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Automated registration of multi-view point clouds using sphere targets

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ABSTRACT

This paper addresses the problem of automated registration of multi-view point clouds generated by a 3D scanner using sphere targets. First, sphere targets are detected from each point cloud. The centroids of the detected targets in each point cloud are then used for rough registration. Congruent triangles are computed from the centroids for the correspondence among them, with which a rigid body transformation is obtained to bring the two point clouds together as closely as possible. After the initial registration, the two point clouds are further registered by refining the position and orientation of the point clouds using the underlying geometric shapes of the targets. These registration steps are integrated into one system that allows two input point clouds automatically registered with no user intervention. Real examples are used to demonstrate the performance of the point cloud registration.

1. Introduction

Measuring the 3D shape of an object is frequently considered in recent manufacturing processes to maintain the quality of products and to control the fabrication process. It is more important in fabrication processes when multiple parts are assembled. The actual 3D geometric shape of each part can be compared with its CAD (Computer Aided Design) model in advance to identify any potential problem in the assembly and correct it if necessary [1]. In the shipbuilding industry, such demand is growing. A ship or an offshore structure is a custom-ordered product, and few standardized parts are used to build a ship. This means that every part should be uniquely designed and fabricated, and the accurate assembly of the parts is critical for the quality of the final product. To achieve the desired quality, the actual shapes of the fabricated parts need to be evaluated against their CAD models to verify that the models have been made accurately. Here, an efficient method to acquire the 3D shape is to use a laser-based 3D scanner.

A 3D scanner is a *line-of-sight* device. Moreover, the field of view that the scanner covers is limited. Therefore, multiple scans in different positions and directions are typically required to scan a large object. The acquired point clouds must be merged into one data set for correct representation of the shape of the object. The merged point clouds, however, fail to represent the shape of the object because each point cloud is defined with respect to a different coordinate system, as illustrated in Fig. 1. Fig. 1(a) and (b) show two point clouds measured from two different locations and directions. Merging the measured point clouds naively with respect to one reference coordinate system produces misaligned point sets as illustrated in Fig. 1(c). The circled parts in Fig. 1(a) and (b), which should be the same object, are not aligned and instead produce two separate objects. Therefore, aligning point sets with respect to a reference coordinate system is necessary to obtain a set of points that correctly represent the shape of a target object; this process is called *registration*.

Registration is a problem that has attracted the attention of researchers from around the world, and diverse algorithms for the problem have been proposed in the related literature. With the significant growth of data in size and complexity due to the extensive use of high-performance scanners, it is difficult for a human to handle them efficiently for registration. Moreover, the linear extensions of the existing algorithms often fail to handle such data. Therefore, it is necessary to develop a method for registration that can handle data of large size robustly and efficiently and that can run automatically.

In this paper, the problem of registration of point clouds is addressed, and a novel method for automatic registration of two point clouds using sphere targets is proposed. The overall process for registration consists of filtering, sphere detection, initial registration and fine registration. The point clouds, each of which contains sphere targets, are produced by a 3D scanner. They are

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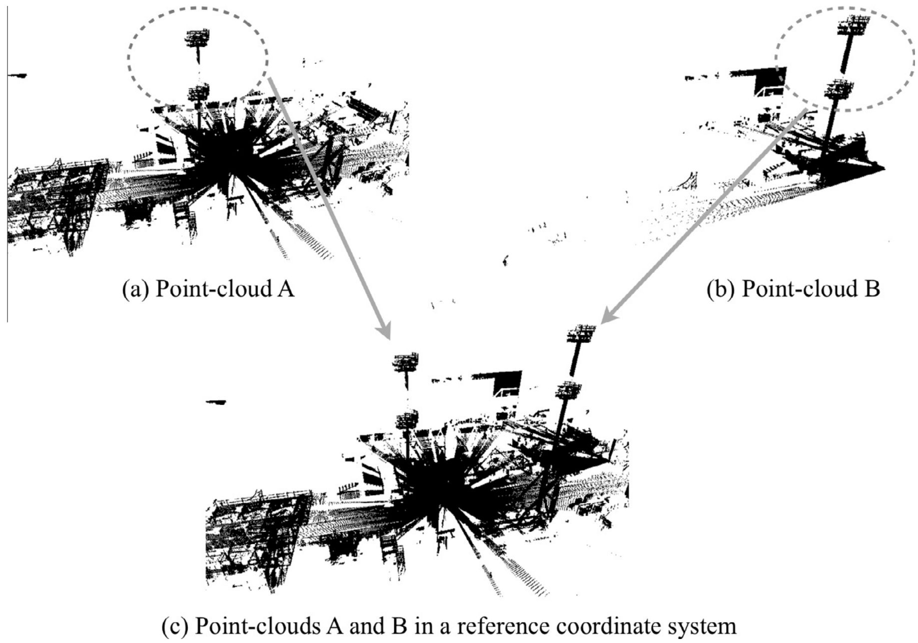

Fig. 1. Point clouds obtained by a 3D scanner. (a) Point cloud A, (b) point cloud B, and (c) point clouds A and B in a global coordinate system with no registration.

filtered to extract points for the targets using differential properties such as normal curvatures and normal vectors estimated from the point clouds. Next, the sphere targets are detected using a sphere detection method. The two point clouds are then registered using the centroids of the sphere targets. This registration is called the initial registration. Next, the positions of the point clouds are finely adjusted to minimize the registration error via a fine registration. The proposed method is different from that in [15]. First, a different filtering method is employed. In this work, differential properties are considered to be filtering criteria. This method is advantageous because more underlying geometric information is obtained, which is used for further registration and data evaluation. Second, a new method for fine registration is proposed. The method is designed to combine modeling and registration in an iterative manner, which produces an accurate registration result.

The primary contribution of this work is as follows. A novel method is proposed to register point clouds with high accuracy using a model-based iterative scheme. In most of the existing methods for the accurate registration of point clouds, the overlapping regions between two point clouds should be detected, and a registration method such as ICP is applied to those overlapping regions. However, the proposed method in this paper does not require such a condition. As long as points are determined to belong to a common object, then fine registration can be performed. Next, two minor improvements are introduced in this work. One is an improved process for detecting spheres from a point cloud. A method of filtering points using differential properties of the underlying geometry is proposed to single out candidate points for spheres, and a selective method is applied to detect spheres from the filtered points. The other is that the concept of parallel computation is introduced to accelerate the detection and registration of point clouds. The methods are implemented in such a way that parallel computation is fully exploited using multiple cores of a CPU, and a significant improvement in computation is achieved.

2. Literature review

Registration of two sets of point clouds consists of computation of the correspondence and the best rigid body transformation. Such computation can be performed using the iterative closest point method in [2]. Since its introduction in the literature, many variants, such as [3–10], have been proposed to improve the performance of the original ICP (Iterative Closest Point) method. There are other types of registration that do not belong to the category of ICP methods. Masuda [11] proposed a method for registration of multiple range images using signed distance fields. Pottmann et al. [12] proposed a method for registration based on the geometric optimization framework of squared distance minimization. A comparative study on the registration of range images was performed in [13]. However, computing the overlapped region and common features is a difficult task, and efficiency in registration can decrease as the number of points increases.

To solve this problem, a target-based approach can be considered. Pre-defined targets are attached to an object, and a scanner scans the object as well as the targets to produce point clouds. Next, the targets are detected from the point clouds and then used to find the correspondence for registration. In [14], three different types of targets (fixed paper, paddle, and spheres) considered in practice were analyzed for registration accuracy. One of the conclusions of the analysis was that the sphere targets are desirable for 3D laser scanning. In [15], a system was proposed for registering point clouds using sphere targets. The system consists of two steps: point processing and registration. The point processing unit filters input points to obtain candidate points on the targets. The points are then fitted with spheres using a quasi-Newton optimization procedure. The centroids of the detected spheres are then used for registration. This method, however, is limited because of three aspects. First, the input points should be pre-processed. Specifically, unstructured data points should be mapped to points on a regular grid, which is an additional step. Moreover, a relatively strong condition that there should exist some free space around the targets is imposed for sphere target placements. Finally, this algorithm only considers a rough registration because sphere detection may not be robust and accurate. This means that a high precision of registration is needed in actual applications.

Automated registration of two point clouds requires the step of finding correspondences between them. For this computation, PCA (Principal Component Analysis) values [16], geometric properties