WINDOW DETECTION FROM TERRESTRIAL LASER SCANNER DATA
A Statistical Approach

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Keywords: Windows detection, Applied statistics, Deformation analysis, Facade segmentation and ROI.

Abstract: This paper proposes a window detection system using applied statistics and image based methods from Terrestrial Laser Scanners which can be used for direct application in a deformation measurement system. It exploits the laser distance information either directly in the laser scanner spherical coordinate space images, or on segmented planar facade patches, both with the assumption that the laser beam penetrates windows. The applied statistical method uses basic local features on local distance variations and decides on an adaptive threshold on the basis of the $1-Sigma$ percentile upper limit with P_{90} 90% and P_{10} 10% produced sample quartiles of the data for the laser spherical coordinate system image and $Q_3 - Sigma$ for the ortho images of segmented 3D facade planes as a location in the order statistics. For window detection the image is binarized and morphological closing is performed using the derived adaptive threshold. Thereafter we do the contour analysis and obtain the bounding rectangles positions that directly form the window segments in the image. We compare the window detection results on the laser spherical coordinate system image with those on ortho images of segmented 3D facades. The system provides a windows detection rate of more than 85% with a processing time of less than a minute in a typical 360 degree laser scan image.

1 INTRODUCTION

Deformation processes in highly populated areas, stemming from underground construction work, unstable and wet underground, as well as earthquakes and other similar disasters, are increasing, not only in alpine areas. Monitoring of such events is a complex task, the more so if a large urban area is involved (Deffontaines et al.,). It requires to establish non-stationary sensor systems several times on similar viewpoints, and re-detect the same set of points of interest for each measurement epoch (Erol et al., 2004). The order of measurements can be predefined either as individual measurements or as repetitive measurements (each hour at same minute, each day at same hour, each month at same day). Such stable points of interest can be found automatically around windows, which in such way form salient candidates for an automatic point-of-interest selection process. The purpose of window detection as described in this paper is therefore to automatically establish a data base of points suitable for deformation monitoring (e.g. from the corners of the detected windows) on one hand, and on the other hand re-detect them for repeated measurement to enable a robust tracking of the same point over time.

1.1 Related Work

The aim of this work is the detection of windows in the original and segmented building facades from Terrestrial Laser Scanner Data. (Bauer et al., 2003) pre-

Ali H., Sablatnig R. and Paar G. (2009).
WINDOW DETECTION FROM TERRESTRIAL LASER SCANNER DATA - A Statistical Approach.
In *Proceedings of the Fourth International Conference on Computer Vision Theory and Applications*, pages 393-397
DOI: 10.5220/0001786303930397

sented a robust approach for detection and partition of planar surfaces in dense 3D point clouds from facades. A feature based building segmentation algorithm for an object dependent 3D generalization is developed by (Frank and Sester, 2004). (Lerma and Biosca, 2005) presented an automatic approach to obtain planar surfaces on scanned monuments and reduce the data volume. The proposed algorithm extract planar surfaces and reduce non relevant data points based on the clustering techniques. An automatic system for the segmentation and extraction of planar parts using RANSAC is developed by (Boulaassal et al., 2007). (Mayer and Reznik, 2006) proposed an approach to determine the 3D position of windows by plane sweeping for building facades interpretation in multiple images. Automatic marker-free registration of Terrestrial Laser Scans using reflectance features is presented by (Bohm and Becker, 2007). A modeling process for 3D object representation by cell decomposition for building reconstruction at different scales is presented by (Becker and Haala, 2007). (Pu and Vosselman, 2007) presented an approach for automatic extraction of windows from terrestrial point clouds. They first segment the laser points in planar segments and then apply two detection strategies for two different classes (covered and non-covered with curtains) of windows. The system is based on different segmentation algorithms and retrieves potential building features like (doors, walls, windows, etc.) to recognize buildings but operates only on frontal views of the buildings.
The system we provide covers more general building views. The first option directly operates on 3D data points and does not involve any 3D segmentation technique. The second option uses 3D segmentation of planar surface patches and thereafter applies window detection. Both options are evaluated on a well known data set, they perform significantly better than the system proposed by (Pu and Vosselman, 2007) in terms of time, accuracy and robustness. Robust window detection can be either applied to the laser spherical coordinate system image or to ortho images of the segmented 3D facades.

1.2 Overview

The laser scanning system provides ordered 3D point clouds in a dedicated image structure. It can be shown that the measured distance significantly changes in the window regions of the facade, either by window penetration, or by (occasional) reflection as show in Figure 1.

It is therefore near at hand to exploit these changes for window detection.

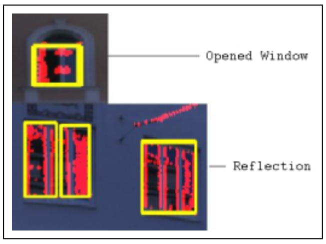

Figure 1: An example of opened window and occasional reflection (The reflection of other building in the window).

The system works optionally directly in the spherical coordinate system laser-scanner distance image or on a digital surface model on segmented planar patches of the facades that were gained by a clustering and indexing using an iterative parameter estimation method (RANdom SAmple Consensus, RANSAC). Local variations in these data structures are analyzed by calculating the differences of the distances between two adjacent pixels. An adaptive threshold is applied to identify candidate pixels for window regions. Morphological operations and contour analysis lead to rectangular regions that are direct bounding boxes around the segmented windows. The planar segmentation facilitates this process, since object dimensions can be directly derived from the planar ortho image and surface models, the calculated rectangles are parallel with the local coordinate axes, and they can therefore directly be used for points-of-interest output on their corners. The global workflow of the system involves 3D data analysis and facade segmentation in order to identify window segments is presented in Figure 2.

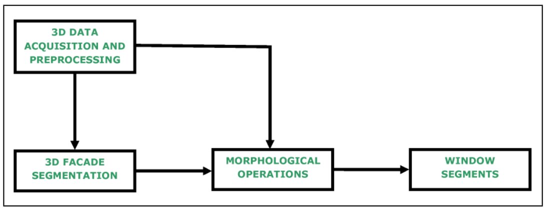

Figure 2: Pipeline for window detection from a 3D laser spherical coordinate system image, or optionally using ortho images from 3D Facade segmentation which facilitates the window detection process.

2 FACADE SEGMENTATION

We collect 3D point clouds using a long-range laser scanner (LPM-2k by Riegl Laser Measurement Systems) with an operating range of 10m-300m. The laser scanner is based on the time-of-flight method, for each single measurement a burst of several hundred laser pulses are emitted. The reflected re-

turn pulses are analyzed by a Digital Signal Processor (DSP) to compile a single distance measurement. Several measurement modes ("first target", "last target", "strongest target") can be selected for the method used by the DSP. These data points are stored in an image structure in a spherical coordinate system, containing, for each measured point, its exact spherical coordinates, its distance from the laser scanner origin, as well as optional RGB texture values.
Plane segmentation iteratively selects a random set of $10-20$ points in a local vicinity within this image. Whenever consistency to a regression plane is within a given threshold for such a sample, this plane is a candidate for a facade patch. Additional constraints apply such as near-horizontal normal vector, minimum number of additionally plane - compliant pixels within the bounding box of the sample, and minimum/maximum angle to other intersecting already identified planar patches. Iterative refinement of the plane is established by a region-growing approach. This solution leads to the results as shown in Figure 3.

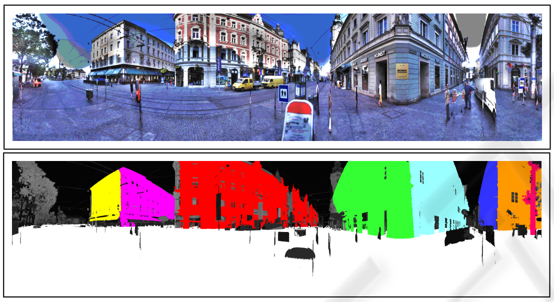

Figure 3: Top: Laser RGB texture (shading corrected) in spherical coordinate system, Bottom: Plane (colored) segmentation using RANSAC.

3 WINDOW DETECTION

Window detection system is a schematic process of 3D data acquisition, analysis and morphological operations to detect window segments in laser spherical coordinate system image and ortho distance images of segmented 3D facades.

3.1 Statistical Analysis of Distances

For the selection of window candidates pixels in the original spherical coordinate laser distance image, the distribution of the local distances variation is obtained by

$$D = dx_1 - dx_2 \tag{1}$$

with D the used difference of local distance, dx_1 the distance at laser image coordinate (x_1, y), and dx_2 the distance at point (x_1+1, y) for each laser image row y.

A confidence interval of $1-Sigma$ percentile upper limit of the mean with P_{90} 90% and P_{10} 10% produced sample quantiles of the data is used as an adaptive threshold value to identify regions of interest (ROIs) as given by (2).

$$T = P_{90} + (P_{90} - P_{10})/2 \tag{2}$$

In contrast to the direct laser images, the facade segmentation provides planes that cover more frontal views used as input to the window detection system for further processing. An adaptive threshold upper limit value is decided on the basis of the third and first quartiles (Q_3, Q_1), 75% and 25% respectively as given by (3).

$$T = Q_3 - (Q_3 - Q_1)/2 \tag{3}$$

T can be directly used for binarization. An example of such an image masking is presented in Figure 4.

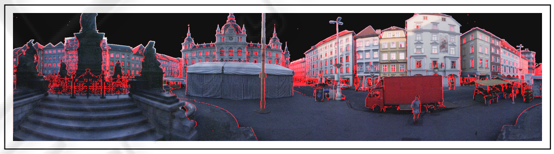

Figure 4: RGB image of urban scene in spherical laser scanner coordinates, overlaid by a binary mask from thresholding that resembles window candidate pixels.

3.2 Morphological Operations and Window Bounding Boxes

The image is binarized using the adaptive threshold value. A morphological higher order operation (closing) is performed using a $3*3$ structuring element. The closing rejoins the splitted windows due to the change of distance on facade and window regions. An example of closing is presented in Figure 5.

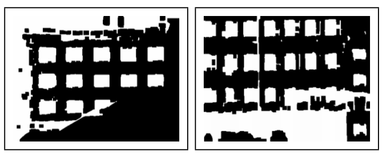

Figure 5: Closing joins the separate portion of the windows to be considered as a single window for the detection framework, examples from facades ortho images.

An Open Source connectivity preserving contour analysis method (find contours) is used to find and retrieve the window regions in the binary image. Thereafter Opening and connected components labeling leads to window contours and their up-right bounding rectangles are calculated. As the windows are of rectangular shape, we determine the area of the contour and the bounding rectangle and decide that R is a valid rectangle around a window, if

$$A_R - A_C < (0.5 * A_R) \quad (4)$$

with A_R being the Rectangle area, and A_C the contour area (4). In experiments we found 0.5 an appropriate threshold value to identify window segments. Determining an adaptive threshold value is subject to further research.

4 EVALUATION AND RESULTS

We have evaluated the system on the laser spherical coordinate system image as well as ortho distance images of segmented 3D facades images of a database acquired from different viewpoints in urban environment. Ground truth was determined manually. To evaluate the window detection rate we counted a *true positive*, if the window is correctly detected in the data-analysis phase, *false negative* if an existing window was not detected and *false positive*, if a window was detected where there is actually no window present. The dataset contains a total of 400 windows being 322 contained in laser spherical coordinate images and 78 in the segmented facades ortho images. The detection rate is provided in the Table 1.

Table 1: Robust Windows Detection Evaluation Results on laser spherical coordinate system image and ortho distance images of segmented 3D facades

Database(400)	Laser Images(322)	Ortho Images(78)
True Positive	283	65
False Negative	39	13
False Positive	10	0

A comparison in terms of window size consistency between the windows detected with and without the optional facade segmentation is given in Figures [6] and [7].

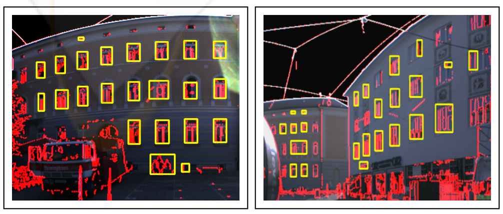

Figure 6: (a), (b) Examples for Window Segments detected by the system on the laser spherical coordinate system image.

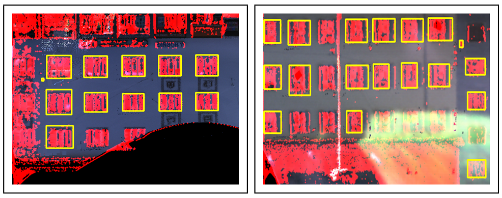

Figure 7: (a), (b) Examples for Robust Window Segments detected by the system on the ortho images of segmented 3D facades.

5 CONCLUSIONS

In this paper we have presented an image-based window detection system to measure 3D objects for urban deformation monitoring applications. The deformation analysis system gathers accurate 3D measurements on unique points of the building surface in different epochs and compares them across various time spans. It is therefore fed with 3D coordinates (i.e. bounding boxes) of the detected windows. The window detection system works directly in the spherical coordinate image of the laser scanner, or optionally on ortho distance images of segmented facades, which is based on RANSAC selection of sample points and iterative regression plane refinement. Window detection relies on a statistical analysis of distance distributions to binarize and segment the images for rectangular bounding boxes of windows. Both data sets reach a detection accuracy of more than 80%. The results on the segmented facades are superior in terms of window size consistency and false positive detections.

Future work will include the integration of the system into a deformation monitoring framework (Reiterer, 2007), the exploitation of window context information (e.g. arrangement of windows w.r.t. each other), and the exploration of other applications such as thermal facade analysis for emission control, or the task of city modeling for virtual reality purposes.

ACKNOWLEDGEMENTS

This work was partially funded by the FWF Austrian research project *"Multi Sensor Deformation Measurement System Supported by Knowledge Based and Cognitive Vision Techniques"* (P18286-N04), *"Österreichische Orient-Gesellschaft Hammer-Purgstall"* and Joanneum Research.

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