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Scopus Compendex and Geobase Elsevier,
Geo-Ref Information Services-USA, List B of Scientific
Journals, Poland, Directory of Research Journals

International Journal of Earth Sciences and Engineering

www.cafetinnova.org

ISSN 0974-5904, Volume 09, No. 04

August 2016, P.P.1711-1715

Global Registration Program Based on Targets

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Abstract: Point cloud registration is one of the core technologies of the three-dimensional laser scanning technology. Because of the limitations of the existing registration methods, the paper presents a registration program, which is the global registration based on targets. Compared with other registration methods, it improves the field efficiency and reduces the burden of field and human, has not error accumulation problem of continuous registration too. Certainly its accuracy is moderate. All of those bring convenience to the data processing. The results are the basic data of 3D model construction, which provides a three-dimensional model for digital city or smart city by GIS (Geographic Information System).

Keywords: *Three Dimensional Laser Scanning, Point Cloud, Global Registration, Target*

1. Introduction

The traditional architecture has regional and national and time characteristics, which is rich values in history, culture, science, and society. However, after wind and rain erosion of hundreds of years, or the collision of modern cultural, or the damage of various social factors, it is an urgent situation for the traditional architecture to the protection and heritage. In addition, with the development of digital city or smart city, the traditional architecture or village is an integral part of the city.

Therefore, based on the GIS technology, it is more and more urgent for the three-dimensional laser scanning technology to solve the traditional architecture or village protection and digitization.

Liu YB., et al. thought, at present, the traditional architecture digitization is the key part of the protection and inheritance technology [1]. And Zhan QM also thought it has been a hot research for the use of three-dimensional laser scanning technology to carry out the traditional building digitization [2]. Because the view limitations of ground field and the needs for practical applications, the three-dimensional laser scanning system need to scan the surface from different locations for access to complete information on object. However, the deferent location scans must be matched and integrated into a unified coordinate system which is only to reflect the entity information [3]. Registration technology is involved in quality testing, face recognition, fingerprint recognition, image matching and stitching of debris in archaeological areas, etc. Point cloud registration is an important application for registration technology in the point cloud data processing, and is one of the core technologies of the three-dimensional laser scanning. Based on the research results in the domestic and foreign registration technique, the paper proposed a global registration method with the target, and unified point cloud data coordinate system in the light of six parameter iteration in photogrammetry, which was verified in scanning practice of ancestral hall of Wang' clan at Jinzhai county in Anhui province.

2. Unified coordinate system on the basis of six parameter iteration

In photogrammetry, the matching method is to find the corresponding points of adjacent images, which are mapped to the space side, and then to calculate the spatial similarity transformation parameters of the adjacent model in order to splice. Figure 1 reflects the transformation of different coordinate systems into the unified coordinate system.

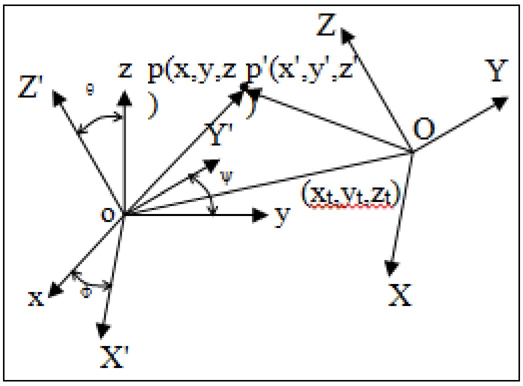

Figure 1: *The definition of the same point in different coordinate systems*

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix} = \lambda \begin{bmatrix} a1 & a2 & a3 \\ b1 & b2 & b3 \\ c1 & c2 & c3 \end{bmatrix} \begin{bmatrix} x \\ y \\ z \end{bmatrix} + \begin{bmatrix} \Delta X \\ \Delta Y \\ \Delta Z \end{bmatrix} \quad (1)$$

In order to complete the conversion between the adjacent coordinate system, it need to be solved 7 spatial similarity transformation parameters: three angle elements, Omega (φ), kappa(ω), Phi(κ); three shift Delta X (ΔX), Delta Y (ΔY), Delta Z (ΔZ) and a scaling factor (λ). which are calculated by the least squares adjustment method with 3 pairs or more than 3 pairs same name points. First of all, the above 7 parameters can calculate according to the known 3 pairs same name points, which is regarded as the initial value. The initial result can be input the following adjustment model as formula 1. In the formula 1, the a1, a2, a3, b1, b2, b3, c1, c2, c3 are the direction cosine composed of angular elements; the ΔX, ΔY, ΔZ is the coordinate of the x, y, z coordinate origin in X, Y, Z coordinate system; the λ is a scaling factor. there is formula 2 after the transformation. Formula 2 types into Formula 1. Formula 3 can get. Formula 4 is its general form.

$$\begin{bmatrix} a1 & a2 & a3 \\ b1 & b2 & b3 \\ c1 & c2 & c3 \end{bmatrix} = \begin{bmatrix} \cos\varphi\cos\kappa - \sin\varphi\sin\omega\sin\kappa & -\cos\varphi\sin\kappa - \sin\varphi\sin\omega\cos\kappa & -\sin\varphi\cos\omega \\ \cos\omega\sin\kappa & \cos\omega\cos\kappa & -\sin\omega \\ \sin\varphi\cos\kappa + \cos\varphi\sin\omega\sin\kappa & -\sin\varphi\sin\kappa + \cos\varphi\sin\omega\cos\kappa & \cos\varphi\cos\omega \end{bmatrix} \quad (2)$$

$$\begin{aligned} X &= \lambda((\cos\varphi\cos\kappa - \sin\varphi\sin\omega\sin\kappa)x - (\cos\varphi\sin\kappa + \sin\varphi\sin\omega\cos\kappa)y - (\sin\varphi\cos\omega)z) + \Delta X \\ Y &= \lambda((\cos\omega\sin\kappa)x + (\cos\omega\cos\kappa)y - (\sin\omega)z) + \Delta Y \\ Z &= \lambda((\sin\varphi\cos\kappa + \cos\varphi\sin\omega\sin\kappa)x + (-\sin\varphi\sin\kappa + \cos\varphi\sin\omega\cos\kappa)y + (\cos\varphi\cos\omega)z) + \Delta Z \end{aligned} \quad (3)$$

$$\begin{cases} X = f_x(\varphi, \omega, \kappa, \lambda, \Delta X, \Delta Y, \Delta Z, x, y, z) \\ Y = f_y(\varphi, \omega, \kappa, \lambda, \Delta X, \Delta Y, \Delta Z, x, y, z) \\ Z = f_z(\varphi, \omega, \kappa, \lambda, \Delta X, \Delta Y, \Delta Z, x, y, z) \end{cases} \quad (4)$$

Launching the multivariate function by the Taylor formula to Formula 4, and taking one order small value, we get Formula 5. If it is small value to seven parameters of spatial similar transformation, the φ, ω, κ put into the formula 5 as approximate substitution, and λ= 1. Then, matrix form of error equation is Formula 6 which is the spatial similar transformation error equation.

$$\begin{aligned} v_x &= \frac{\partial fx}{\partial \Delta X} d\Delta X + \frac{\partial fx}{\partial \Delta Y} d\Delta Y + \frac{\partial fx}{\partial \Delta Z} d\Delta Z + \frac{\partial fx}{\partial \varphi} d\varphi + \frac{\partial fx}{\partial \omega} d\omega + \frac{\partial fx}{\partial \kappa} d\kappa + \frac{\partial fx}{\partial \lambda} d\lambda - l_x \\ v_y &= \frac{\partial fy}{\partial \Delta X} d\Delta X + \frac{\partial fy}{\partial \Delta Y} d\Delta Y + \frac{\partial fy}{\partial \Delta Z} d\Delta Z + \frac{\partial fy}{\partial \varphi} d\varphi + \frac{\partial fy}{\partial \omega} d\omega + \frac{\partial fy}{\partial \kappa} d\kappa + \frac{\partial fy}{\partial \lambda} d\lambda - l_y \\ v_z &= \frac{\partial fz}{\partial \Delta X} d\Delta X + \frac{\partial fz}{\partial \Delta Y} d\Delta Y + \frac{\partial fz}{\partial \Delta Z} d\Delta Z + \frac{\partial fz}{\partial \varphi} d\varphi + \frac{\partial fz}{\partial \omega} d\omega + \frac{\partial fz}{\partial \kappa} d\kappa + \frac{\partial fz}{\partial \lambda} d\lambda - l_z \end{aligned} \quad (5)$$

$$\begin{bmatrix} v_x \\ v_y \\ v_z \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 & X' & -Z' & 0 & -Y' \\ 0 & 1 & 0 & Y' & 0 & -Z' & X' \\ 0 & 0 & 1 & Z' & X' & Y' & 0 \end{bmatrix} \begin{bmatrix} d\Delta X \\ d\Delta Y \\ d\Delta Z \\ d\lambda \\ d\varphi \\ d\omega \\ d\kappa \end{bmatrix} - \begin{bmatrix} l_x \\ l_y \\ l_z \end{bmatrix} \quad (6)$$

In above Formula, $l_x = X - \Delta X - \lambda X'$, $l_y = Y - \Delta Y - \lambda Y'$, $l_z = Z - \Delta Z - \lambda Z'$

$$\begin{bmatrix} X' \\ Y' \\ Z' \end{bmatrix} = \begin{bmatrix} a1 & a2 & a3 \\ b1 & b2 & b3 \\ c1 & c2 & c3 \end{bmatrix} \begin{bmatrix} x \\ y \\ z \end{bmatrix}.$$

In Formula 6, the X', Y', Z' expressed coordinate after rotation; the vx, vy, vz is correction of observation value x, y, z; the dΔX, dΔY, dΔZ, dλ, dφ, dω, dκ expressed the corrections for 7 undetermined parameters; and the lx, ly, lz expressed constant term of error equation. If the coordinates of each point are to be barycentralization, the error equation can be expressed as Formula 7.

$$\begin{bmatrix} v_x \\ v_y \\ v_z \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 & \overline{X} & -\overline{Z} & 0 & -\overline{Y} \\ 0 & 1 & 0 & \overline{Y} & 0 & -\overline{Z} & \overline{X} \\ 0 & 0 & 1 & \overline{Z} & \overline{X} & \overline{Y} & 0 \end{bmatrix} \begin{bmatrix} d\Delta X \\ d\Delta Y \\ d\Delta Z \\ d\lambda \\ d\varphi \\ d\omega \\ d\kappa \end{bmatrix} - \begin{bmatrix} l_x \\ l_y \\ l_z \end{bmatrix} \quad (7)$$

$$\overline{X} = x_i - \frac{\sum x_i}{n}, \overline{Y} = y_i - \frac{\sum y_i}{n}, \overline{Z} = z_i - \frac{\sum z_i}{n}, i = 0,1,2\ldots n,$$

In Formula 7, the $\overline{X}$, $\overline{Y}$, $\overline{Z}$ are barycentralization coordinates of the space point in the rotating coordinate system, which can avoid calculation of undetermined unknowns dΔX, dΔY, dΔZ. In order to obtain more accurate spatial similarity transformation parameters, we can calculate by multiple pairs of points with the same name. It can be listed 3 error equations for each pair same name. If there are n pairs of points with same name, we can list the 3n error equations (see formula 8). In the formula 8, we can set according to the following formula 9:

$$\begin{bmatrix} v_{x1} \\ v_{y1} \\ v_{z1} \\ \ldots \\ v_{xi} \\ v_{yi} \\ v_{zi} \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 & \overline{X}_1 & -\overline{Z}_1 & 0 & -\overline{Y}_1 \\ 0 & 1 & 0 & \overline{Y}_1 & 0 & -\overline{Z}_1 & \overline{X}_1 \\ 0 & 0 & 1 & \overline{Z}_1 & \overline{X}_1 & \overline{Y}_1 & 0 \\ \ldots & & & & & & \\ 1 & 0 & 0 & \overline{X}_i & -\overline{Z}_i & 0 & -\overline{Y}_i \\ 0 & 1 & 0 & \overline{Y}_i & 0 & -\overline{Z}_i & \overline{X}_i \\ 0 & 0 & 1 & \overline{Z}_i & \overline{X}_i & \overline{Y}_i & 0 \end{bmatrix} \begin{bmatrix} d\Delta X \\ d\Delta Y \\ d\Delta Z \\ d\lambda \\ d\varphi \\ d\omega \\ d\kappa \end{bmatrix} - \begin{bmatrix} l_{x1} \\ l_{y1} \\ l_{z1} \\ \ldots \\ l_{xi} \\ l_{yi} \\ l_{zi} \end{bmatrix}, i = 1,2,3\ldots n; \quad (8)$$

$$V = \begin{bmatrix} v_{x1} \\ v_{y1} \\ v_{z1} \\ \ldots \\ v_{xi} \\ v_{yi} \\ v_{zi} \end{bmatrix}, B = \begin{bmatrix} 1 & 0 & 0 & \overline{X}_1 & -\overline{Z}_1 & 0 & -\overline{Y}_1 \\ 0 & 1 & 0 & \overline{Y}_1 & 0 & -\overline{Z}_1 & \overline{X}_1 \\ 0 & 0 & 1 & \overline{Z}_1 & \overline{X}_1 & \overline{Y}_1 & 0 \\ \ldots & & & & & & \\ 1 & 0 & 0 & \overline{X}_i & -\overline{Z}_i & 0 & -\overline{Y}_i \\ 0 & 1 & 0 & \overline{Y}_i & 0 & -\overline{Z}_i & \overline{X}_i \\ 0 & 0 & 1 & \overline{Z}_i & \overline{X}_i & \overline{Y}_i & 0 \end{bmatrix}, X = \begin{bmatrix} d\Delta X \\ d\Delta Y \\ d\Delta Z \\ d\lambda \\ d\varphi \\ d\omega \\ d\kappa \end{bmatrix}, L = \begin{bmatrix} l_{x1} \\ l_{y1} \\ l_{z1} \\ \ldots \\ l_{xi} \\ l_{yi} \\ l_{zi} \end{bmatrix} \quad (9)$$

The total error equation is expressed in matrix form as formula 10.

V=B*X-L (10)

X= (BTB) -1BTL (11)

According to the principle of measurement adjustment, supposing that the right matrix is the unit weight matrix, we can know that the formula 11 is the solution of corresponding normal equation. In formula11, we get the dΔX1, dΔY1, dΔZ1, dλ1, dφ1, dω1, dκ1. These values are added to initial values and form new approximate values as follow:

$$\begin{aligned} &\varphi_1 = \varphi_0 + d\varphi_1, \Delta X_1 = \Delta X_0 + d\Delta X_1, \omega_1 = \omega_0 + d\varphi_1, \Delta Y_1 = \Delta Y_0 + d\Delta Y_1, \\ &\kappa_1 = \kappa_0 + d\kappa_1, \Delta Z_1 = \Delta Z_0 + d\Delta Z_1, \lambda_1 = \lambda_0 + d\lambda_1 \end{aligned}$$

The new approximate values are again as initial values, which can be reestablished the error equation. Its solutions are new corrections. By iteration, until the correction is less than the specified limit so far. It can be concluded that the independent parameters of the rotation matrix as follow:

$$\varphi = (((\varphi_0 + d\varphi_1) + d\varphi_2) + \cdots);$$
$$\omega = (((\omega_0 + d\omega_1) + d\omega_2) + \cdots);$$
$$\kappa = (((\kappa_0 + d\kappa_1) + d\kappa_2) + \cdots);$$
$$\lambda i = \lambda i\text{-}1\ (1 + d\lambda 1)$$
$$\Delta X = (((\Delta X_0 + d\Delta X_1) + d\Delta X_2 + \cdots);$$
$$\Delta Y = (((\Delta Y_0 + d\Delta Y_1) + d\Delta Y_2 + \cdots);$$
$$\Delta Z = (((\Delta Z_0 + d\Delta Z_1) + d\Delta Z_2 + \cdots);$$

Therefore, after obtaining 7 parameters, we can apply the spatial similarity transformation formula 1 to make the x, y, z of model point into the coordinates of X, Y, Z coordinate system.

3. The program of global registration based on targets

In this paper, the whole registration scheme is similar to the introducing external coordinate system method which has reported by Zuo GZ and Shi GG [4]. In the introducing external coordinate system program, the coordinate system transform can make each scanning station coordinate match to a unified external coordinate system and complete the point cloud data matches of global scanning object. Here, the external coordinate system coordinate system is replaced by independent scanning station coordinate. The various scans can be matched to this independent scanning station coordinate. With the increasing accuracy of the three-dimensional laser scanner, the benefits of this approach is that it does not require too much equipment, reduces the burden of field and human, also bring convenience to the data processing. Figure 2 shows the field working process of the program.

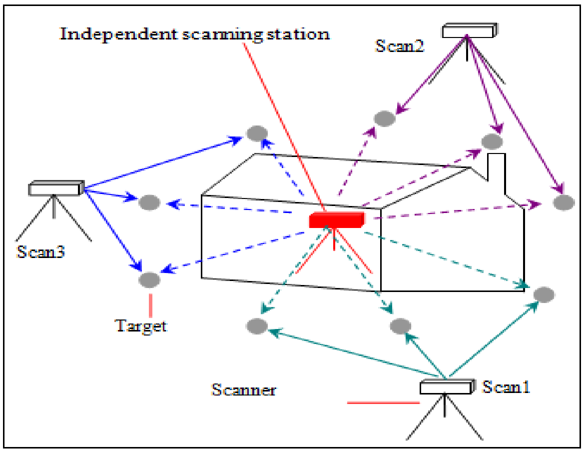

Figure 2: *Field program of global registration based on targets*

4. Program verification

4.1. Experiment equipment

Experiment used Faro HE880 scanner and ancillary equipment, Dell M90 notebook, Self-made planet targets, etc.

4.2. Experiment procedure

First: Reconnoitered outdoor experimental site of ancestral hall of Wang' clan, in the wall we laid control targets. The target interval was kept about 4 meters, which showed a ring distribution.

Second: We set 3 stations. The distance was about 10 meters between each station and the wall. Scan parameter was set to 1mm*1mm. Each station included 4 targets. The vertical direction was about -60° ~ 80°. The non-linear relationship was considered about target layout. It was about equal to the distance between each of the two stations and the wall target.

Again: In Figure1, we firstly scanned all targets by three-dimensional laser scanner which was used as independent scanning coordinate. And then, in Figure 2, the targets of 1, 2, 3-station were scanned sequentially.

The last: After the fourth scan, experimental data collection ended.

4.3. Data processing

The center coordinates of the targets were extracted by the software of Faro Scene. And the neighbor stations registration parameters would be gained with the registration algorithm based on six parameters which has reported by Shi GG., et al. [5] and Raumonen [6]. Table1, Table 2 and Table 3 showed the results.

Table 1: *The Center Coordinates of Global Scanning and First Station Scans, unit: meter*

Coordinates	X	Y	Z
Global01	-9.3143	12.1478	-0.4788
	-14.6564	38.4632	-0.1927
	-8.7692	34.5889	0.0815
	2.1949	26.6489	-0.1903
Station01	-9.6501	8.0398	-0.5927
	-15.6448	34.2539	-0.3099
	-9.7979	30.4899	-0.0274
	1.5120	22.8868	-0.3127
Rotation Matrix01	$\begin{pmatrix} 0.1205 & 0.9671 & 0.0020 \\ 0.9671 & -0.1205 & -0.0007 \\ -0.0010 & -0.0025 & 1.0000 \end{pmatrix}$		
Translation Matrix01	[12.3241 11.2231 3.2312]		

Table 2: *The Center Coordinates of Global Scanning and Second Station Scans, unit: meter*

Coordinates	X	Y	Z
Global02	6.3483	12.8970	-1.1802
	9.2649	2.3431	0.1624
	8.1194	-8.1539	-1.3224
	8.5283	-16.2800	-1.16297
Station02	7.3204	12.0080	-1.2183
	9.3805	1.2932	0.1259
	7.3687	-9.1454	-1.3603

	7.0806	-17.2826	-1.1988
Rotation Matrix02	$\begin{pmatrix} 0.5315 & 0.3672 & 0.0060 \\ 0.3672 & -0.5315 & -0.0005 \\ -0.0020 & -0.0062 & 1.0000 \end{pmatrix}$		
Translation Matrix02	$[8.5232 \quad 21.3242 \quad 11.4719]$		

Table 3: *The Center Coordinates of Global Scanning and Third Station Scans, unit: meter*

Coordinates	X	Y	Z
Global03	5.1007	-18.8734	-0.4632
	0.9415	-16.7479	-1.2493
	-7.4045	-7.8534	-0.9277
	-12.9507	1.6845	-0.5995
Station03	1.0072	-19.2801	-0.4873
	-2.4934	-16.1949	-1.2786
	-8.3738	-5.5052	-0.9627
	-11.3783	5.1089	-0.6312
Rotation Matrix03	$\begin{pmatrix} 0.8378 & 0.4692 & 0.0080 \\ 0.4692 & -0.8378 & -0.0009 \\ -0.0030 & -0.0085 & 1.0000 \end{pmatrix}$		
Translation Matrix03	$[15.1324 \quad 18.7845 \quad 21.4432]$		

5. Conclusions

According to the above scheme, the point cloud data obtained from the three stations are as shown in Figure.2; Figure.3 shows the point cloud data in the same coordinate system without registration. On the basis of each registration parameters of Table 1, the point cloud of each scan can be matched to the independent scanning station coordinate system. The Figure.4 showed scan object point cloud picture of the same coordinate based on the program, which verified the feasibility of the program.

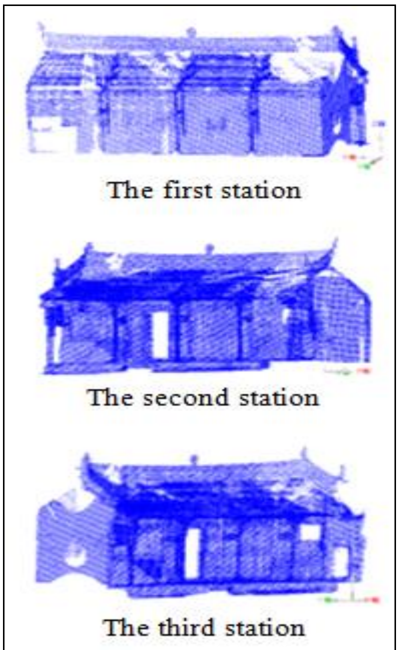

Figure3: *Point cloud data for each station*

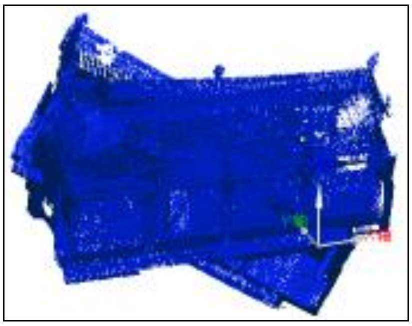

Figure 4: *Point cloud data in the same coordinate system without registration*

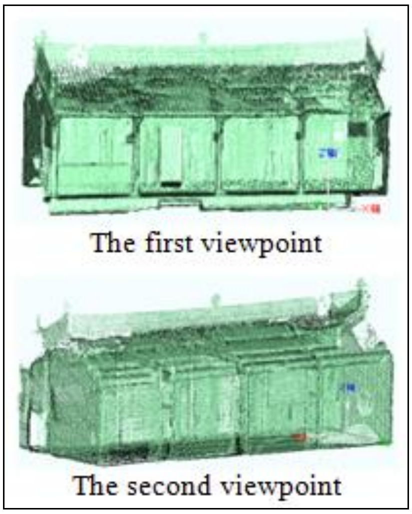

Figure 5: *Point cloud data in the same coordinate system based on the program*

Compared with the introducing external coordinate system method, it is more efficient and fast, and do not need too much manpower and equipment, but the accuracy will be slightly lower than the former. However, with increasing precision of the scanner, it is sufficient to meet the general engineering. In contrast to the neighbor stations registration method with targets, it has not error accumulation problem of continuous registration. Certainly its accuracy and efficiency is higher too. Therefore, the project can be given priority consideration for such programs which requires both accuracy and efficient.

In order to establish an independent scanning coordinate system, it's worth noting that the program of global registration based on targets must consider how to arrange reasonably all targets which can be scanned by three-dimensional laser scanner in one station.

6. Acknowledgments

This work was supported by Science and technology project of Anhui Province (1501041132).

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