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Coregistration of terrestrial lidar points by adaptive scale-invariant feature transformation with constrained geometry

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To obtain an accurate 3D model of the real world using a laser scanner, point clouds should be registered precisely. To increase the registration accuracy, the authors used wavelet based noise removal filters on the point cloud data, and extracted feature points from intensity images using the SIFT (scale-invariant feature transformation) method for two overlapping point clouds. These feature points were then used for a corresponding point matching to obtain a rigid body transformation matrix by an iterative technique.

With initial CTNC (closest-to-next-closest) ratio of 0.4, points were extracted and the transformation matrix was calculated. Under this geometric condition, the CTNC ratio was increased to obtain more points for matching. Then, the transformation matrix was recalculated with these points, giving more reliable results. The outliers were removed by random sample consensus (RANSAC) processing.

To measure and analyze the performance of our approach in pairwise registration, additional transformation parameters were computed using the Polyworks commercial software. Comparison of the two methods showed no significant difference in mm level. In the final stage, all the scan data are rapidly adjusted using global registration, due to a small number of accurate control points. Thus, the proposed coregistration method can be used to obtain fast 3D modeling results on construction sites where registration targets cannot be installed.

1. Introduction

Prompt and reliable surveying results are required for effective verification of the design versus as-built condition on construction sites. Terrestrial lidar can measure several million points in a few minutes with a high accuracy and has been used for three-dimensional modeling of facilities by many researchers [1–4]. However, lidar surveying requires “line of sight”, and for a complex structure, lidar instruments should thus be set up at multiple locations to minimize shadow areas; therefore, range data taken from different viewpoints should be aligned together in one global coordinate system for successful reconstruction [5]. Common practice for accurate registration is to use common targets as tie objects on construction sites [6–10].

To avoid manual intervention using artificial targets, which is time and labor consuming, a growing body of work addresses the problem of autonomous registration in relation to both range images and terrestrial laser scans [11]. In addition, several reviews and comparison studies for multiple range image registration are available in the literature [12–15]. 3D data registration is typically classified into two steps, a coarse registration step and an automated fine registration step [15]. To focus our attention on the particular algorithm we consider, we review a more specific approach that can be distinguished by range-based and auxiliary image-based approaches. In general, the registration approaches use distinctive features to determine the transformation model between two terrestrial lidar. Automatic registration is achieved by automating feature extraction and feature matching.

When searching for corresponding features in the two data sets, there are a variety of criteria that one can use for classifying points as being similar or interesting or key points, such as color, local surface normals, local curvature shape, edgeness, texture, etc. [13,16]. These features are extracted from the terrestrial range or image data and a complete variety of feature types may be considered. Point-based, line-based, plane-based and hybrid approaches have been extensively considered to search and detect correspondence with neighboring two point clouds [17–19].

The iterative closest point (ICP) algorithm is a point-based technique and requires a relatively less accurate initial approximation [20,21]. Stamos and Leordeanu [22] suggested another feature-based registration technique that searches for line and plane pairs in 3D point cloud space. Their experiments were conducted on campus buildings and a cathedral, which have numerous lines and simple surfaces. Overlaps between adjacent scans were quite high. A range segmentation algorithm can be applied to extract planar regions and linear features at the areas of intersection of neighboring planar structures. The least-squares 3D surface matching algorithm is a surface-based matching technique that requires a good initial

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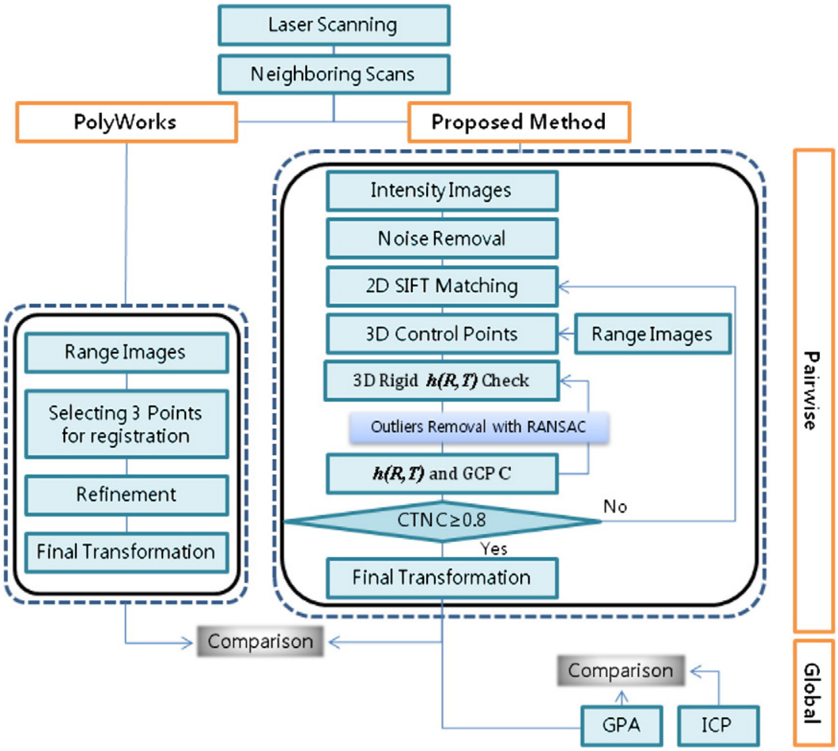

Fig. 1. Study flow chart.

approximation for reliable results [21]. Jaw and Chuang [23] suggested a feature extractor to register multiple scans onto a common coordinate system. The extractor collects three types of features (namely, point, line and plane), which were used to estimate 3D spatial similarity transformation parameters. These features can also be extracted from range images of terrestrial lidar and used for registration of point clouds [24]. Barnea and Filin [11] exploit 3D rigid-body transformation invariant features to reduce significantly the computational load involved in the matching between key features in range images. Line- and surface-based matching may give better results than point-based matching, but it requires a few assumptions for defining lines and surfaces. Because of the lack of 3D texture in a range image, there can be a lack of distinctive and therefore easily and reliably matchable features [19].

Recently, local features can also be extracted using images which are acquired with the range data by recording either co-registered camera images or reflectance images representing the energy of the backscattered laser light of an active sensor. These images provide additional and useful information about the local area which might not always be represented in the range measurements [25].

Kang [26] proposed a point cloud registration method using panoramic intensity images. This method included pairwise image matching by feature extraction. In subsequent research, Akca [27] showed that intensity images provided good supplementary information when identifying a reliable solution for matching surfaces with complex shapes. Al-Manasir and Fraser [28] proposed a registration procedure for terrestrial lidar data using photogrammetric orientation parameters of lidar stations. The approach is based on the extraction of SIFT features as reliable feature points. Wang and Brenner [29] considered not only the gray values, but also the surface geometric properties of the scale-invariant feature transformation (SIFT) feature descriptor. The use of SIFT feature detection in the intensity image of a range camera which is then used in the corresponding range image to identify the 3D location of those pixels was shown by Zhou et al. [30].

Weinmann et al. [25] proposed the fast, accurate and robust RANSAC-based registration scheme, including the EPnP algorithm, to estimate the coarse transformation parameters from the 3D-to-2D correspondences. After the extraction of characteristic 2D points based on SIFT features, these points are projected into 3D space by using interpolated range information.

This paper presents a method for automatic image-based registration of terrestrial lidar data. Radiometric and geometric information are utilized for estimating the transformation parameters between two point clouds. Various filters are applied to the intensity images to reduce noise, which increase the number of key points found by the SIFT method. Rigid body transformation parameters which are used as input in subsequent iterations are determined based on initial key points. The closest-to-next-closest (CTNC) SIFT ratio is relaxed to identify more key points and improve geometrical distribution. Outliers among these key points are removed by random sample consensus (RANSAC) during rigid body transformation [31]. Fig. 1 shows the research and experiment flow. This can be subdivided into two major parts: pairwise registration and global registration. The transformation parameters from pairwise registration are compared with the results derived from commercial software. Also, we compared the ICP algorithm with Generalized Procrustes Analysis (GPA) result using a reference point from the suggested method in global registration. The presented approach reduces the processing speed for the registration of large point clouds and performs a marker-less automatic registration without the need for any prior knowledge.

The paper is organized as follows. In Section 2, a proposed registration method is explained in detail. Section 3 shows three experimental results and provides a technical discussion. A final section provides an outline to some conclusions.

Table 1
Wavelets properties.

Family name	Short name	Property	Vanishing moments
Bi-orthogonal	BiorNr.Nd	Bi-orthogonal, symmetry	Nr
Coiflets	CoifN	Orthogonal, near symmetry	2 N
Daubechies	DbN	Orthogonal, asymmetry	N