Research on Optimization of Point Cloud Registration ICP Algorithm

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Abstract Point cloud data, as a basis for the three-dimensional data types has attracted more and more attention these years. compared with other types of three-dimensional data, point cloud data can be collected by simple ways, and it contains surface texture, surface color, and other types of features on the surface of the target object. Recently, in the field of cloud data processing, many new point cloud processing methods have been proposed on the basis of existed theory, among which, the most notable one is the newly proposed algorithm in the field of point cloud registration. In this paper, an improved point cloud registration algorithm based on classical ICP algorithm is proposed. In the classical ICP algorithm, the main part which limit the efficiency of the algorithm is the iterative search process of the corresponding point, the new algorithm proposed in this paper uses the 4-point coincidence algorithm to accelerate the corresponding point search process as an improvement to the classical ICP algorithm, and to verify its improvement by experiment.

Keywords point cloud data; point cloud registration; ICP algorithm; 4-point consistent algorithm

1 Introduction

With the development of 3D scanning technology and related hardware manufacturing technology, there are a variety of cheap and useful scanning equipment could be used for documenting high-precision 3D data. And the acquired 3D can be applied to many areas including digital city, intelligent transportation, game, films [1] and so on. Point cloud data is a basic three-dimensional data type, it could be obtained through a variety of scanning equipment by directly scan, and retain a large number of surface features related to the target object, and thus it applicate in the machine vision, 3D printing, reverse engineering and many other fields [2]. The point cloud data obtained from direct scanning is derived from the massive surface measurement point on the surface of the target object [3]. The surface measurement point can achieve the accurate performance of the surface features of the target objects [4]. In practice, however, the point cloud data about the target object, which is simply obtained by the three-dimensional scanning, is often disturbed by a variety of factors, among them, due to differences in the scanning angle, which caused by the difference between the different points of view and the applicable coordinate system, could have a huge impact on the accuracy and operability of the overall point cloud data. Therefore, it is necessary to register the obtained point cloud data so that the point cloud data which sets at different angles will apply to the same three-dimensional coordinate system.

Point cloud registration refers to the need to deal with the set of points to a series of rotation, translation and other operations to transform the point set to the target perspective [5], that is, transfer point cloud data from different scanning angles to the same three-dimensional coordinates. The study of point cloud registration began in the 1980s and has a breakthrough in the 1990s. In 1992, Besl and Mckay of General Motors Laboratory proposed the Iterative Closest Point (ICP) algorithm [6], the algorithm obtains the transformation parameters of the point set transformation by collecting and analyzing the geometric and geometric distances between the corresponding points between two or several point sets, and further derives the transformation matrix of the point set, transforms the set of points by transform matrix and makes the final result reach the precision requirement. The algorithm is now a classic algorithm in the field of point cloud registration. At present, many new 3D point cloud registration algorithms are actually improved types of ICP algorithm. But with the expansion of point cloud data applications, the classic ICP algorithm has been unable to adapt to the current operational requirements, and gradually exposed many of its design shortcomings [7]. Since the classical ICP algorithm is based on the iterative algorithm, the processing speed can be very high, but the processing efficiency of the algorithm can also be affected by the iterative process, and the requirement of the classical ICP for the initial point cloud dataset is difficult to achieve in the real scene, therefore, the corresponding processing module in the ICP algorithm needs to be improved to accommodate the current point cloud registration processing requirements.

2 ICP algorithm and the improved method

At present, the general-purpose three-dimensional scanner equipment has realized that the surface characteristic of the target object can be collected with high precision and converted into three-dimensional point cloud form [8]. At the same time, considering the various problems that may be encountered on the actual use, such as limited field of view, the surface of the object is complex, ambient light interference, scanners need to go through a number of different angles under the scan to get all the objects surface 3D information [9]. In order to process point cloud data in the same coordinate system, it is necessary to register the point cloud data at different angles [10].

2.1 Classic ICP algorithm

The specific operation of the point cloud registration is to transform it into a unified three-dimensional coordinate system by rotating the pan-point data at different viewing angles or coordinate systems. The main form of the registration operation is the conversion of the point cloud data coordinate system, and then the fitting operation of several points is completed, so that the scattered point set can be a complete set of point clouds that express the surface features of the target object. In the process of registration operation, the transformation of point set can be divided into Euclidean transformation and rigid transformation.

The main method of 3D point cloud registration operation can be expressed by equation 1:

$$P_m = M \cdot P_d + T \tag{1}$$

In equation 1, P_m and P_d are denoted by two corresponding points at two different points of view, which can be searched by iterative methods, Where the P_m belongs to the set of target points, P_d belongs to the set of points to be processed, M represents the rotation matrix for the rotation of

P_d, and T represents the translation matrix that translates P_d. It can be seen from the equation 1, in the point cloud data registration operation, the first thing need to do is quantifying and estimating geometric positional relationship between the two cloud points. And the estimate of the relationship between the corresponding points in the point cloud is the key problem in the point cloud registration operation.

The essence of the Iterative Closest Point (ICP) algorithm is an optimal iterative registration method based on the least squares method. The ICP algorithm performs iterative search and iterative transformation of the corresponding points between the point sets. The key point is the search of the corresponding point and the selection of the rotation translation matrix.

The computational idea of the ICP algorithm can be regarded as a process of minimizing the operation of the objective function as shown in Equation 2:

$$f(R,T) = \sum_{i=1}^{n} \left\| P_i^k - (RP_i + T) \right\|^2 \tag{2}$$

Where P_i represents the corresponding point to be processed, R represents the rotation matrix, T represents the translation matrix and the offset variables that need to be taken into account in the operation. It can be found from Equation 2 that the objective function calculates the sum of the Euclidean distances between the corresponding points between several point sets. From the above analysis, it can be seen that the core step of the ICP algorithm lies in the search for the corresponding point P_i and the operation of the corresponding operation matrices R and T, so that the classical ICP algorithm can be completed for the two known points to be registered Its registration operation:

(1) Find the corresponding point: Because the initial state do not know the two points between the corresponding points is punctual. Therefore, in the case of the original point cloud data, we can first set the rotation of the original rotation matrix, and then use the rotation and translation matrix to deal with the point cloud to transform, and then the original matrix transformation results obtained with the target point cloud comparison. If the distance between some points in the two point clouds is less than the set threshold (the threshold setting will be discussed below), these points can be determined as the corresponding points. The decision for the corresponding point is also the origin of the "nearest point" in the ICP (iterative nearest point) algorithm name.

(2) Optimize the *R* and *T* matrices: Through the first step of the process, we can use the *R* (rotation) matrix and *T* (translation) matrix to extract the corresponding point of the point cloud data to transform. In the classical ICP algorithm, the degree of freedom of the rotation translation matrix is only 6, but the maximum number of corresponding points are treated when the redundancy detection value needs to be considered. The best solution at the present is to use the least squares method and the like method to solve the optimal rotation of the rotation matrix.

Iterative operation: In the second step of the process, we will get the optimized rotation of the translation matrix, however, the use of this step to optimize the matrix after the point cloud rotation shift operation does not necessarily allow the point cloud to be accurately registered to the target point cloud, but because of the step of the operation, the point cloud to be processed changes, at this point, the ICP algorithm needs to return to the second step to re-select the optimal rotation translation matrix, the second step is iterated. The iteration is terminated when the Euclidean distance square sum obtained from the initial objective function 1 is lower than a certain set value, or the change amount of the rotation translation matrix is ultimately below a certain value. And then get the three-dimensional point cloud model after registration.

Based on the above steps, we can get the algorithm flow chart shown in Figure 1:

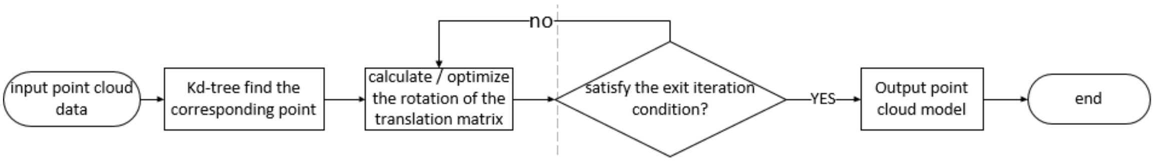


Fig. 1. Classic ICP algorithm flow chart.

2.2 Analysis of ICP Algorithm

For the classical ICP algorithm, the corresponding point search and the rotation translation matrix are optimized by using the nearest neighbor search algorithm to find the optimal pair of points, and make it to rotate the translation matrix to make it modify and Optimization, the entire process iterates until the output value reaches the iteration termination condition. It should be noted that the optimization process for the rotation translation matrix will reduce the Euclidean distance between the corresponding points of the cloud point and the target point cloud, so the rotation translation matrix optimization operation will reduce the initial target of the ICP algorithm Function of the value, which means that the ICP algorithm has convergence.

In the process of algorithm operation, it should be noted that the algorithm need to set two important parameters to ensure that the ICP algorithm can be successfully implemented, the two important parameters are the corresponding point in the search process of the adjacent distance parameters, and the iterative process of the iteration termination parameters. The choice of parameters should be based on the requirements of practical application. For example, if the accuracy of the required model is 1mm, the point pairs with adjacent neighbors less than 1mm should be set as corresponding points in the corresponding point search process. Should be terminated when the adjacent distance of each matching point is less than 1 mm.

2.3 Improved ICP algorithm

Because the main processing steps of ICP algorithm are based on iterative calculation, when the number of points which contained in the point cloud data is too large, it is easy to have a bad effect to the efficiency of ICP algorithm. At the same time, in the actual application, the points data often tends to have many inaccurate and even erroneous points or points after the pretreatment can have an effect on the final result. Also, the ICP algorithm is not able to handle the point cloud where the initial position is too large in many cases correctly. As there are many deficiencies in the traditional algorithm, later researchers get a lot of room for improvement [11]. In this paper, we try to use the 4-point coincidence algorithm to replace the module with the kd-tree method in the traditional ICP algorithm to improve the search efficiency of the corresponding point.

The four-point Congruent (4PC) algorithm's core search strategy is to find four corresponding points [12] in the same plane at the point cloud and target point cloud, as shown in Figure 2:

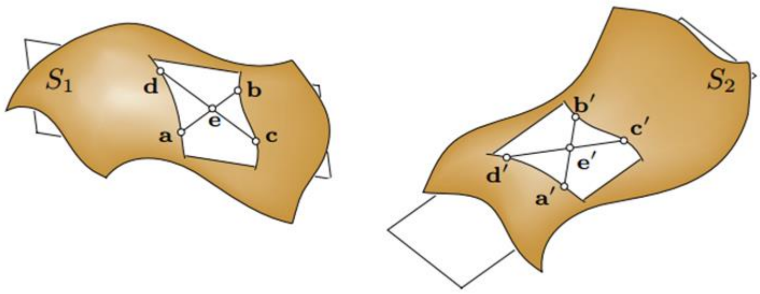


Fig. 2. 4-point coincidence algorithm

In Fig. 2, *S1* and *S2* represent the point cloud surfaces of the point cloud and the target point cloud, respectively, and *a, b, c, d* and *a* ^, *b* ^, *c* ^, *d* ^ Represents the points of the *S1* and *S2* surfaces in the same plane. As shown in the figure, the four coplanar points in the *S1* and *S2* surfaces intersect at the *e* and *e* ^ points, respectively. These common plane points The connection consists of several triangles, and the following relationship can be obtained from a similar triangular theorem:

$$|ae| \,/\, |eb| = |a^1e^1| \,/\, |e^1b^1|,\ \ |de| \,/\, |ec| = |d^1e^1| \,/\, |e^1c^1| \qquad (3)$$

The invariant relationship of the above lines is invariant in the point cloud rigid transformation or affine transformation.

Therefore, in the process of performing the corresponding point retrieval, the search for the midpoint of the common point can be converted into the search for *e* and *e* ^, so that the time complexity of the algorithm in the key search operation is reduced, the time complexity of the consistent algorithm is:

$$o(n^2 + k)$$

(4)

In the 4-point coincidence algorithm, the Euclidean distance of the four points of the common plane affects the robustness of the algorithm. Generally speaking, the farther the distance of the four points is, the higher the robustness of the algorithm is, the better the effect of the corresponding point means that the accuracy of the cloud model is higher after the subsequent registration. But it should be noted that, during the operation, the search for four coplanar points receives the effect of point cloud overlap, in addition, the point cloud noise will also affect the effect of the algorithm.

In many cases, the ICP algorithm needs to input a three-dimensional point set and a primary rotation-shift matrix before the operation. If the input initial data is incorrect, the greedy strategy used in the ICP algorithm may lead to an error in the algorithm and the minimum value obtained by the objective function is only adapted to the local optimal point. Therefore, in the case of no significant breakthrough in the current rough registration method, it is possible to try to further optimize the corresponding point search method in ICP algorithm to improve the processing efficiency of ICP algorithm in dealing with large-scale point cloud data.

Before the optimization of the ICP algorithm, it is necessary to set a criterion for the processing effect of the ICP algorithm. At present, the evaluation standard of the commonly used ICP algorithm is the most common standard, and its English abbreviation is LCP (Largest Common Point set).

The main criterion of the standard is based on the size of the degree of overlap, the calculation method of the overlap degree is: for the existing two point sets A and B, given a transformation matrix M, A can be achieved through the M and B registration, After the registration of the point cloud B at any point within a given range, there is a point in the A, then this point is the coincidence point, the point of the number of coincidence points accounted for the number of points is the ratio of the degree of overlap.

In the process of registration, the main factor that determines the overlap degree is the search speed of the corresponding point. Therefore, after introducing the 4-point coincidence algorithm in the classical ICP algorithm, we can improve the efficiency of the corresponding point The effect of the final processing results to enhance the degree of overlap, so as to achieve the purpose of improving the ICP algorithm to enhance the improvement of the flow chart as shown below:

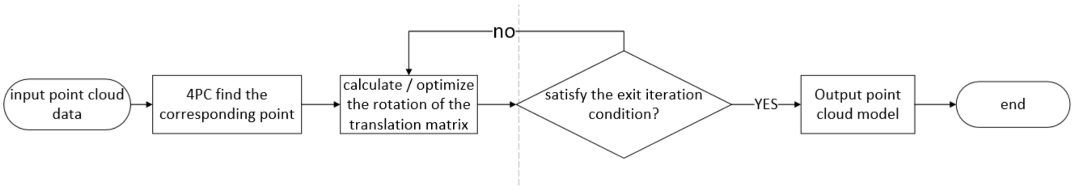


Fig. 3. Improved ICP algorithm flow chart

3 Improved ICP algorithm test

The improved ICP algorithm replaces the greedy search strategy in the original algorithm using a 4-point consistent point search strategy, which requires an experiment to verify its improved performance.

The test used in the test three-dimensional point cloud data from the Internet public test data, the provider is the point cloud library (Point Cloud Library). Code running environment for the VisualStudio2015 and PCL-1.8.0 point cloud development environment, the operating system used for the windows10 operating system, computing equipment for the Lenovo G400 laptop.

The specific steps of this test are as follows:

1) Enter the 3D point cloud data.

2) the input of the three-dimensional point cloud data preprocessing operation.

3) The three-dimensional point cloud data subjected to preprocessing operation is processed using the improved ICP algorithm.

4) output point cloud registration results, record processing time.

The registration process is as follows, the gray point cloud represents the target point cloud, and the red point cloud represents the point cloud being processed. The algorithm execution process is the registration process of the red point cloud to the black point cloud:

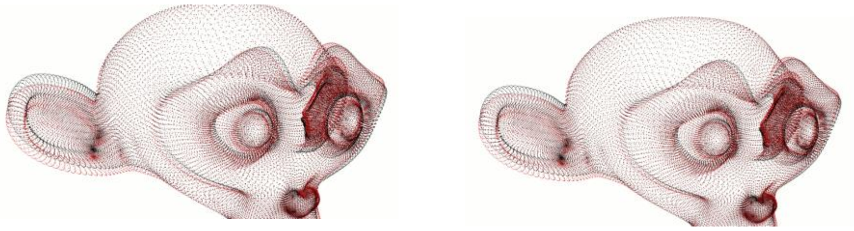
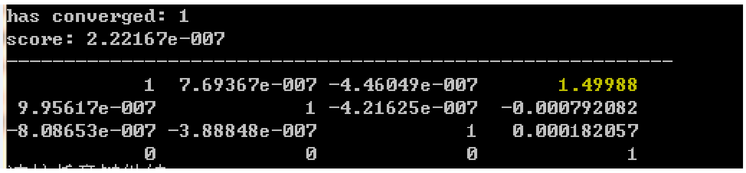
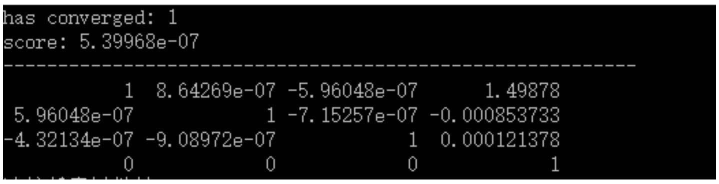


Fig. 4. Classic ICP algorithm registration effect (left) and improved ICP registration effect (right)



```
has converged: 1
score: 2.22167e-007
------------------------------------------------------------
            1  7.69367e-007 -4.46049e-007        1.49988
 9.95617e-007             1 -4.21625e-007  -0.000792082
-8.08653e-007 -3.88848e-007             1   0.000182057
            0             0             0             1
```

Fig. 5. The distance between the obtained point and the final transformed matrix is obtained by the classic ICP algorithm



```
has converged: 1
score: 5.39968e-07
--------------------------------------------------------
            1  8.64269e-07 -5.96048e-07       1.49878
 5.96048e-07            1 -7.15257e-07 -0.000853733
-4.32134e-07 -9.08972e-07            1  0.000121378
            0            0            0            1
```

Fig. 6. The distance between the obtained point and the final transformed matrix is obtained by the improved ICP algorithm

In Fig. 5 and Fig. 6, the "has converged" indicates whether or not the registration process is completed. When the registration process is completed, the value is 1 and vice versa. "Score" represents the sum of the squares of the points to be operated from the set of points to be set. The bottom of the dashed line shows the final resulting translation of the translation matrix.

As shown in Fig. 4, the improved ICP algorithm is similar to the final effect of the point cloud registration of the classical ICP algorithm. Compared with the comparison between Fig. 5 and Fig. 6, compared with the classical ICP algorithm, the improved ICP algorithm has the same position and angle Far away from the point set has a better robustness.

In the course of the experiment, we calculated the running time of the classical ICP algorithm and the improved ICP algorithm, and reduce the accidental error by performing multiple tests and calculating the average time consumed by the two algorithms. At the same time, To the convergence of the value of the statistics, the results shown in Table 1.

Table 1. Comparison of Classical ICP Algorithm and Improved ICP Algorithm.

Algorithm	Average time of registration (in seconds)	Average convergence
Classic ICP	289.79	0.011475
Improved ICP	224.93	0.010973

It can be seen from Table 1 that the improved ICP algorithm is faster than the classical ICP algorithm, but the final convergence value of the two algorithms is not obvious.

The experimental results show that under the experimental conditions, the 4-point coincidence algorithm improves the efficiency of the corresponding point processing ICP algorithm in the convergence value of the difference is not the case with the classic ICP algorithm better point cloud registration efficiency.

4 Conclusion

Based on the analysis of ICP algorithm, an improved method of corresponding point search, which based on the 4-point coincidence, is proposed by synthetically applying 4-point coincidence algorithm, stereo geometry analysis method and matrix transformation, and the method is able to enhance the ICP algorithm for point cloud data registration efficiency. This improved method is suitable for point cloud registration in a variety of scenarios and exhibits good handling under experimental conditions. However, the optimization of the point cloud registration algorithm is still a difficult problem in the field of 3D data processing. The optimization route proposed in this paper still has some optimization space, and it is still worthy of further research work.

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