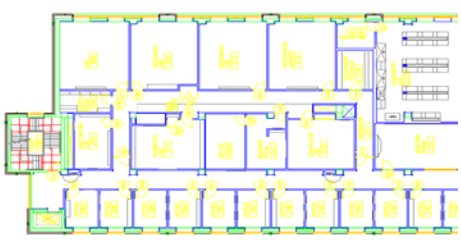


Figure 5. Part of the second floor plan

5.2 Results of Semantic and Geometric Parsing

From the architectural floor plans, the outline strings of each floor are extracted and semantically and geometrically parsed. Figure 6 shows the line strings of the ground floor (left) and the second floor (right).

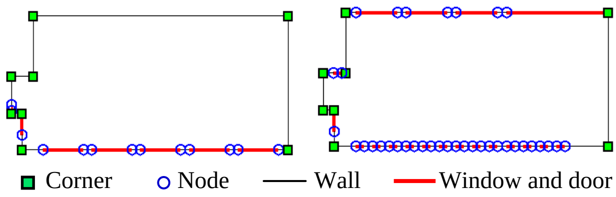
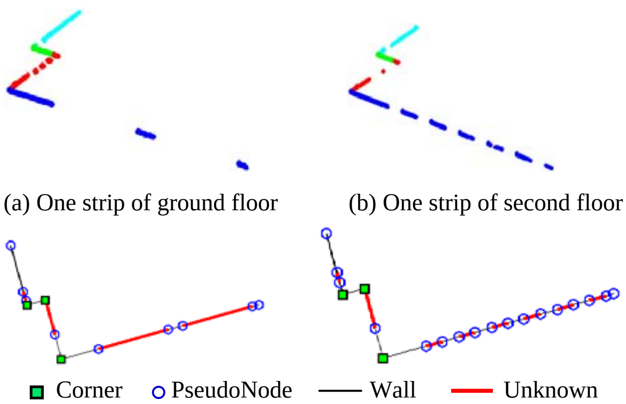


Figure 6. Semantically and geometrically parsed line strings

After segmentation, TLS points on building walls were extracted as shown in Figure 3(b). Then the TLS points were cut into section strips with a constant height of 0.2 metre. Figure 7(a) and 7(b) are two examples of the section strips of the ground floor and the second floor respectively. Figure 7(c) and 7(d) are the corresponding semantically and geometrically parsed line chains.



(a) One strip of ground floor (b) One strip of second floor

(c) Parsed line chain of (a) (d) Parsed line chain of (b)

Figure 7. Section strips and semantically and geometrically parsed line chains

5.3 Matching Results and Accuracy

There are totally 21 pints in the line string extracted from the ground floor and 44 points in the line strings of other floors. Table 1 shows the number of points in the line chains in the best matching case of each floor.

Floor	Ground	Second	Third	Fourth
Nr of points in line chain	12	20	20	20

Table 1. Number of points in the line chains in the best matching case of each floor

Table 2 shows the matching results after using the similarity measure in the best matching cases. It can be seen that there are many multiple matches were found because of the similar window structures. Then as shown in Table 3, after confirming multiple matches, the numbers of point pairs of each floor were much reduced. There is one spurious point pair found for second and third floor respectively. This is because there is one extra line segment was detected in the corresponding line string due to the occlusion. Comparing Figure 7(d) with Figure 6, we can see it. We use an error limit of 5 cm in the iterative refinement process. After refinement, 2 more point pairs were added to the list for ground, third, and fourth floor respectively. One more point pairs was found and added to the list of second floor. Comparing Table 3 and Table 2, it can be seen that except for the two end points and two extra points in the line chains of the second, third and fourth floor due to occlusion, all the points in the line chains were matched and used for the calculation of the final transformation.

Floor	Number of point pairs		
	Similarity score>0.9	Singular matches	Multiple matches
Ground	14	6	8
Second	125	5	120
Third	125	5	120
Fourth	124	4	120

Table 2. Matching results after using the similarity measure

Floor	Number of point pairs		
	After confirming multiple matches	After removing spurious matches	After iterative refinement
Ground	8	8	10
Second	15	14	15
Third	15	14	16
Fourth	14	14	16

Table 3. Matching results after refinement

Table 4 summarizes the registration accuracy based on the best matching cases of each floor. As can be seen, an average of 2.3 cm registration accuracy was achieved. The accuracies of each floor are very close and stable. The accuracy of ground floor is a little bit lower than the others. This could be because of the occlusion of the trees. For the third and fourth floor, the accuracies are the same because there is almost no occlusion there. Figure 8 shows the final co-registered line strings and 3D TLS points.

	Ground Floor	Second Floor	Third Floor	Fourth Floor
RMS(m)	0.0253	0.023	0.0215	0.0215

Table 4. Registration accuracy

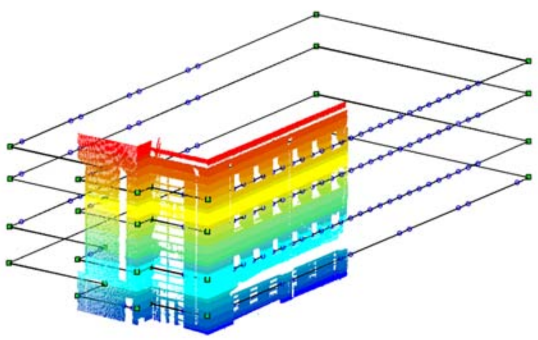


Figure 8. Co-registered line strings and 3D TLS points

6. CONCLUSIONS AND FUTURE WORK

In this paper, a general semantic and geometric information integrated point matching based method for co-registration of 3D TLS points and 2D floor plans was presented. The method simplifies the 3D point to 2D line registration problem to 2D point-point matching and uses the invariant geometric and semantic context information of the points as a base to find the best matching cases. From the test, the proposed method can find all the corresponding points and a high registration accuracy of less than 2.5 centimetres was achieved.

The advantage of the semantic and geometric information integrated point matching is that it only needs to find at least 3 corresponding point pairs and can deal with uncertainty and ambiguity caused by occlusion. The proposed method can find and use all the potential matching points and therefore can produce a reliable registration. It scans all the building to find the best match case and therefore can be applied to buildings with different storey structures. It can also be used for registration of multiple scans of TLS data.

An obvious limitation of the proposed method is that it may produce wrong results when two or more facades of a building have the same structures. Other constrains need to be found and incorporated into the point matching algorithm in the future to overcome this limitation. The proposed method also needs to be further tested and improved using more datasets.

The paper proved the feasibility to register 2D floor plans with 3D TLS data. The integration of 2D CAD data, BIM and 3D GIS data can be further explored. Especially, after the horizontal registration of 3D TLS data and floor plans, it provides a good start point for the integration of indoor and facade models. In next step, research will be focused on this direction.

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