SEMANTIC FEATURE BASED REGISTRATION OF TERRESTRIAL POINT CLOUDS

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Commission III, WG 2

KEY WORDS: Registration, Terrestrial laser scanning, Feature extraction

ABSTRACT:

As an active remote sensing technique, Terrestrial Laser Scanning (TLS) is popular for constructing detailed 3D models of complex objects. To create a complete 3D scene, TLS point clouds scanned from multiple positions need to be registered to the same coordinate system. Conventional registration methods demand significant amount of manual work. Recent studies use geometric features (points, lines and planes) matching to automate the registration procedure. However, a fully automatic and simple registration method is still a popular research interest. In this paper, a new registration approach is proposed which uses semantic information to automate the geometric feature matching. Knowledge is used to identify semantic meaning of geometric features and classify them. The semantic type and spatial pattern of features is organized and analysed in a hierarchical manner. This provides a basis for structured feature matching reducing the search space and hence instigating automation in registration. Geometrical properties of obtained matches are used for coarse and fine registration through least squares adjustment. Our proposed approach was tested for registering building façade scans which yielded successful registration with high accuracy level.

1. INTRODUCTION

Terrestrial laser scanning (TLS) is emerging as a successful technology in constructing detailed and accurate 3D models of complex objects. With the explicit 3D coordinates of object surface and reflected intensity of laser beam (Slob and Hack, 2004), terrestrial point clouds have been widely used to reconstruct realistic 3D scenes for applications such as urban planning, environment, transportation, and virtual city tourism (Pu, 2008).

To document a complete 3D scene, scans from multiple positions need to be registered in one common coordinate system. At present, Iterative Closest Point (ICP) algorithm (Besl and McKay, 1992) is widely used for this purpose. The ICP method requires manual operation to calculate the initial transformation (also referred as coarse registration) with or without the use of markers, based on which fine registration is done. A lot of improvements and variations of ICP methods have been researched to automate the registration procedure. Some methods (Brenner and Dold, 2007; Hansen, 2006; Stamos and Leordeanu, 2003) extract features like lines and planes from overlapped point clouds and analyze the feature correspondences. The corresponding features are then used for registration. Another number of methods (Barnea and Filin, 2008; Bendels et al., 2004; Dold and Brenner, 2006; Kang, 2008; Wang and Brenner, 2008; Wendt, 2007) make use of imagery as a bridge. The images can be either optical images which are captured together with laser scanning, or intensity images which are generated from laser beams' angle coordinates and reflectance values. The feature matching problem is therefore transferred to image space, where plenty of image processing algorithms can fulfil the task.

However, robust, quick and fully automatic registration is still an ongoing research topic. More attention is paid to increasing the efficiency of feature matching, which is obviously the main bottleneck for an automated registration process. Stamos and Leordeanu (2003) make segmentation to different scans, extract features out of the segments, and then build a topological graph for matching and registration. Brenner and Dold (2007) compute registration parameters by imposing angular constraints on planar structures and search for most appropriate transformations using score functions but emphasize on the need for efficient and selective function. Dold and Brenner (2008) give a plane-equations-based selective score function but point out the function to be vulnerable to scene symmetry. Brenner et. al. (2008) present several issues for investigations of coarse registration. Some of which are: faster segmentation methods for planar patches; use of other properties for prioritization of correspondences. Wang and Brenner (2008) state that handling of huge datasets, irregular point distribution, multiple views and relatively low textured surfaces make fully automatic registration of TLS point clouds still a question. They further recommend the use of primitives other than geometric constraints for prioritization of correspondences.

The researches above mainly focus on extracting and matching of geometric features such as point, line and planes, which are rather vulnerable to variety of point cloud density and symmetries in the scene. Geometry feature based registration methods can also be computationally heavy, considering the great number of geometry features containing in a single point cloud. This paper presents a new registration method which introduces knowledge to identify the semantic meaning of each geometric feature. Once the meaning is known, the feature matching will just be straightforward.

In TLS processing, implicit use of semantics has been done for building grammar to derive and model façade description. Ripperda (2008) used such a grammar based approach for façade reconstruction while methods by Becker and Haala (2008) and Becker et al. (2008) concentrated on grammar derived from already reconstructed facades that serve as knowledge base for automatic modelling of façades.

Our method starts with segmentation of each scan individually. Then the geometry information of each segment and the

topological relations between segments are analyzed according to knowledge. This semantic meaning extraction procedure will associate each segment with an identity label such as "ground", "wall no. 1", "roof of wall no.2", "first floor window of wall no.1". Then correspondent features from two scans can be easily matched according to same semantic type and same pattern (topological relation with other features). Finally, geometric properties (point, line or plane) of matched semantic features are used to calculate the coarse and fine transformation matrices between two scan coordinate systems.

The remainder of the paper is organized as follows: section 2 explains the semantic feature extraction and matching strategies. Section 3 explains the functional model for pair wise registration. Section 4 demonstrates our registration method with two datasets, and discusses some remaining problems. Conclusions and suggestions for future work are drawn in the final section.

2. SEMANTIC FEATURE EXTRATION AND MATCHING

2.1 Semantic features extraction for façade modelling

Pu and Vosselman (2006) give a semantic feature extraction method for TLS façade point cloud. This method first defines several important building features based on human knowledge about building facades. Assumptions, such as "walls are the large vertical regions on building facade", "roofs are the non-vertical regions on top of walls", "extrusions are largest regions on walls, and intersect walls", are defined and translated to features constraints. Then the TLS point cloud for a building facade is segmented with a surface growing algorithm (Vosselman et. al., 2004), so that points belonging to the same planes are grouped together. Finally, each segment is compared with different building feature constraints to determine which feature this segment represents. This method works fine for most façade features, except for windows. This is because insufficient laser reflection from window glasses result in their poor segmentation. Pu and Vosselman (2007) add a window extraction method which detects the holes on walls, to complete the extraction of façade features. The extracted semantic features are shown in Figure 1. Although semantic features are extracted from registered point clouds in the above approach, the idea can be referenced to extract meaningful structures from individual scans for registration purpose.

2.2 Strategy for semantic feature matching

With determined semantic type, the spatial pattern in a scan can be organized as a semantic tree. The leaves of the tree contain the semantic features' identity labels and detailed geometry information (area, direction, centroid, etc.). The branches of the tree reflect the hierarchical relations between features. The feature matching between scans is therefore turned to a structured trees' matching. Successful matching of two trees should provide enough feature correspondences for both coarse registration and least square adjustment.

The idea of general semantic feature matching is presented above. Adaptation of the methodology should be made in practice according to different applications. Figure 2 gives a design for registering scans of building façades. Because walls, roofs and windows are the most common features on building facades, they are extracted and organized for matching. Using semantic knowledge of the façade and its surroundings such as
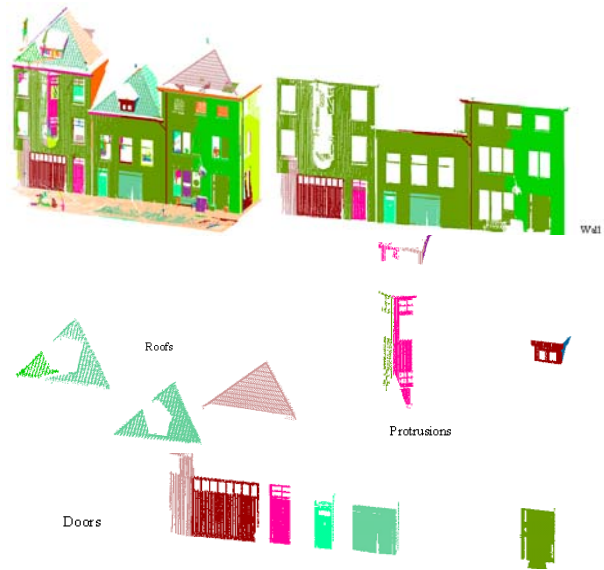

Figure 1. Semantic feature extraction from terrestrial laser scan

top edge of façade, ground information and floor height, the building is divided into its number of floors based on which secondary semantic features (such as windows) are grouped. This grouping leads to search and verification of windows in one floor only, reducing the search space. Once grouped, topology is described by determining vertical and horizontal neighbours for every semantic feature in every floor. Vertical neighbours refer to features that are vertically aligning with the feature under consideration. Horizontal neighbours are feature pairs in every floor with calculated distance between them.
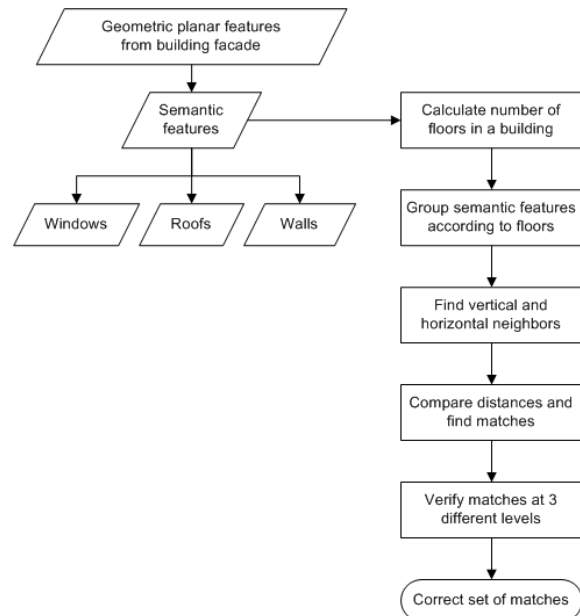

Figure 2. Overview of matching method

For every floor, feature pairs are matched according to the distance calculated. Successful matching results either in singular matches or multiple matches. Singular match are feature pairs whose distance in a scan is equal to only one pair in another scan while multiple matches exist when there are many pairs. Singular matches are verified by searching for singular matches amongst vertical neighbours. If at least one

another singular match is found in vertical neighbours, the matches for all pairs are confirmed as correct ones. Multiple matches are also verified in a similar way with one extra step where corresponding horizontal pairs are checked. As a final confirmation, from the lexicographically ordered matched set in every floor, a reference feature is taken and distance for every feature in that floor is calculated. Comparison of distances then gives a final set of correct matches. This step also helps in removing spurious matches. Matched semantic features are used next for pairwise registration.

3. PAIRWISE REGISTRATION

Coarse registration of a pair of scans is based on plane transformation model where advantage is taken of the two available perpendicular planes of ground and façade. Initial parameters are estimated using normal vectors of planes because perpendicular planes give a good estimate of two axes of a coordinate system. As translation is linear in transformation and well taken care of in fine registration by points, the rotation parameters need to be better approximated. This is accomplished by using the perpendicular planes.

The plane based functional model proposed by Jaw and Chuang (2008) is used for this purpose. All transformation parameters (3 for rotation and 3 for translation) are approximated by rigid transformation using minimum of two planes that are perpendicular. Scale is set as global scale for all scans and therefore set to 1. Since façade wall and ground are already segmented, these perpendicular planes are used in coarse registration.

For fine registration, instead of using points exclusively, plane normal vectors are integrated into the model in least squares adjustment. The integrated functional model is presented as:

$$X_1 - \left(RX_2 + \vec{t} \right) = 0 \qquad (1)$$
$$N_1 - RN_2 = 0 \qquad (2)$$

where,
X_1 and X_2 = centroid points of matched windows in two different coordinate systems
N_1 and N_2 = normal vectors of planes in two different coordinate systems
R = rotation matrix
t = translation vector

4. TEST CASES

Our proposed approach is tested for two building facades scanned using Riegl LMS – Z360i. Semantic features taken for matching are wall and windows, because they are the most common and representative features on building facades. Matching is demonstrated for windows within a single building façade.

4.1 The registration

Dataset 1 (Figure 3) is a building façade of University of Twente library. Scan 1 of this dataset (Figure 3a) has dense point cloud with some wall sections missing while scan 2 (Figure 3c) has less dense point cloud without missing portions.

Bottom of the building contains obstructions (stalls or sheds) that prevent acquisition of complete façade. Extracted windows in the two scans don't have same sizes and in lower floor a window is missing. In scan 1 (Figure 3b), a gap exists between some windows implying that those windows could not be extracted from that region due to missing wall sections.
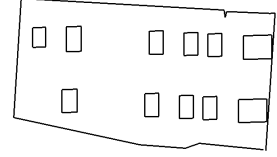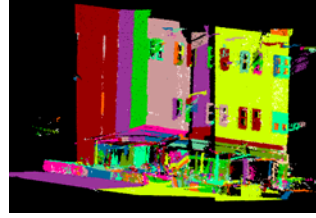
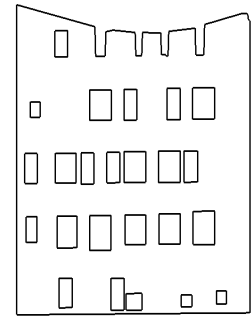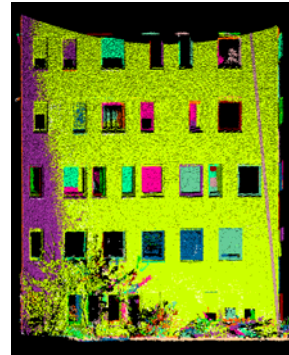(a) Segmented façade scan 1   (b) Extracted semantic features
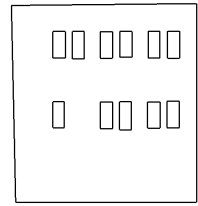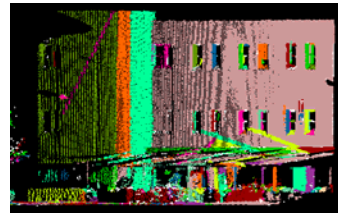
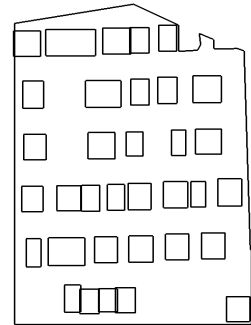(c) Segmented façade scan 2   (d) Extracted semantic features

Figure 3. Segmented and extracted semantic features in example dataset 1

(a) Segmented façade scan 1   (b) Extracted semantic features

(c) Segmented façade scan 2   (d) Extracted semantic features

Figure 4. Segmented and extracted semantic features in example dataset 2

Dataset 2 (Figure 4) is south façade of ITC building. Segmented façade of scan 1 shows that scanner has failed to detect topmost floor as it was too close to the building while scanning. At the bottom floor, because of ground vegetation, parts of some window features have been occluded. These obstructions have led to missing features and incomplete feature construction as depicted in Figure 4 (b) and (d). Under these conditions, our matching strategy is applied.

In the feature matching task, top edge of the wall is detected for calculating number of floors. When top edge is not detected as in case of scan 1 in dataset 2, ground segment is used. Centroid points of windows were taken for distance calculation and registration thereafter. Table 1 shows the results of feature matching.

Dataset	Number of extracted windows in scan 1	Number of extracted windows in scan 2	Number of matched windows
Dataset 1	11	11	8
Dataset 2	23	33	19

Table 1. Results of feature matching

Pairwise registration is carried out using coordinates of corresponding centroid points of windows and planes of ground and wall where scan 1 is taken as the reference scan. Figure 5 and visual check show successful pairwise registration. Front views of registered output of both datasets show that fusion is correctly achieved as multi colored walls from two scans – pink and red have fitted nicely without any tilts and deflections. A closer inspection from the top (for dataset 1) and side view (for dataset 2) further demonstrates this clearly.
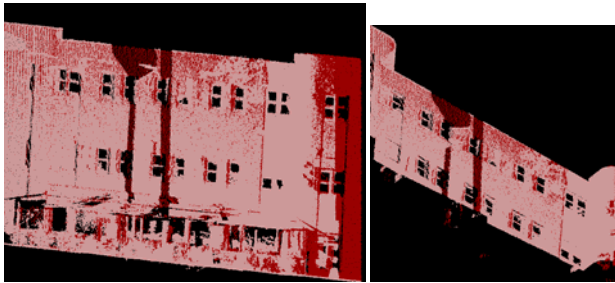
(a) Registered output of dataset 1   (b) Another view
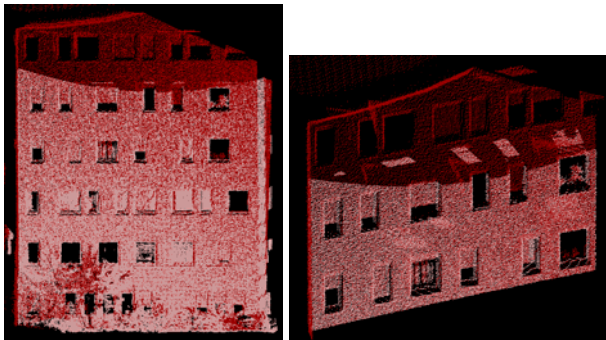
(c) Registered output of dataset 2   (d) Another view

Figure 5. Results of registration. Reference scan is in pink.

Provided the façade features are accurately extracted, coarse and fine registration of a scan pair can be successfully achieved with good alignment of scans. Even in situations where there are missing floors and windows, considerable number of matches have been generated.

4.2 Result evaluation

The result quality is evaluated by checking the residuals and comparing distances of points to plane before and after registration respectively. Table 2 shows the results of matching assessment.

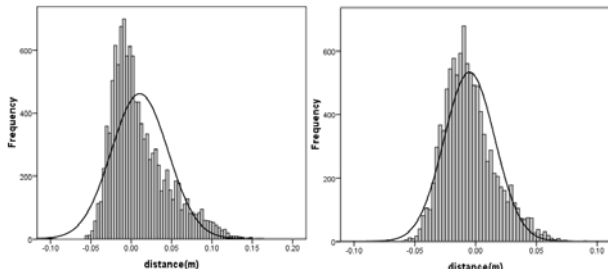| Dataset	Mean (m)	Standard deviation (m)
Dataset 1	0.03	0.01
Dataset 2	0.13	0.12

Table 2. Residuals of automatically matched points

In dataset 1 (Table 2), automatically matched points achieved registration of acceptable accuracy with mean residual of 3cm and 1 cm standard deviation. For dataset 2, residual is higher with 13cm. This is unexpected since both datasets should have the same level of accuracy. Residual plot of automatically matched points for dataset 2 revealed an outlier. Although visual examination showed a well aligned wall, such outliers appear if the centroid points do not coincide. In this case, its source is inconsistent dimensions of extracted semantic features between scans. This issue occurs when there are obstructions, disturbances or occlusions in front of a building. In the given dataset, extraction of the most right window in ground floor is affected by garden vegetation. Removal of this outlier reduced residual mean from 13cm to 10cm while standard deviation reduced to 7cm. However, dataset 2 has lower accuracy than dataset 1 which is not expected. The cause behind this result is examined and discussed in later part of this section.

Standard deviations and histograms of point to plane distances in scans before and after registration should not be drastically different. RANSAC is applied to construct planes from points in local surfaces of wall. Unexpected skewed distribution was found in distance histogram of dataset 2 (Figure 6b). The source behind this skewness is found to be the same as for high mean residual. The wall of dataset 2 building façade is slightly non planar with some degree of curvature. This affected the semantic feature extraction method as well as the accuracy assessment method used. This wall shape affected the feature extraction method wherein the wall points are reprojected to a fitted plane altering the original values. Primarily this extraction method is developed for automatic 3D city modelling and for this purpose; it does not have any major impact on its quality. However, for registration, wall curvature incurred an error in the measurement of features and wall points which propagated to the registered output.
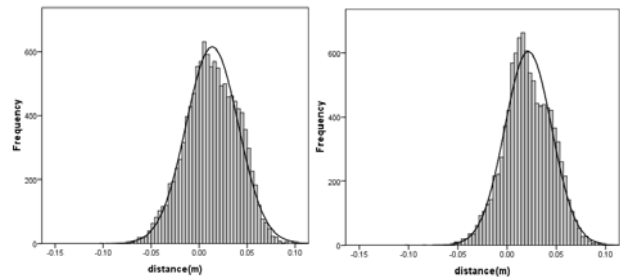
(a) Dataset 1 before registration (left) & after registration (right)

(b) Dataset 2 before registration (left) & after registration (right)

Figure 6. Histograms of point to plane distances in scans before and after registration

However, standard deviations for both datasets is similar and lower after registration (Table 3) implying well registered scans with mean standard deviation of approximately 2.3cm. This means that correct set of matches are acquired and registration using these points is successful denoting the registration from this automatic method to be of acceptable quality.

Mean standard deviation (m)	Dataset 1	Dataset 2
Before registration	0.028	0.035
After registration	0.024	0.021

Table 3. Standard deviations (m) calculated for points to plane distances

5. CONCLUSIONS

In this paper, we give a suggestion of a semantic aided feature matching concept, which will lead to a more robust and efficient registration process. In order to avoid heavy searching and matching in all geometry features, the actual meaning of each geometry feature is determined first, and organized systematically. The search space is therefore greatly localized by semantic type and hierarchical relations between different semantic features. A derivation method for registering building façades' scan is implemented, which focuses on the common façade features of wall and windows. Experiment results on two datasets demonstrate the promising effect of our idea.

The algorithm generated well registered scan pairs with acceptable accuracy level, but it relies on a relatively correct identification of semantic features. The current knowledge base is only able to understand certain types of buildings, so it is foreseen that the presented algorithm is still not applicable to complex architectures. Automation of registration means efficiency in TLS processing which will subsequently help in hastening the process of 3D model construction. In future, registration can be extended from pairwise to global to minimize error propagation. Outliers in automatically matched features need to be removed by robust estimation technique such as RANSAC. Use of more systematic semantic knowledge can be further explored that focuses on overcoming the problem of methods being vulnerable to scene symmetries.

REFERENCES

Barnea, S. and Filin, S., 2008. Keypoint based autonomous registration of terrestrial laser point-clouds. ISPRS Journal of Photogrammetry and Remote Sensing, 63(1): 19-35

Becker, S. and Haala, N., 2008. Integrated LIDAR and image processing for the modelling of building facades. Photogrammetrie Fernerkundung Geoinformation(2): 65 - 81

Becker, S., Haala, N. and Fritsch, D., 2008, Combined knowledge propagation for facade reconstruction, International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, XXXVII Part 5, Beijing, China, July 3-11, 423-429

Bendels, G.H., Degener, P., Wahl, R., Kortgen, M. and Klein, R., 2004, Image-based registration of 3D-range data using feature surface elements, The 5th International Symposium on Virtual reality, Archeology and Cultural Heritage, The Eurographics Association, Belgium, December 7-10, 115-124

Besl, P.J. and McKay, H.D., 1992. A method for registration of 3-D shapes. IEEE Transactions on Pattern Analysis and Machine Intelligence, 14(2): 239-256

Brenner, C. and Dold, C., 2007. Automatic relative orientation of terrestrial laser scans using planar structures and angle constraints, ISPRS Workshop on Laser Scanning 2007 and SilviLaser 2007, Espoo, Finland, pp. 84-89

Brenner, C., Dold, C. and Ripperda, N., 2008. Coarse orientation of terrestrial laser scans in urban environments. ISPRS Journal of Photogrammetry and Remote Sensing, 63(1): 4-18

Dold, C. and Brenner, C., 2006, Registration of terrestrial laser scanning data using planar patches and image data International Archives of Photogrammetry, Remote Sensing and Spatial Information Sciences XXXVI, Part 5, Dresden, Germany, September 25- 27, 78-83

Dold, C. and Brenner, C., 2008, Analysis of score functions for the automatic registration of terrestrial laser scans, International Archives of Photogrammetry, Remote Sensing and Spatial Information Sciences, XXXVII, Beijing, China, July 3-11, 417-422

Hansen, W.v., 2006, Robust automatic marker-free registration of terrestrial scan data, The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences 3, XXXVI, 3, Bonn, Germany, 105-110

Jaw, J.J. and Chuang, T.Y., 2008. Feature-based registration of terrestrial LIDAR point clouds. In: J. Chen, J. Jiang and H.-G. Maas (Editors), International Society for Photogrammetry and Remote Sensing, XXI Congress, Comission III. Processing of Point Clouds from Laser Scanners and Other Sensors, WG III/3 International Archives of Photogrammetry, Remote Sensing and Spatial Information Sciences, Beijing, China, pp. 303-308

Kang, Z., 2008, Automatic registration of terrestrial point cloud using panoramic reflectance images, International Archives of Photogrammetry, Remote Sensing and Spatial Information Sciences, XXXVII, Part B5, Beijing, China, July 3-11, 431-436

Pu, S., 2008, Generating building outlines from terrestrial laser scanning, The International Archives of Photogrammetry, Remote Sensing and Spatial Information Sciences XXXVII, Part B5, Beijing, China, July 3-11, 451-455

Pu, S. and Vosselman, M.G., 2006. Automatic extraction of building features from terrestrial laser scanning. In: H.G. Maas and D. Schneider (Editors), ISPRS commission VI symposium Image engineering and vision metrology. ISPRS, Dresden, Germany

Pu, S. and Vosselman, M.G., 2007. Extracting windows from terrestrial laser scanning, ISPRS workshop : Laser scanning 2007 and SilviLaser 2007 International Society for Photogrammetry and Remote Sensing (ISPRS), Espoo, Finland, pp. 320-325

Ripperda, N., 2008. Grammar based facade reconstruction using rjMCMC. Photogrammetrie Fernerkundung Geoinformation(2): 83-92

Slob, S. and Hack, R., 2004. 3D terrestrial laser scanning as a new field measurement and monitoring technique. In: R. Hack, R. Azzam and R. Charlier (Editors), Engineering geology for infrastructure planning in Europe: a European perspective Springer, Berlin, pp. 179-190

Stamos, I. and Leordeanu, M., 2003. Automated feature-based range registration of urban scenes of large scale, IEEE Computer Society Conference on Computer Vision and Pattern Recognition, 2. pp. 555-561

Vosselman, G., B. Gorte, G. Sithole and Rabbani, T., 2004. Recognizing Structure in Laser Scanner Point Clouds. International Archives of Photogrammetry, Remote Sensing and Spatial Information Sciences, vol. 46, part 8/W2, Freiburg, Germany, October 4-6, pp. 33-38

Wang, Z. and Brenner, C., 2008, Point based registration of terrestrial laser data using intensity and geometry features, International Archives of Photogrammetry, Remote Sensing and Spatial Information Sciences, XXXVII, Part B5, Beijing, China, July 3-11, 583-589

Wendt, A., 2007. A concept for feature based data registration by simultaneous consideration of laser scanner data and photogrammetric images. ISPRS Journal of Photogrammetry and Remote Sensing, 62(2): 122-134