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Range image registration based on 2D synthetic images

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ABSTRACT

Proposed in this paper is a new procedure of range image (point cloud) registration reducing the risk of the original Iterative Closest Point (ICP) algorithm which gets stuck in a local minimum. To reduce this risk, it is essential to achieve the fine initial alignment of the given range images. The proposed procedure employs a 2D image registration method to achieve the fine initial alignment instead of a 3D feature based registration method. Although the 2D image registration method has also the risk of mismatching, we minimize the risk by increasing the number of test cases and selecting the answer that gains the most votes. To generate effective test cases, multiple 2D images are synthetized from the given range images by varying the orientation and resolution. The proposed procedure is implemented and tested for various examples, with experimental results showing that it outperforms existing methods.

1. Introduction

A 3D scanner is a device to create a point cloud data by scanning a real-world object. The collected point clouds can then be used to generate a 3D digital model in a process called reconstruction. Although there is a variety of technologies available for acquiring the shape of a real-world object, Structured Light Systems (SLS) are currently most popular due to their fast measuring speed, simple optical arrangement, non-contact measurement, moderate accuracy, low cost, and ability to function under varying ambient light conditions [1–5]. Fig. 1 shows a general configuration of an SLS consisting of a projector and cameras. The projector illuminates the object with a structured light source, and the cameras capture the scene to produce 3D range image. The range image can be considered as a point cloud containing the spatial coordinates for the surface points of the object.

Since a SLS can measure only the area visible from a specific scanning orientation, the full reconstruction of a real-world object requires three major steps: (1) acquiring multiple range images from different viewpoints to cover the entire surface area of the given object, (2) applying a 3D registration process to the acquired range images, and (3) merging the multiple range images to generate a 3D digital model. This paper is focusing on the second step, the registration of range images, of which the accuracy is very important to ensure the quality of the reconstructed 3D model.

The most common method for 3D registration is the well-known Iterative Closest Point (ICP) algorithm [6], which minimizes the distance between two point clouds. The ICP algorithm works for a pair of point clouds, a target and a source. The target point cloud is kept fixed, while the source point cloud is transformed (with a combination of translation and rotation) to minimize the distance between them.

The original ICP algorithm [6] sets the closest points as the correspondence and optimizes the root mean squared deviations. Chen [7] employed point-plane distance by estimating the normal vectors of the point clouds. Ever since then, there have been various researches on the ICP algorithm [8], and they can be roughly categorized into five groups: improving computing speed through efficient correspondence detection [9–14], improving accuracy by defining the appropriate energy function [15–20], combining existing algorithms [21–23], finding correspondence by using probability [19,24,25], and eliminating correspondence outliers [26,27].

Although the ICP algorithm usually offers good results, it has the risk of becoming stuck in a local minimum, especially in cases where there is only a rough initial alignment between the target and the source point clouds. As shown in Fig. 2(a), the ICP algorithm works well when the two point clouds are within an acceptable range in terms of their position and orientation. The ICP algorithm can become stuck in a local minimum, however, if the two point clouds are outside this acceptable range, as shown in Fig. 2(b).

To overcome this problem, many researchers have investigated methods to achieve the fine initial alignment of the two point clouds [28]. Most have focused on the use of 3D features in the given point clouds. Previous research on initial alignment can be classified by the type of 3D feature used: curves [29,30], feature histograms (FPFH) [31], 4-point congruent sets [32], and spin images [33]. Nevertheless, these initial alignment methods using 3D

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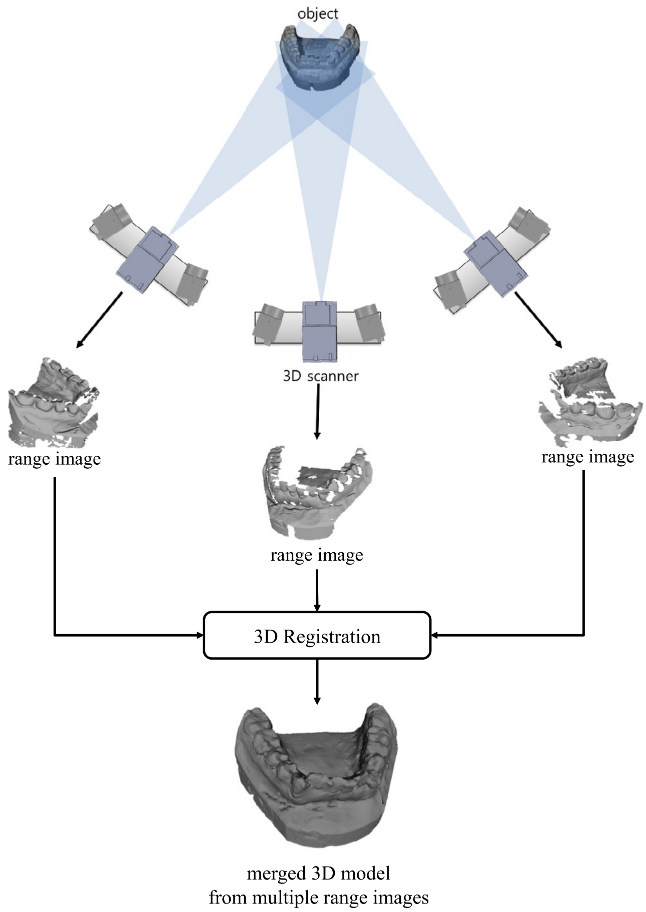

Fig. 1. Configuration of a structured light system.

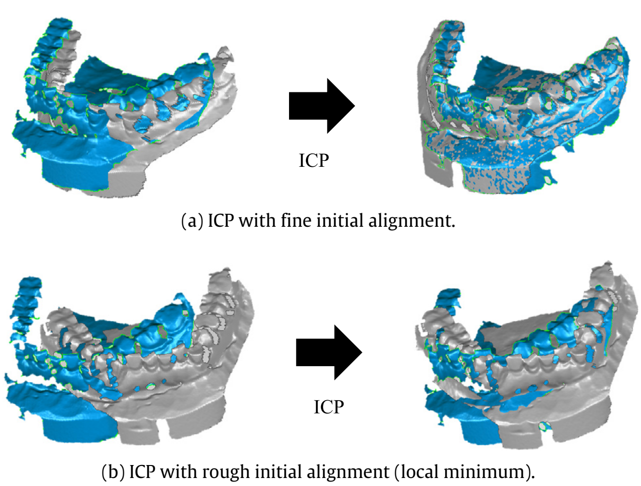

Fig. 2. Limitation of the ICP algorithm.

features may not generate useful results when the scanned data has occlusions or a consistent curved geometry such as a cylinder or a cube.

As the relationship between a 2D image and a 3D point cloud can be obtained, the matching relations of 2D features can be used to achieve the initial alignment. Since 2D image registration methods [34,35] use only the texture and the intensity of the image for calculations, they are much faster than 3D registration and can find 2D features robustly. From this reason, some authors proposed the method using 2D images in 3D registration [36,37]. However, these methods perform poorly if the viewpoint of the camera moves beyond the threshold degree, because the scene, the geometry, and the intensity of the image changes. Moreover, the algorithm can only perform on a flat and textured surface. This is one of the fundamental problems of 2D image registration algorithms. Therefore, there always exists a risk that registration may return incorrect matching relations, and currently no solution has been found that can eliminate this problem completely.

The objective of this paper is to develop a new registration procedure that minimizes the risk faced by the original ICP algorithm, that of becoming stuck in a local minimum. To reduce this risk, it is necessary to achieve the fine initial alignment of the range images. Our approach is to reduce the risk of using 2D registration by generating multiple pairs of synthetic images from the given range images by changing their resolution and orientation in order to obtain a large number of test cases. Each pair contains two synthetic images, one from the source range image and the other from the target range image. For each pair of 2D synthetic images, we can obtain matching relations using the 2D registration. The proposed approach selects the matching relations which obtain the most votes from the multiple pairs of 2D synthetic images.

As shown in Fig. 3, the proposed registration procedure consists of five steps: (1) synthetizing a 2D image set from both the target range image and the source range image, (2) applying 2D registration to the test cases, each of which is a pair of synthetic images, one from the target image set and the other from the source image set, (3) finding the matching relations that obtain the most votes from the test cases and removing the outliers, (4) transforming the source range image to achieve fine initial alignment, and (5) applying the ICP algorithm to the aligned range images.

The remainder of this paper is organized as follows. Section 2 addresses the proposed approach to the fine initial alignment of given range images with image registration. Section 3 describes the details and the overall procedure of the proposed algorithm, and Section 4 shows the results of the experimentation. Finally, concluding remarks are given in Section 5.

2. Approach to the fine initial alignment of range images with image registration

As mentioned earlier, initial alignment algorithms work on two range images (a target point cloud and a source point cloud). Since a range image is generated from 2D images from an SLS, the correspondence between a 2D image pixel and a 3D point cloud vertex can be obtained. Therefore, 2D image registration can be used to achieve the initial alignment of the 3D data. The 2D image registration algorithm works on two given images (a source image and a target image), and consists of two major steps: (1) finding two sets of interesting points from both images using the detector, and (2) finding matching relations between the interesting points using the descriptor. This matching relations can be used to calculate the transformation matrix for the initial alignment. One of the most popular 2D image registration methods is the well-known Speed Up Robust Features (SURF) algorithm [38]. SURF is based on rotation invariant features and is known to be efficient. The proposed approach employs SURF to find the correspondence between the 2D images (the source image and the target image). However, the reliability of SURF is weakened when the viewpoint changes between images, a fundamental problem of the 2D image registration algorithms.

In SURF, a Hessian corner detector is used to calculate the interesting points. The pixels with a value above the minimum threshold are considered interesting points. We set this variable to 400 [39]. Fig. 4(a) displays the interesting points according to