INVESTIGATION OF IMAGE RECONSTRUCTION ALGORITHM BASED ON THE STRUCTURED LIGHT METHOD

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Abstract:

This paper proposes a new method of recognition of spatial objects on the basis of approaches related to technical vision. The developed algorithm is used to combine several point clouds by adding a target object to the scene on the example of a sphere. The algorithm introduces a restriction on some parameters, such as the sphere radius, to reduce the impact of noise in point clouds. Even for point clouds with overlapping regions, the proposed algorithm is more accurate because the corresponding points are selected from a continuous and ideal surface, instead of the actual measured points. Furthermore, the proposed algorithm is less sensitive to target size, point density, noise and the overlap factor, so it is more accurate than the algorithm of registration of the centers of the spheres and the ICP algorithm. The proposed algorithm can be used for scanning large, complex, curved surfaces where parts of the object overlap each other. Experiments and analysis of the proposed algorithm are carried out. To evaluate the proposed algorithm, three spheres were taken. Two simulations were carried out with overlapping data and with non-overlapping data. The size of point clouds is two-thirds of the hemisphere according to the field of view. Experiments were carried out on the basis of recorded data and real experimental data, respectively. The simulation was repeated several times with different points of extraction and reproduction of random noise. The statistical results were presented in the table. The practical significance lies in the possibility of using the results obtained in the study in the field of three-dimensional scanning.

Keywords:

Image restoration, structured light method, object recognition.

ACM Computing Classification System:

Image and video acquisition, computer vision representations, computer vision problems.

Introduction

Currently, there is a development of methods for processing the characteristics of spatial objects. Research is carried out in order to create "smart home" systems, robotic systems, remote control systems, etc. In this regard, relevant research is presented with the development of new approaches to the recognition of spatial objects based on technical vision.

All image analysis operations are performed using a variety of video sensors, special sources of structured lighting and modern computing tools equipped with appropriate software. In technical vision, one of the most important goals is to obtain three-dimensional information from the stage.

This problem has been studied for many years. To obtain this information, there are two types of methods: passive and active. Passive methods extract objects from the scene, such as corners, edges, lines from images.

Numerous observations of these features allow us to use triangulation methods to recover three-dimensional information of the scene.

One of the most well-known methods, when two combined cameras are used to obtain this information, is a stereo vision. However, these methods cannot be used when the scene texture contains few or no functions.

Active methods are used in these situations [1, 2]. Among these systems, structured light is the most popular. These systems typically consist of a perspective camera and a light emitter, which can be either a projector or laser projection.

The iterative nearest point algorithm is the main algorithm used in the accurate registration of three-dimensional point cloud data.

Its accuracy largely depends on the accuracy of the corresponding pairs of points. However, for some point clouds with constant curvature, such as a plane or a sphere, the method cannot find the exact matching point pairs and returns an incorrect result.

To solve the above problems, a method of high accuracy registration based on the restrictions on the spheres based on the method of structured light is proposed.

1 Analysis of the Influence of The Main Factors on Modeling

To evaluate the proposed method, take three spheres and place them as shown in (Fig.1).

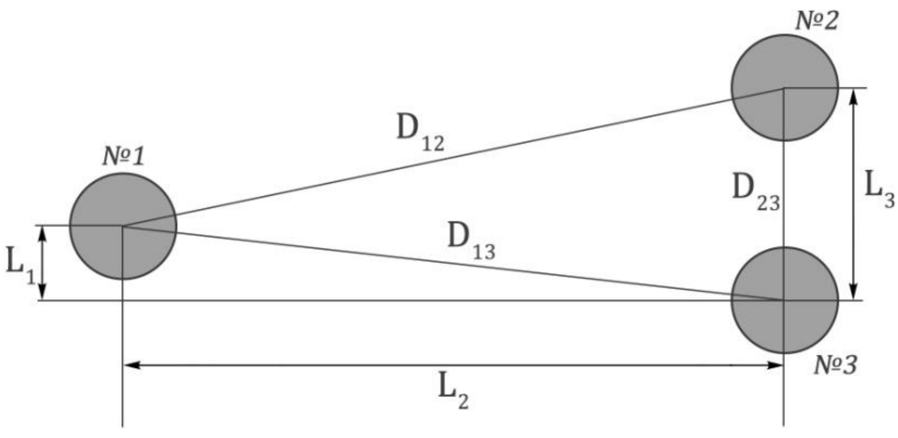

Fig.1. Diagram of the relative location of the spheres.

The distances between the spheres are set to L_1 = 36 mm, L_2 = 315 mm and L_3 = 103 mm, and the radius of the sphere let be r = 25.4 mm. Then the scope of the data modeled in “Matlab” program (Fig.2).

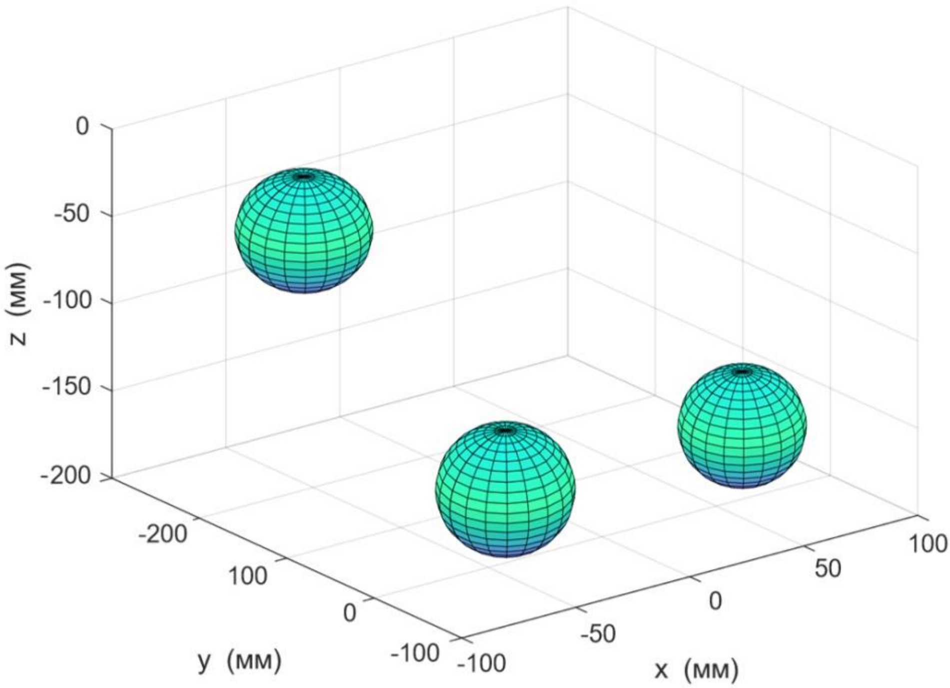

Fig.2. Simulated spheres in “Matlab”.

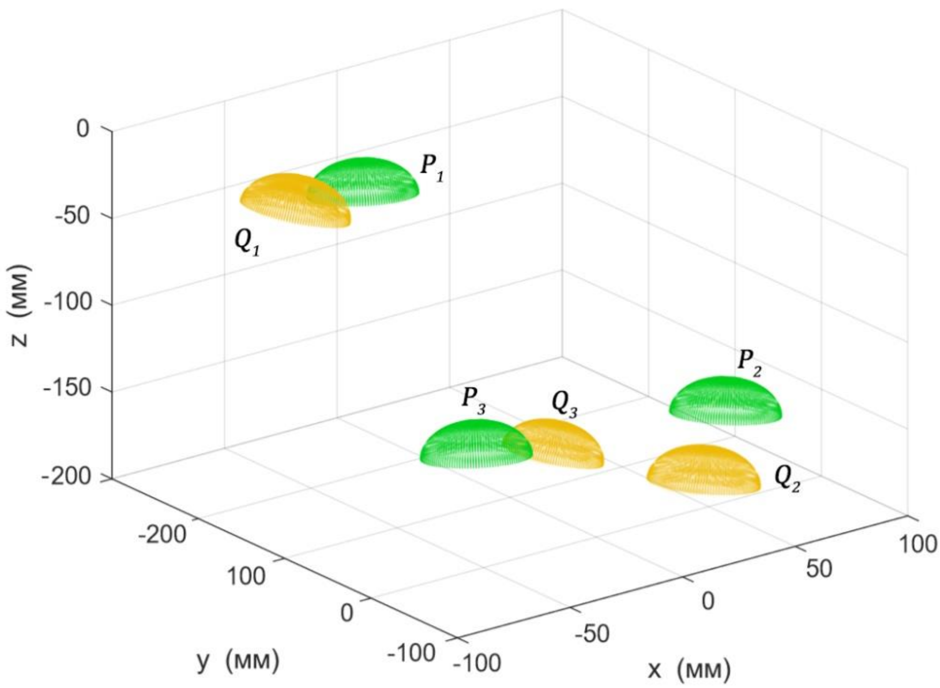

Fig.3. Clouds of points with overlapping data.

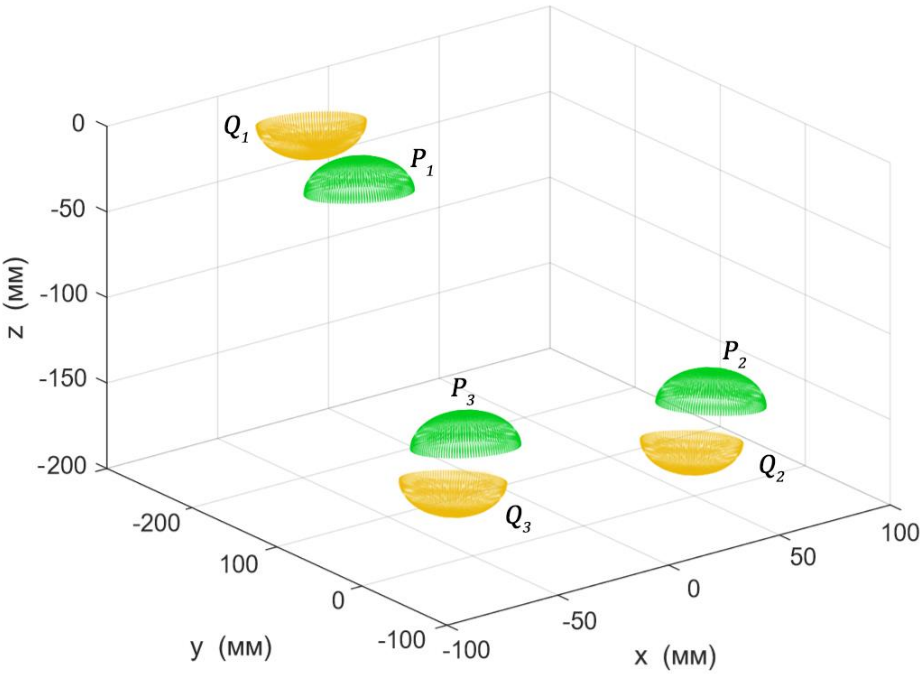

Fig.4. Clouds of points with non-overlapping data.

Two simulations were performed with overlapping data (Fig.3) and with non-overlapping data (Fig.4). The size of the point clouds is equal to two thirds of the hemisphere in accordance with the field of view.

The first two spherical point clouds (represented as P and Q) are randomly allocated at regular intervals from the same upper spherical surfaces, respectively.

The one cloud is indicated in green (Q_1~Q_3), and the other is indicated in orange (P_1 ~ P_3).

Two other clouds of points are extracted from the upper and lower spherical surfaces, respectively, which have non-intersecting data.

Then random Gaussian noise is added at these points. It should be noted that these extraction points in the two point clouds do not coincide, since their initial extraction positions are random and different, which is intended for the maximum possible modeling of the actual measurement situation [3, 4].

Then one of the point clouds is transformed to an arbitrary position by turning and moving. (Fig.3) shows the converted clouds with a fixed point and overlapping data, and (Fig.4) shows clouds of points with non-overlapping data, where the transformed cloud of points is indicated in orange, and the cloud of fixed points in green.

As a rule, the size of the sphere, the density of registration points, the noise at the registration points, and the overlap factor can cause radius shift and position errors at the centers of the spheres [5, 6].

Thus, the accuracy of registration mainly depends on these factors. The simulation is carried out by changing the size of the sphere, the noise level in this simulation is repeated several times with a random re-generation of simulation points.

The average value of the displacements between the registered points and their theoretical positions is calculated for the result of the registration each time, and the average value is calculated for the final registration error, as shown in equation (1):

$$Err_{Mean} = \frac{1}{N_t} \cdot \sum \left[\frac{1}{N} \sum_{i=1}^{N} ||\acute{q}_i - (R \cdot q_i + T)|| \right] \quad (1)$$

where q_i - vectors representing i-th registered point and its theoretical position, respectively; R and T - solving the rotation matrix and displacement vector, respectively; N - the number of modeling points, N_t - simulation time. Then, the final registration errors by equation (1) change with only one variable while fixing other factors

2 The Influence of the Size of the Sphere

In (Fig.5) are shown the errors caused by changes in the radius of the sphere, where the errors decrease with increasing radius, since a greater number of points increase the accuracy of positioning of the centers of the spheres.

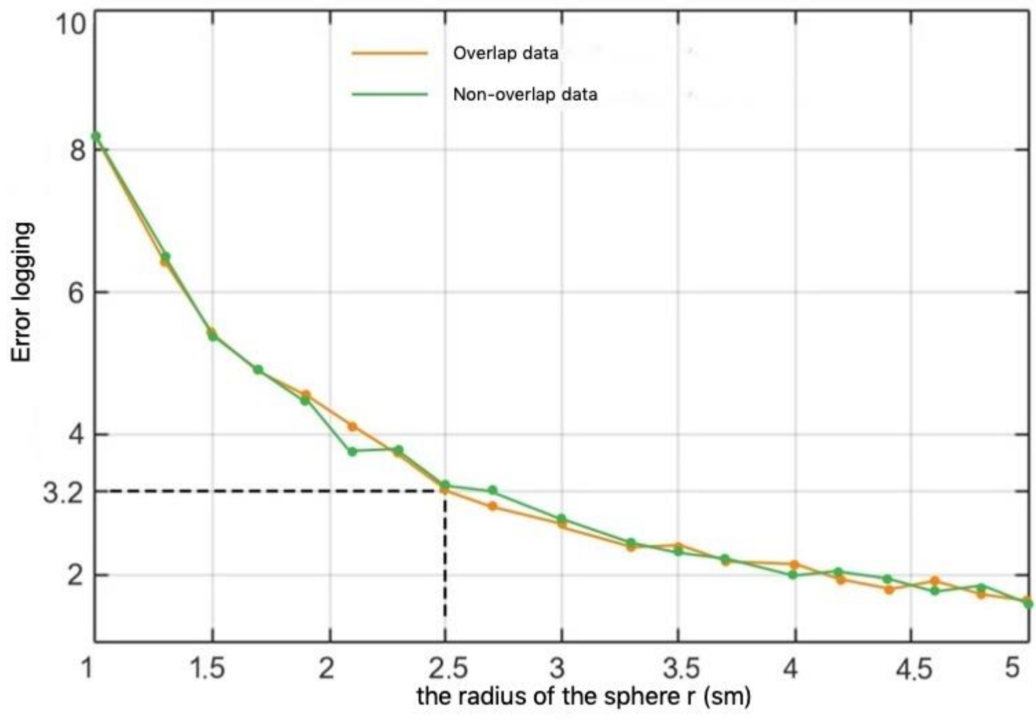

Fig.5. Graph of registration errors, on the radius of the sphere.

However, when the radius is greater than 2.5cm, accuracy improves slightly. Accordingly, if the radius of the sphere is set to r = 25.4 mm it is sufficient for scanning in practice, where the average error of 3.2 µm is achieved under specified conditions.

(Fig.5) also shows that registration errors with non-overlapping data are similar to results with overlapping data.

3 Influence of Point Density

(Fig.6) shows scanning errors resulting from changes in dot density.

The figure shows that registration errors increase with decreasing point density, and registration errors with non-overlapping data are also similar to results with overlapping data.

A smaller distance between points can improve the accuracy of registering points, but the time taken to measure and process data will increase significantly.

Thus, the spacing between the points, being set at about 2 mm × 2 mm, is acceptable under tuning conditions, where the average error is 3.2 μm.

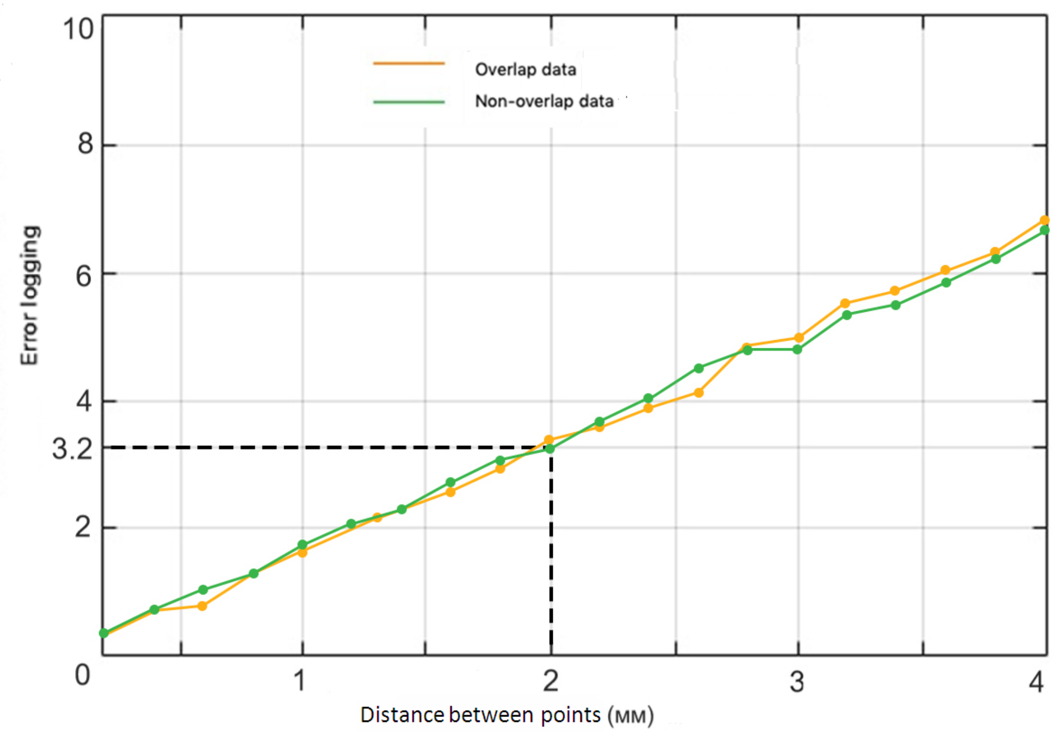

Fig.6. Graph of registration errors versus change in distance between points.

4 Noise Effect

The effect of noise is divided into two aspects: 1. effect of noise standard deviation and 2. the effect of the average error:

1. Effect of noise standard deviation.

In (Fig.7) registration errors are shown due to the effect of standard deviation of noise (average error u = 0).

This shows that errors increase with a growth of the standard deviation of noise, while errors with and without overlapping data remain unchanged. However, the rate of change is very small. Even if the standard deviation reaches 150 microns, the error is only about 25 microns. Thus, the proposed method is not sensitive to standard deviation of noise [7, 8].

2. The effect of the average error.

The average error leads to the fact that the radius of the fit has an offset from the previously known radius. (Fig.8) shows the registration deviations resulting from the influence of the average error. This shows that registration errors with overlapping data hardly change with an increase in the average error, but registration errors with non-overlapping data increase significantly with an increase in the average error [9, 10].

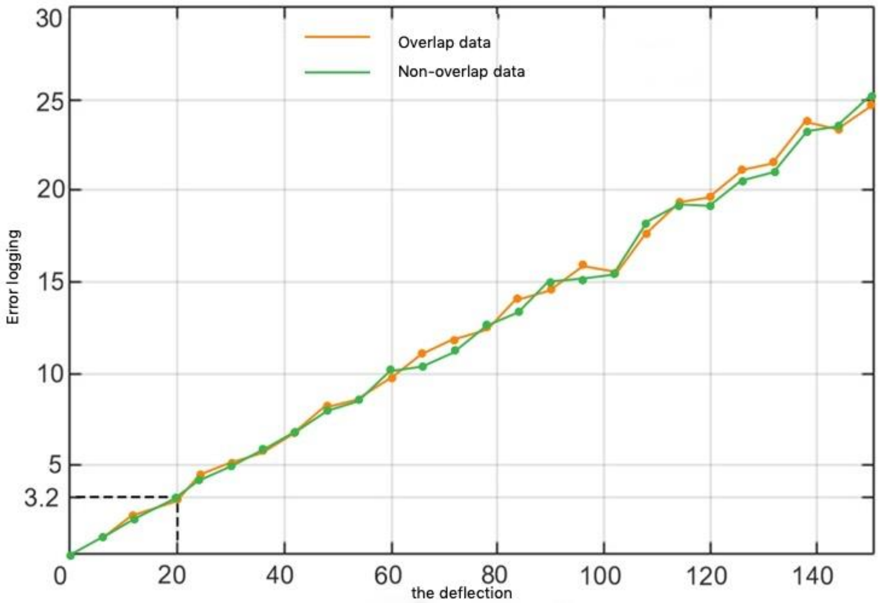

Fig.7. Graph of registration errors versus noise deviation.

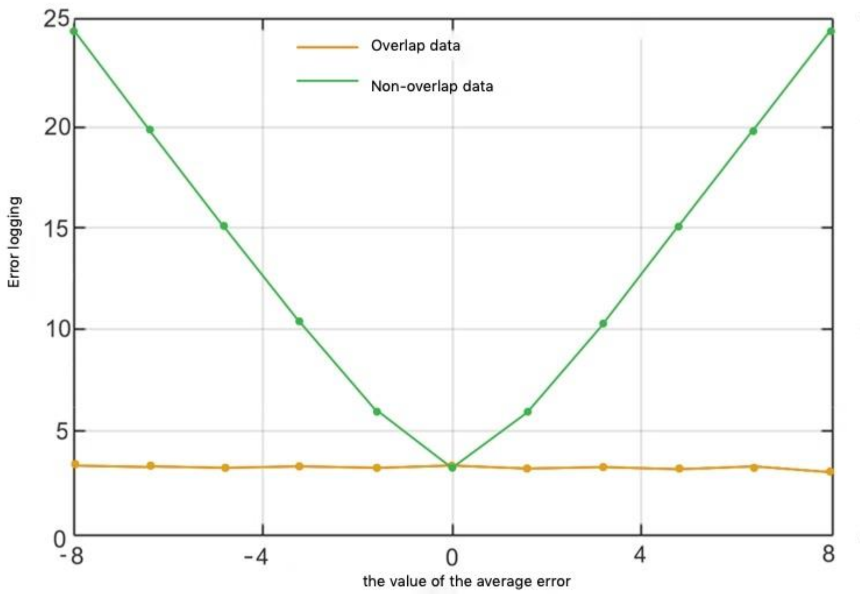

Fig.8. Registration errors are changed with an average error.

The reason is that the shift of the radius leads to the fact that the registered clouds of points deviate from their theoretical positions. However, for two point clouds with a complete overlap of their position, the deviations are the same, and this counteracts the registration errors. Thus, the average error has a great influence on the accuracy of registration, and it must be reduced or eliminated before registration. The average measurement error is a systematic error and can usually be fixed in advance.

5 Overlap Effect

(Fig.9) shows errors obtained from the influence of coefficient overlap, wherein the overlap ratio represents the proportion of regions overlapping with the registered points.

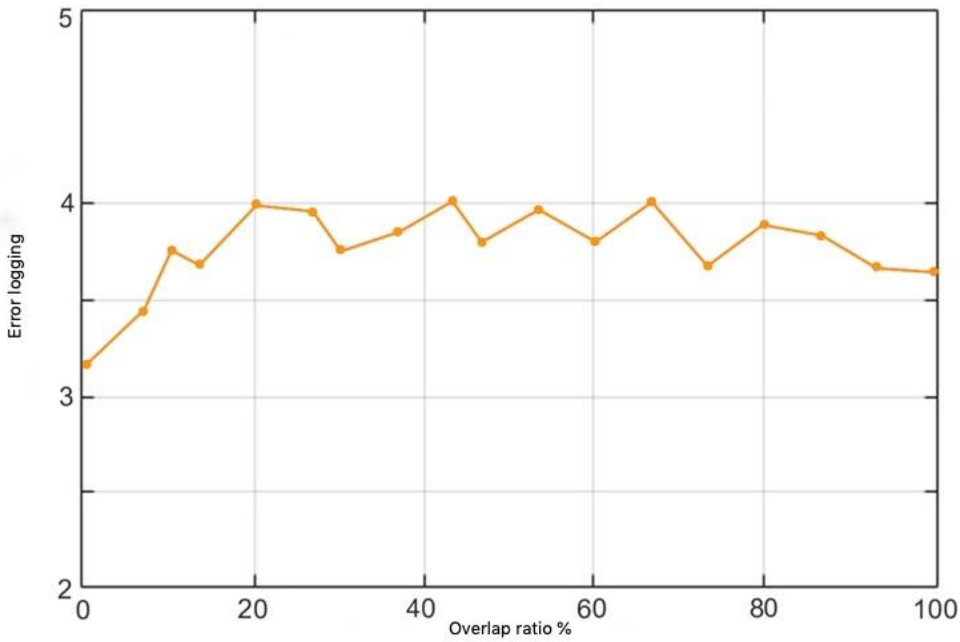

Fig.9. Graph of registration errors versus overlap ratio.

Registration errors do not change significantly (less than 1 micron), regardless overlap. Thus, the new method is not sensitive to the coefficient of overlap, this method can also solve the problem of registration with non-overlapping data.

From the above analysis, it is shown that the registration results with non-overlapping data are consistent with the results with overlapping data, except for the mean error. Therefore, the proposed method is an effective method for registering point clouds with non-overlapping data.

6 The Influence of the Number of Spheres

To check the effect of the number of spheres on the registration accuracy, a curved metal plate was scanned. A plate with a length of 1 m is measured from several points of view, and six spheres r = 25.4 mm are located side by side and rigidly fixed with a plate for registration .

The plate is a curved sheet, in which it is difficult to obtain data overlap between the concave and convex surfaces. In addition, concave and convex surfaces have several overlaps, which can reduce the registration accuracy. Obviously, it is difficult to accurately record clouds of plate points with existing methods.

The plate is measured in the upper, middle and lower segments, and each segment is measured from four angles. Thus, about 12 boiling angles must be registered. When using the new top three spheres are used to register the concave and convex surface of the upper section and register the upper and middle segments; while the lower three spheres are used to register the lower clouds of plate points.

To assess the accuracy of the registration of the new method, the measuring point of the six realms are installed on target areas, and departing radius between the adjustable radius and actual radius is calculated as shown on the on (Fig.10) where SCR (orange graph) is also used for comparison.

The average radius of displacement is about 0.0380 mm, and the average slope of the SCR is about 0.1166 mm. This indicates that the registration accuracy of a new method is much better than SCR.

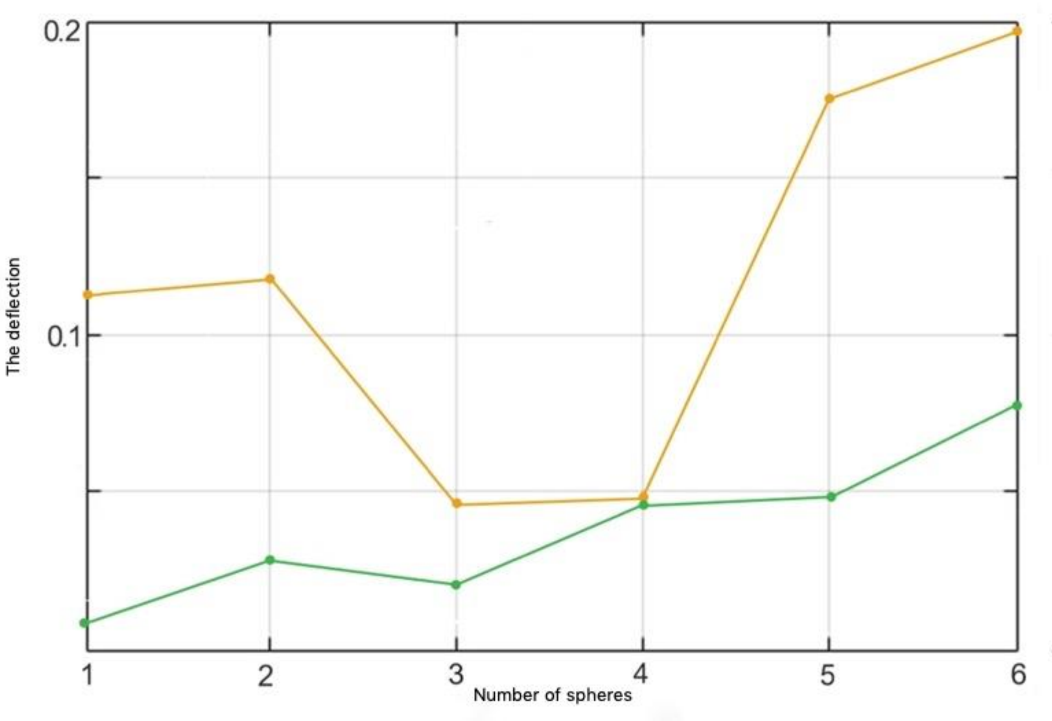

Fig.10. Graph of dependence of the radius of deviation from the number of spheres.

In general, the new method solves the problems of inaccurate registration with non-overlapping regions or an invariant curvature surface. Theoretically, its accuracy is not limited by the size of the object being measured, and by adding only some target objects, it is convenient to achieve high-precision registration.

7 Comparison of Registration Accuracy

To verify the accuracy of the SCR, ICP methods and the proposed method, experiments were carried out on the basis of the recorded data and real experimental data, respectively. The simulation is repeated several times with different points of extraction and reproduction of random noise. Statistical results are shown in (Tab.1) and (Tab.2) where registration errors are obtained by equation (1).

Table 1. Registration of results by three registration methods with overlapping data

Method	Time (sec)	Registration Error with Overlapping Data		
		Average mistake (μm)	Standard deviation noise a (μm)	Maximum (μm)
SCR	3	10.1	6.7	53.4
ICP	104	22.4	11.1	62.1
New method	96	3.3	1.7	11.6

Table 2. Registration of results by three methods of registration with non-overlapping data

Method	Time (sec)	Registration error with non-overlapping data		
		Average mistake (μm)	Standard deviation noise a (μm)	Maximum (μm)
SCR	3	11.4	6.9	60.2
ICP	104	/	/	62.1
New method	96	3.2	1.7	11.5

These tables show that the proposed method has the best registration accuracy, the average error of which is 3.3 μm, and the standard deviation of the noise is 1.7 μm in both cases containing overlapping data and non-overlapping data; The average SCR error is only about 11.4 microns, and the standard deviation of the noise is 6.9 microns in these cases; while the average ICP error is 22.4 μm, and the standard deviation of the noise is 11.1 μm for overlapping data, but non-overlapping data cannot be recorded.

In actual experiments with a measuring system, a standard ball with a radius of 25.4 mm and a plate of 110 mm × 110 mm with three spherical targets are measured from several types to form overlapping and non-overlapping data, respectively. The deviation of the surface of the ball from the reference sphere is less than 5 microns, and the plate roughness does not exceed 5 microns. Only three spherical targets are used for registration, and the ball and the plate are simply used as the object of assessment. As registration errors, the residuals of the ball and the plate are used, where the offset between the radius of the fit and the actual radius value is calculated as the average error for the ball. The statistical results of registration errors are given in (Tab.3) and (Tab.4).

Registration accuracy is worse than when modeling, which follows from inaccurate experimental data, but still a new method has high accuracy and ICP - the worst, which is similar to the simulation results. As a rule, the ICP algorithm is a high-precision registration method, but the corresponding pairs of points from the two extracted clouds of points are not sufficiently accurate, which leads to an incorrect result. The noise causes errors in fitting the centers of the spheres, which leads to inaccurate alignment of the two cloud points using the SCR method.

Table 3. Registration of results by three registration methods with overlapping data

An object	Method	Registration error with non-overlapping data		
		Average mistake (mm)	Standard deviation noise a (mm)	Maximum (mm)
Ball	SCR	0.036	0.028	0.144
	ICP	0,260	0.130	0.433
	New method	0.012	0.023	0.107
Plate	SCR	0	0.041	0.121
	ICP	0	0.104	0,224
	New method	0	0.020	0.069

Table 4. Registration of Results with Non- Overlapping Registration Methods

An object	Method	Registration error with non-overlapping data		
		Average mistake (mm)	Standard deviation noise a (mm)	Maximum (mm)
Ball	SCR	0.048	0.033	0.112
	ICP	/	/	/
	New method	0,009	0.028	0.119

The new method additionally optimizes the transformation matrices with a limited radius after obtaining a good initial value using the SCR method. Therefore, we obtain more accurate corresponding pairs of points, instead of an extracted cloud of points, which is a key factor in obtaining an optimal convergence result. Therefore, the proposed method achieves the best accuracy.

Conclusion

In this paper we propose a new method for registering constraints using spheres, which is adapted for precision registration multipoint cloud points with non-overlapping regions.

The proposed method introduces the use of the restriction of some parameters to reduce the effect of noise in point clouds. Even for point clouds with overlapping areas, the proposed method is more accurate, since the corresponding points are selected from a continuous and ideal surface, instead of real discrete measured points. Conversion parameters are determined by the optimization method with weight functions. In this case, the effect of large noise is reduced, and the registration stability is improved. Modeling and experimental results show that the proposed method effectively solves the problems of impossible registration or registration with low accuracy. In addition, the proposed method is less sensitive to the size of the target, the density of points, noise, and the overlap coefficient; therefore, it is more accurate than the method for registering the centers of the spheres of the center and the general ICP algorithm. Theoretically, not only spheres, but also other objects, such as cones, cylinders, can be used as target objects during registration. Therefore, the proposed method is more accurate than the method of registering the centers of the spheres and the general ICP algorithm.

The proposed method can be used when scanning complex, curved surfaces.

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