Research on Point Cloud and BIM Model Registration Supported by Adaptive Genetic Algorithm

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Abstract. Steel beam structure in the construction process, especially in the splicing process, there will be errors, which will bring certain hidden dangers to the construction safety. Based on the registration of point cloud and model, digital detection is realized, so as to accurately determine the deviation between point cloud data and BIM model. Based on this, this paper first studies the mathematical description of the registration problem between point cloud and BIM model, then analyses the ameliorative adaptive genetic algorithm, and finally verifies the feasibility and effectiveness of the ameliorative adaptive genetic algorithm.

Keywords: Point Cloud, Adaptive Genetic Algorithm (AGA), Registration

1. Introduction
With the continuous growth of social economy, infrastructure construction and various types of buildings continue to emerge, which puts forward higher requirements for the structural design and construction of buildings. For steel-concrete structure or pure steel building, there will be errors in the construction process of steel beam structure, especially in the splicing process. These errors will lead to differences between the actual results and the design drawings, which will bring certain hidden dangers to the building safety. At present, the digital detection method is usually used to detect the spliced building structure, so as to ensure the reliability of the structure. For complex structures, registration based on point cloud and model is often used to realize digital detection, so as to accurately determine the deviation between point cloud data and BIM model.

However, when the point cloud is more complex, it is difficult to choose the initial curve and accelerate the iteration speed based on the characteristics of the point cloud. With the increasing number of iterations, the amount of registration calculation between the point cloud data and BIM design model (the two models) increases significantly, resulting in the slow convergence speed[1]. Therefore, it is of great practical value to construct an adaptive genetic algorithm (AGA) to support the registration of point cloud data and BIM model, reduce the number of iterations, avoid premature convergence and improve the registration accuracy.

2. Mathematical Description of Registration Problem Between Two Models
2.1. Registration of the two models

In the splicing process of steel beam structure, due to the influence dimension of clamping angle and positioning accuracy, there will inevitably be differences in spatial position and angle between the reconstructed point cloud model and its BIM model. Therefore, it is necessary to calculate the transformation parameters from the coordinate system of point cloud to the design coordinate system of BIM model. The projection of angular velocity of rigid body rotation in the intermediate coordinate system is common:

\[
\begin{bmatrix}
\omega_{x_2} \\
\omega_{y_2} \\
\omega_{z_2}
\end{bmatrix} = \begin{bmatrix}
\psi_{x_2} \\
\psi_{y_2} \\
\psi_{z_2}
\end{bmatrix} + \begin{bmatrix}
\dot{\theta}_{x_2} \\
\dot{\theta}_{y_2} \\
\dot{\theta}_{z_2}
\end{bmatrix} + \begin{bmatrix}
\phi_{x_2} \\
\phi_{y_2} \\
\phi_{z_2}
\end{bmatrix}
\]

(1)

The translation parameters and rotation parameters of the spatial transformation relationship are determined, and the coordinate transformation matrix is determined by these two kinds of parameters, so that the best matching effect can be achieved between the 3D digital sample model and BIM model after the coordinate transformation, so as to correct the deviation in the point cloud\cite{2}. The coordinate transformation matrix is as follows:

\[
C^u_b = \begin{bmatrix}
\cos \beta \cos \gamma & -\cos \beta \sin \gamma & \sin \beta \\
\sin \alpha \sin \beta \cos \gamma + \cos \alpha \sin \gamma & \sin \alpha \sin \beta \sin \gamma + \cos \alpha \cos \gamma & -\sin \alpha \cos \beta \\
-\cos \alpha \sin \beta \cos \gamma + \sin \alpha \sin \gamma & \cos \alpha \sin \beta \sin \gamma + \sin \alpha \cos \gamma & \cos \alpha \cos \beta
\end{bmatrix}
\]

(2)

In which, \(C^u_b\) is the rotation matrix, \(\alpha, \beta, \gamma\) is the rotation angle of the 3D digital sample model around the x, y, z axis. The reference coordinate system applied is shown in Figure 1 below. The origin is set at the center of mass of the carrier; Y-axis is horizontal and along the direction of carrier motion, and z-axis is vertical upward.

![Figure 1. The reference coordinate system applied](image)

2.2. Initial registration of two models

Put the point cloud model and BIM model in the same coordinate system, respectively determine the bounding boxes and corresponding vertices of the two models, and then find the corresponding vertices in the bounding boxes of the point cloud model and BIM model to be registered, and the corresponding relationship is shown in Figure 2. By aligning these datum points, the initial registration of point cloud model and BIM model is realized, in which, the rotation matrix is as follows:

\[
H_o = \begin{bmatrix}
H_x & \begin{bmatrix} J_x & 0 & 0 \end{bmatrix} & \omega_x \\
H_y & \begin{bmatrix} 0 & J_y & 0 \end{bmatrix} & \omega_y \\
H_z & \begin{bmatrix} 0 & 0 & J_z \end{bmatrix} & \omega_z
\end{bmatrix}
\]

(3)
After the initial matching, the deviation range between the two models is not large, and the range of translation variable and rotation angle is fixed within a certain value, so the variation range of the matching variable can be determined.

![Coordinate system correspondence between point cloud model and BIM model](image)

**Figure 2.** Coordinate system correspondence between point cloud model and BIM model

3. Ameliorative Adaptive Genetic Algorithm

3.1. Basic principle of genetic algorithm
Genetic algorithm is based on a kind of computational simulation in the process of biological evolution to solve the optimization problem. In this algorithm, with the increase of population size and species of biological simulation, it is easier to produce better offspring\(^3\). On the contrary, with the decrease of population size and space, the convergence process will be much earlier. Therefore, genetic algorithm is used to simulate the living environment of population, so as to determine the adaptability and evolution process of individual population to the environment, so as to find the optimal individual in a specific population space, that is, the optimal solution of the problem.

In addition, in the process of population evolution, there will be duplication and replication operations, or the difference between the offspring and the parent is small. These phenomena are intuitive manifestations of premature population convergence, which will lead to a significant reduction in the efficiency of genetic algorithm in the process of finding the optimal individual. Therefore, in the application of genetic algorithm, it is necessary to find the fitness of individuals from multiple directions, so as to speed up the calculation process of the optimal solution.

3.2. Adaptive change of crossover probability and mutation probability
As an important source of new individuals in genetic algorithm, crossover operator can make genetic algorithm find the optimal individual in a specific population\(^4\). However, the premise of finding the optimal individuals is that there are many genes in the population; otherwise, it is impossible to find the optimal solution by using crossover operator. In this case, mutation operator is needed to obtain the missing genes. Mutation operator can find the optimal solution in the global range by simulating gene mutation.

It can increase the probability of gene exchange and help to determine the optimal solution in the global range, and reduce the probability of gene mutation and the destruction of the optimal solution process adaptively. In addition, due to the low dispersion of the population in the late stage of evolution, it is easy to produce premature phenomenon, which makes the evolution of the population fall into local optimum. In order to get the global optimal solution, mutation operation should be carried out first to increase the probability of gene mutation, so as to get rid of local extremum through the improvement of the algorithm.

3.3. Optimal preservation strategy
By adaptively changing the crossover probability and mutation probability, it can be seen that the cross operation is carried out first and then the mutation operation is carried out in the early stage, and then the crossover operation is carried out in the later stage of population evolution, which is helpful to obtain the optimal solution in the global range \(^5\). In the later stage, sufficient protection strategy is
another way to obtain the optimal individuals. By iteratively comparing the highest fitness of the offspring of genetic operation with the former generation, the new generation which most in line with the fitness value is selected to ensure the optimal individual and avoid the damage of the optimal individual in the process of crossover and mutation operation.

3.4. Verification of ameliorative adaptive genetic algorithm

In order to verify the accuracy and effectiveness of the ameliorative AGA in the registration of two models, the roof two models of a steel structure building are studied[6]. The roof of the research building is composed of all steel structure, and a control group is set to compare the registration results of the ameliorative AGA and BIM model in point cloud and traditional algorithm respectively, as shown in Table 1 below.

Table 1. Comparison of ameliorative AGA and traditional algorithm

| Algorithms             | Registration time consuming | Average error |
|------------------------|-----------------------------|---------------|
| Ameliorative AGA       | 5165.7 s                    | 29.45 mm      |
| Traditional algorithm  | 578.9 s                     | 2.63 mm       |

From the comparison results of the two control groups, the ameliorative AGA has obvious advantages in the efficiency of obtaining the global optimal solution because of the traditional algorithm.

4. Conclusion

In summary, the significant increase of registration calculation between the two design models results in slower convergence speed and larger error, which leads to the difference between the actual results and the design drawings, which will bring certain hidden dangers to the building safety. An adaptive genetic algorithm designed in this paper can guarantee the optimal individual and avoid the damage of the optimal individual in the process of crossover and mutation. Compared with the traditional algorithm, the adaptive algorithm has obvious advantages in registration time and registration accuracy, so it has high application value.

Acknowledgments

This work was financially supported by Ministry of Education's first co-education project in 2019 (201901051025), Computer Basic Education Research Project of the National Institute of Higher Learning (2019-AFCEC-044).

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