3D Point Cloud Registration Algorithm Based on Central Vector

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Abstract

In order to solve the registration problem of three-dimensional point cloud in the case of disorder, data occlusion and noise interference, a point cloud registration algorithm based on central vector is proposed. Firstly, the central vectors of two point clouds are solved, and then the objective optimization function is constructed, Finally, particle swarm optimization algorithm is used to solve the rotation matrix and translation vector respectively, so as to achieve point cloud registration. In the simulation experiment, the algorithm can realize registration quickly and has good stability.

Keywords

Point cloud registration, Central vector, Particle swarm optimization, Noise.

1. Introduction

With the rapid development of point cloud registration technology, point cloud registration has been widely used in three-dimensional reconstruction, product defect detection and machine vision. Three-dimensional point cloud registration is the process of splicing and transforming part of point cloud data collected by the same object from different perspectives, and finally obtaining a complete three-dimensional point cloud in a unified coordinate system. Among many point cloud registration algorithms, Iterative Closest Points (ICP) proposed by Besl[1] et al. in 1992 is the most widely used. Based on the four-element operation model, this method searches for the nearest correspondence point between two points cloud and calculates its optimal transformation matrix. The algorithm is simple to implement and has high accuracy, but the calculation is complex and the iteration time is too long. It relies too much on the better initial value and easily falls into the local minimum value.

Therefore, in order to improve the registration speed and accuracy of ICP algorithm effectively. He et al. [2] proposed a Principal Component Analysis (PCA). This method provides better initial values for ICP algorithm by transforming high-dimensional data into low-dimensional subspace. However, this algorithm can not get better initial values when point cloud data is noisy. Ying et al. [3] proposed a Scale-ICP algorithm based on 7-dimensional space iteration. This algorithm improves the convergence speed of ICP, and can be used for registration of different scales, but its stability is poor. Sharp et al. [4] proposed an ICPIF (Iterative Closest Points using Invariant Features) algorithm, which can effectively improve the accuracy of finding point pairs by determining point pairs through Euclidean space invariants (curvature, moment invariants, spherical harmonic function invariants, etc.) of the target under test. Yang et al. [5-6] proposed a global optimal solution algorithm (Go-ICP). This algorithm directly realizes fine registration by combining global optimization with ICP. It accelerates the convergence speed while guaranteeing the registration accuracy, but easily falls into local minimum. In literature [7-8], a registration method based on genetic algorithm (GA) is proposed. This method transforms point cloud into triangular network to search the nearest point by genetic algorithm, so as to realize point cloud registration. However, the registration accuracy needs to be improved, and it is generally used for initial registration.

To solve the above problems, a point cloud registration method based on central vector is proposed. Firstly, the central vectors of two point clouds are solved separately, and then the objective optimization function is constructed. Finally, particle swarm optimization algorithm is used to solve the rotation matrix and translation vector respectively, so as to achieve point cloud registration. The simulation results show that when the point cloud is in disorder and noisy environment, the proposed algorithm can achieve fast registration and has good stability.

2. Initial registration of point clouds based on central vector

2.1 Principle of point cloud registration

Traditional registration algorithms usually use classical ICP algorithm. The rigid geometric transformation between the target point cloud $P = \{p_1, p_2, \cdots, p_n\}$ and the point cloud to be registered $Q = \{q_1, q_2, \cdots, q_m\}$ is expressed in Formula 1.

$$p_i = Rq_j + T, i = 1, 2, \cdots, n; j = 1, 2, \cdots, m(m=n) \tag{1}$$

In the formula, $R \in \mathbb{R}^{3\times3}$ is a rotation matrix, and $R^T R = I$;$T \in \mathbb{R}^{3\times1}$ is a translation vector. Traditional ICP algorithm has a high requirement for the initial value of registration point cloud. Without a better initial value, ICP algorithm is difficult to achieve accurate registration. From equation (1), the following relations can be obtained

$$\sum_{i=1}^{n} p_i = \sum_{j=1}^{m} \left(Rq_j + T\right) \tag{2}$$

The central vector of two sets of point clouds is

$$\bar{P} = \sum_{i=1}^{n} p_i / n, \bar{Q} = \sum_{j=1}^{m} q_j / m \tag{3}$$

By introducing formula 3 into formula 2, we can deduce that

$$\bar{P}=R\bar{Q} + T \tag{4}$$

By synthesizing the above relations, the following objective functions can be obtained

$$J = \underset{R,T}{\arg\min} \left\| \bar{P}\text{-}\left(R\bar{Q} + T\right) \right\|_2^2 \tag{5}$$

The optimization algorithm is used to optimize the formula until it converges.

2.2 Particle Swarm Optimization (PSO)

Particle Swarm Optimization (PSO) does not have the crossover and mutation operation of genetic algorithm. It relies on the particle speed to complete the search. In the iterative evolution, only the optimal particle transmits the information to other particles, and the search speed is fast. Therefore, particle swarm optimization (PSO) is used to optimize the objective function to achieve point cloud registration.

Suppose that in a D-dimensional target search space, there is a community of N particles, in which the particle i is represented as a D-dimensional vector, and the velocity of particle i at t time is updated as follows:

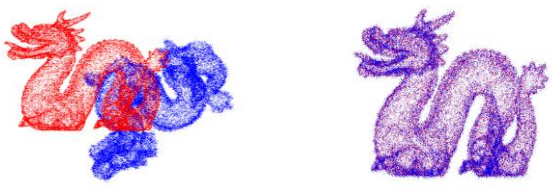
$$V_{iD}^{(t+1)} = V_{iD}^{(t)} + c_1 r_1 \left(p_{iD}^{(t)} - R_{iD}^{(t)}\right) + c_2 r_2 \left(p_{gD}^{(t)} - R_{iD}^{(t)}\right), i = 1, 2, \cdots, N \tag{6}$$

Where $V_{iD}^{(t)}$ is the velocity change of the particle i at t time; c_1, c_2 are positive constants, named self-cognition and social knowledge, which means that the abilities of learning from particle itself and the effects from the whole particle swarm respectively; r_1, r_2 are two random numbers between 0 and 1, which reflect the randomness of PSO for global optimization; $p_{iD}^{(t)}$ is the best place in the history that the particle i has experienced at t time; $p_{gD}^{(t)}$ is the best place that all particles in the group have experienced at t time; $R_{iD}^{(t)}$ is the place of the particle i at t time. After the speed update, the position of the current moment is updated. The PSO location is updated as follows:

$$R_{iD}^{(t+1)} = R_{iD}^{(t)} + V_{iD}^{(t+1)} \tag{7}$$

3. Experimental simulation

The classical Dragon (43695 points) three-dimensional point cloud data provided by Stanford University were used for experimental simulation. The simulation experiment is carried out under the version of MATLAB 2017a, i5-3470CPU@3.20GHz quad-core processor and GT620. The registration data Dragon point cloud (blue) is rotated and shifted randomly, and 20 dB white Gaussian noise is added. The initial state of the target point cloud (red) and the point cloud to be registered (blue) is shown in Fig. 1 (a), and the effect of the algorithm is shown in Fig. 1 (b).



(a) (b)

Fig 1. Point cloud status chart (a) Initial state; (b) Registration state

The registration accuracy and time of this algorithm are shown in Table 1.

Table 1 Registration accuracy and time

MSE/mm	Time/s
7.7029e-04	11.3

From Table 1 (b), we can see that the registration effect of this algorithm is very good. As can be seen from Table 1, the registration accuracy of this algorithm is high and the registration time is fast.

4. Conclusion

In this paper, a registration algorithm based on central vector is proposed for scattered point clouds. This algorithm can automatically register two sets of point cloud data with partial overlap and noise without any prior information. Particle swarm optimization (PSO) is used to optimize the objective function of the central vector to achieve point cloud registration. The experimental results show that the proposed algorithm has good robustness.

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