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Local to global registration of multi-view range scans using spanning tree

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ABSTRACT

Registration is a prerequisite in 3-dimensional reconstruction. This paper proposes an effective approach for multi-view registration of range scans using a spanning tree. Given initially posed scans, it is necessary to estimate the overlap percentage for each scan pair and construct a spanning tree. Based on this tree, pairwise registration can be sequentially used to align the root scan and its directly connected scans. Then, local multi-view registration is applied to the root scan and its connected scans, which must be merged into the root scan after the local registration. By updating the spanning tree, the new root scan with its connected scans can be recursively processed and merged until all scans are merged into one scan. Finally, global registration can be applied to all scans to reduce the accumulated errors generated from scan merging. Experimental results confirm that the proposed approach can achieve multi-view registration with excellent performances.

1. Introduction

The 3-dimensional (3D) model or scene reconstruction has attracted significant attention in many domains including computer vision [1], computer graphics [2], robotics [3] and medical image processing [4,5]. At present, the development of 3D acquisition devices has made it possible to capture accurate and dense range scans from real objects. Owing to the limited field of view and self-occlusion, an object cannot be captured in its entirety from a single viewpoint by one acquisition device. Accordingly, multi-view scans must be acquired from different viewpoints to capture the entire object and each of them has its own reference frame. For 3D reconstruction, these scans must be transformed into an unified co-ordinate system by multi-view registration [6]. Therefore, multi-view registration is a prerequisite for 3D model reconstruction.

For the registration problem, the most popular solution is the iterative closest point (ICP) algorithm [7], which can achieve rigid registration of absolutely overlapping scans with good accuracy. However, it cannot address the registration of partially overlapping scans, which is a common problem in practical applications. Further, it is widely known to be susceptible to local minima. To address the front issue, Chetverikov et al. [8] proposed the trimmed ICP (TrICP) algorithm, which introduces an overlap parameter into a least square function to automatically trim outliers and obtains accurate results for registration of partially overlapping scans. Nevertheless, this approach is time-consuming. Subsequently, Phillips et al. [9] proposed the improved TrICP algorithm with good efficiency. To avoid local minima, a genetic algorithm [10,11] or

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particle filter [12] has been utilized to determine the optimal solution for the registration problem. These approaches are all pairwise registration methods, which are the basis of the majority of multi-view registration.

Compared with pairwise registration, multi-view registration is somewhat more difficult owing to the extensive number of registration parameters. For this difficult problem, Chen and Medioni proposed the primary approach [13], which repeatedly aligns two scans and merges them into one until all scans are integrated into the entire model. Although this approach is considerably effective, it suffers from an error accumulation problem. To address this issue, Bergevin [14] proposed a multi-view registration approach based on the ICP algorithm. For one point in each scan, this approach must assign a corresponding point in each other scan and then refine registration parameters for each scan by the minimization of residual errors. As this approach simultaneously considers all other scans to refine registration parameters of one scan, it can overcome the error accumulation problem. However, it is inefficient owing to the establishment of many correspondences for each point in one scan. Subsequently, the multi-z-buffer technique is used to accelerate the establishment of the point-to-point correspondence [15]. Multi-view registration can also be viewed as a graph optimization problem [16]. In this approach, one scan and its rigid transformation to another scan can be viewed as a node and an edge, respectively. Subsequently, multi-view registration can be casted into a diffusion of rigid transformations over the graph of adjacent scans. As these approaches are not required to update point correspondences, they are efficient. However, they cannot really reduce the error; rather only transfer the registration errors between coordinate frames.

To guarantee accurate results for multi-view registration, these above-mentioned approaches must be provided with suitable initial parameters, which can be estimated by some coarse registration approaches [17,18]. Given appropriate initial parameters, probabilistic approaches have been proposed to solve the problem of multi-view registration. By viewing scans as realizations of a Gaussian mixture (GMM), Georgios et al. [19] casted the registration problem into a clustering problem, which can be solved by the Expectation-Maximization (EM) algorithm. Mateo et al. [20] proposed a multi-view registration approach within the Bayesian framework. By considering pairwise correspondences as missing data, multi-view registration can be viewed as the inferred problem of maximizing a posteriori, which can also be solved by using the EM algorithm. Although this kind of approach may obtain accurate results for multi-view registration, it is time-consuming.

Recently, Govindu and Pooja introduced the motion-averaging algorithm [21] to solve the registration of multi-view range scans. Given a set of initially posed scans, it first employs the ICP algorithm to estimate relative motions (rigid transformations) of scan pairs and views them as the input to the motion-averaging algorithm to calculate accurate results for multi-view registration. Although this approach is effective, its accuracy must be further improved owing to the adoption of the ICP algorithm for relative motion estimation. Subsequently, Li et al. [22] proposed an improved approach for multi-view registration with the motion-averaging algorithm. To obtain an accurate estimation of the relative motion, it first estimates the overlap percentage for each scan pair and then applies the TrICP algorithm to these scan pairs with high overlap percentages. Zhu et al. [23] proposed the coarse-to-fine approach for multi-view registration. In this approach, initial registration parameters must be provided in advance and each scan, except for the first one, must be sequentially pairwise registered to the coarse model integrated by the other scans. Then, the output of pairwise registration can be immediately returned to refine the coarse model for the registration of the other scans. Although this approach is effective, it is sensitive to initial registration parameters.

In this paper, a robust approach is proposed for multi-view registration of initially posed scans using a spanning tree. Given initially posed scans, it first estimates the overlap percentage for each scan pair involved in the multi-view registration. According to the estimated overlap percentages, it constructs a spanning tree, where each node denotes a scan and each arc indicates the connected scan pair including high overlap percentage. Based on the spanning tree, a local multi-view registration approach can be applied to the root scan and all scans located in the second level of the spanning tree. Subsequently, all scans located in the second level can be merged into the root scan and the spanning tree can be correspondingly updated. Then, the new root scan and its directly connected scans can be recursively processed and merged until all scans are merged into the root scan. Finally, a global multi-view registration approach must be applied to all the scans to reduce the accumulative errors generated from the local multi-view registration. After the global registration, accurate results can be obtained for multi-view registration.

This paper is organized as follows. Section 2 briefly reviews some related algorithms. In Section 3, the proposed approach is presented for multi-view registration of initially posed scans. In Section 4, the proposed approach is tested and evaluated on public datasets. Finally, conclusions are drawn in Section 5.

2. Preliminaries

This section presents a brief review of the TrICP algorithm for pairwise registration and the coarse-to-fine approach for multi-view registration.

2.1. TrICP algorithm

Although the TrICP algorithm is a pairwise registration approach, it is the basis of the proposed approach. Suppose there are two partially overlapping scans, the data shape and the model shape. The goal of registration is to determine the optimal transformation between these two scans. This pairwise registration problem can be solved using the trimmed ICP algorithm [8,9], which achieves registration in the manner of the ICP algorithm using iterations. Given initial parameters, the following