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A flexible method for multi-view point clouds alignment of small-size object

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ABSTRACT

Alignment is a key step of the point cloud processing. We propose a flexible, easy-implemented, low-cost alignment method for multi-view point clouds of small-size objects (≦50 cm). The method is based on the idea of rotating measurement, firstly more than three pieces of point clouds of cylinder calibration pattern are used for calibrating the center axis of a single-axis turntable in the scanner's coordinate system, so the rigid relationship of the turntable and scanner can be obtained. Then the rotation matrix can be calculated using the known angle parameter of the turntable, and finally an arbitrary view of point cloud can be easily transformed into a unified coordinate system by the rotation transformation. Our method does not require overlapping feature or co-markers constraint between point clouds, and only the rigid relationship between the scanner and the turntable and rotate angle need to be known. More importantly, the calibration of the turntable is flexible and low-cost: (1) the calibration pattern can be a common cylinder objects (such as cup, paper tube, caddy, water pipe, etc.), (2) the turntable and the alignment method can be integrated with variety 3-D scanners. The result of experiment has demonstrated the efficiency and automatic characteristic of the alignment method compared with other two convention methods.

1. Introduction

In recent years, 3-D scanning and measurement techniques have got a rapid development, such as laser scanning technology, stereo vision technology, and structured light scanning technology. which have been widely used in reverse engineering, heritage, cosmetic restoration, industrial measurement and so on. In the above applications, multi-view scans are often considered in order to obtain a complete surface shape and overcome the limited view of the scanning device. These multi-view point clouds need to be aligned before subsequent processing (such as wrapping and shaping), that means, point clouds are transformed into a global coordinate system by translation and rotation operations. There are three common forms of point cloud alignment: manual alignment, instrument-dependent alignment, and automatic alignment [1–3]. Manual alignment relies on manual editing to archive transformation between multi-view point clouds, while the method is less efficient and requires common features between point clouds. Instrument-dependent alignment extends measurement range through a precision rotating platform, theodolites, laser tracker and other devices, and transforms multi-view point cloud into a unified

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coordinate system by the rigid relationship between auxiliary devices and the scanner. Such a method does not require common features between point clouds. The alignment process is fast but requires precise calibration for the hardware or manually pasting co-markers. Automatic alignment is executed by a certain error criteria or statistical regularity between two point clouds in order to eliminate the dislocation. Such a method requires common features between point clouds, and in some cases, may require some manual intervention. Most of the existing automatic alignment algorithm is based on Besl's famous method- iterative closest point method (ICP) [4], but the efficiency and stability of the traditional ICP algorithm are relatively low, so many improved algorithms [5–10] have appeared, but these algorithms exist shortcomings such as long operation time and low accuracy for objects with flat or low-curvature surface.

For small-size objects (such as small parts, teeth and cultural relics), the alignment accuracy will be low because of the deformation of the co-markers pasted on the small area and low curvature of the surface [11]. Co-markers method may be failed for objects which co-markers is not allowed to posted on (such as antiques). Manual or automatic alignment is also not suitable for small-size objects because there may be little common features while both of them need obvious common feature between point clouds in order to get a good alignment. In addition, small-size objects with repetitive or symmetrical shape have a higher proportion, such as vases and cups, which happens to be the degenerate case of automatic alignment algorithms. Therefore, for the alignment of point clouds of small size objects, a very natural idea is that if the rigid motion during the scanning is known, it is very easy to transform multi-view point clouds into a unified coordinate system. There are two commonly forms of rigid motion for point cloud alignment: (1) a mechanical device for accurate positioning, such as articulated arm for flexible scanning measurement [12,13], (2) using multiple degree of freedom motion platform (such as translation platform and rotating platforms) for scanning. The former one is high cost and with complex structure, usually is used for high precision single point measurement, which is not suitable for dense point cloud alignment. One form of the latter—rotating motion of single or multiple axis has been widely used in surface model reconstruction [14,15]. We consider that single-axis rotational motion solution is a good one for multi-view point cloud alignment because of the size and symmetry features of small-size objects.

A turntable has been designed in our paper shown in Fig. 1. The rigid relationship between the turntable and the scanner is calculated by calibration process, then the measurement object is placed on the turntable whose rotation angle and frequency has been set according to the complexity of the object, and next the turntable is driven by software to rotate as the set angle and frequency meanwhile the scanner captures the surface point cloud at the current view. Make sure there is no relative movement between the object and the turntable during the capturing stage. The rotation matrix can be built according to the rigid relationship between the turntable and the scanner, and then the rotation matrix is used to transform multi-view point clouds into a unified coordinate system.

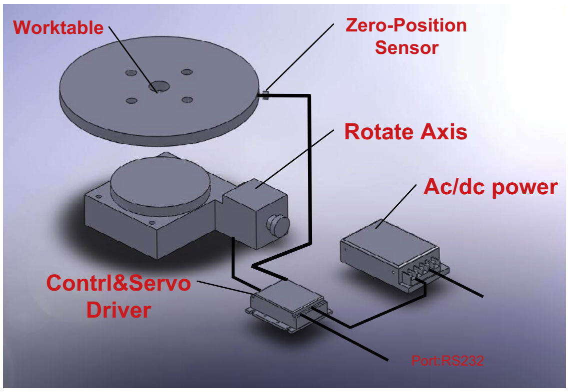

Fig. 1. Structure of the turntable. The main components are: (1) one working table, (2) one zero position sensor, (3) one rotate axis, (4) one ac/dc power, (5) one servo controller connected by the RS232 cable to upper monitor.

The key step of alignment method proposed in our paper is the calibration of rigid relationship between the turntable and the scanner. Meanwhile our method is flexible that means it can be used in any 3-D measurement system whose output is point cloud. Therefore, the source data used in calibration is the surface point cloud of a cylindrical pattern. Specifically, the turntable is taken as a spatial axis in the global coordinate system which provided by the scanner. The motion of the object on the turntable can be taken as a pure rotation around this spatial axis. If the geometrical constraint of multi-view objects is known, the parameters of the spatial axis can be calculated so the calibration of the turntable is done. Such a geometric constraint is provided by a cylindrical calibration pattern, which is commonly used in daily life (such as glass, paper tube and pipe), and the cylinder constraint is relatively simple and easy to implement. In the experimental part, the calibration pattern is a piece of water pipe, which is low cost and easy to obtain.

There are three aspects affecting the accuracy of the calibration parameter in our method: (1) the accuracy of the point cloud; (2) the accuracy of the calibration algorithm; (3) the accuracy of the rotate angle of the turntable. The last item can be ensured by using a high accuracy servomotor, so its' error can be ignored in actual implementation. A rigorous calibration algorithm is proposed in our paper, which can converge fast and achieve a high precision result. We can achieve an ideal alignment effect of multi-view point clouds as long as the accuracy of point cloud is high enough, which is ensured by the scanner.

In summary, the main contributions of our paper are as following:

(1) Designed a flexible, easy to implement, low-cost alignment method for multi-view point clouds.
(2) Designed a set of rotating equipment, which can very easily integrated into any kind of 3-D scanner whose output result is point cloud data.