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An integrated approach for modelling and global registration of point clouds

Tahir Rabbani *, Sander Dijkman, Frank van den Heuvel, George Vosselman

Delft Institute of Earth Observation and Space systems, Delft University of Technology, Kluyverweg 1, 2629HS Delft, The Netherlands

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Abstract

Point cloud acquisition by using laser scanners provides an efficient way for 3D as-built modelling of industrial installations. Covering such an installation with point cloud data often requires data acquisition from multiple standpoints. Before the actual modelling can start the transformation parameters of all scans need to be determined. Two methods to register point clouds of industrial scenes with different coordinate definitions are presented. Corresponding object models in different scans are used to determine the translation and rotation parameters of the scans. The first method, called Indirect method, is a two-step approach as object fitting and registration of the scenes is done separately. The second method, called Direct method simultaneously determines the shape and pose parameters of the objects as well as the registration parameters. Both methods are designed such that optimal use can be made of the knowledge of shapes present in industrial environments. Compared to ICP the presented approach combines registration and modelling and thus avoids the accumulation of errors. Furthermore, the simultaneous registration of multiple scans is possible. The presented approaches are based on non-linear least squares and provide quality measures in the form of covariance matrix of the estimated parameters, which can be used to decide if more scans are needed, and how and where they should be captured. Results are presented on some point cloud data-sets from actual industrial sites, where registration was done without using any artificial targets.

Keywords: Reverse Engineering; Registration; Laser Scanning; Industrial Reconstruction

1. Introduction

In the process industry there is a growing demand for accurate three-dimensional models. These models are needed for different applications like documentation, revamping, planning, and for implementing services based on augmented and virtual reality (STAR, 2004).

Accurate modelling of big industrial installations, using traditional techniques like tacheometry, is very time consuming. Although image based modelling using traditional photogrammetry is comparably faster, it still requires a lot of manual interaction. It is quite difficult to automate the process of reconstruction using only image information. This is especially true for industrial sites due to their complexity and the presence of occlusions and clutter. In contrast to images, point clouds provide explicit 3D information and their use for modelling applications could result in comparably higher levels of automation. It is nowadays feasible to obtain point clouds with accuracies of 5 mm at distances up to 50–200 m (Laser scanner survey, 2005). Most

* Corresponding author. Tel.: +31 15 2788338; fax: +31 15 2782348.
E-mail address: t.rabbani@lr.tudelft.nl (T. Rabbani).

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scanners offer the opportunity to adjust the point density. A typical scan consists of one point every 10–20 mm. However, it is possible to measure with a higher point density in case more detail is required.

1.1. Previous work

To model big industrial sites the first problem that occurs is defining one coordinate system for all point clouds. This means that for each point cloud in the project the relative orientation and position have to be found and possibly connected to the factory coordinate system. When a scene can be represented as two point sets with known correspondences, the rigid transformation consisting of six parameters (three rotation angles and three translation parameters) in a least square sense can be calculated using a closed form solution(Horn et al., 1988). Due to the discrete nature and finite sampling density of point clouds, finding accurate corresponding points in them is highly error-prone, which means that the straightforward approach is usually not applicable.

The iterative closest point (ICP) algorithm (Besl and McKay, 1992) for point cloud registration works without any pre-knowledge about the point-to-point correspondences. It establishes point-to-point correspondence iteratively based on the minimum Euclidean distance. If the initial values are good enough, this procedure usually converges. ICP is a pair-wise registration procedure, and cannot reliably handle simultaneous registration of multiple scans. This results in the propagation of registration errors as more scans are acquired and added to a project. Secondly a large overlap area is required for proper functioning of these algorithms. Typically an overlap area of 25–30% is recommended for acceptable results. Furthermore, dealing with occlusions can be problematic, as ICP blindly uses points without any consideration for the underlying geometry.

Different approaches have been proposed to make ICP more robust by filtering the correspondences for effective handling of occlusions (Zhang, 1994; Guehring, 2001). The wrong correspondences are detected by comparing with a dynamic distance threshold, leading to a better behavior in the presence of noise and occlusions.

ICP in its original form provides no measure about the precision and reliability of the estimated parameters. Some attempts have been made to remove this limitation. For example in the approach of Guehring (2001) statistical properties of the registration parameters are estimated during registration through ICP.

To improve the convergence properties of ICP many variations on Euclidean distance function have been proposed in the literature. Most of these algorithms do not establish point-to-point relationships, but instead look for the relationship between points in one set to the local surface-approximations of the points of the other data-set (Chen and Medioni, 1992; Dorai et al., 1994). A variation of ICP for the simultaneous registration of more than two scans is presented by Eggert et al. (1998). To speed up closest point-on-surface search they use k–d trees. A comparison of different ICP variations is given by Rusinkiewicz and Levoy (2001). There they found point to the tangent plane distance to perform better than other distance measures.

A method for automatic registration of point clouds and images for the reconstruction of buildings is presented by Stamos and Leordeanu (2003). Their planar faces are detected through segmentation of the point cloud. The intersection of these planes gives lines in 3D, which are used in a RANSAC-based (Fischler and Bolles, 1987) framework for point cloud registration. Similarly, vanishing point detection in images and its relation with parallel lines in the point clouds is used for range-to-image registration. This framework exploits the domain specific knowledge to infer appropriate constraints, which results in high degree of automation for modelling of architectural scenes.

Many different approaches have been presented for the segmentation of a point cloud into planar and curved surfaces. A comparison of different methods for planar segmentation is given by Hoover et al. (1996). A similar comparison for curved segmentation is given by Min et al. (2000). A model based segmentation algorithm is presented by Marshall et al. (2001) which identifies the points belonging to simple surfaces like planes, spheres and cylinders etc. For least square fitting of these objects to 3D points techniques are given by Lukács et al. (1998). A method for automatic detection of cylinders in point clouds using an efficient two stage Hough transform in given by Rabbani and van den Heuvel, 2005b. Using these methods detection and fitting of simple object models to point clouds can be automated with a great degree of success.

1.2. Presented approach

Our approach is based on the assumption that dense and accurate 3D point clouds of the industrial sites contain enough geometric information for automatic detection and fitting of simple objects like planes, spheres, cylinders and tori. Rather than registering first and then modelling, we model first and then use the