A novel accuracy evaluation method for large scale vision measurement

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In order to evaluate the measurement accuracy of large scale vision measurement system and reconcile the measurement results with national standard, the method named “the variance of fitting point” was proposed. Firstly, several line segments of known length with common vertex were placed in the view field and these length values were considered as true values. In vision measurement system coordinate, these line segments could not cross one point because of the error existence. According to the length constraint, a point would be fitted by the least error square algorithm. Finally, the measurement accuracy was denoted by the variance of the fitting point. In the experiment, the lengths of the control target points measured by laser tracker were considered as true value. Meanwhile, the proposed method was compared with the statistical method. Experimental results indicate that the variance of fitting point could reflect the measurement accuracy. The RMS of evaluation variance is (0.0506, 0.0329, 0.0400).

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1. Introduction

In manufacturing industry, usually the engineers needed measure various apparatus and large size work piece. Many measurement task required high precision in term of large scale and on the work field. The common CMM technology can not meet these requirements. So the Lager-scale coordinate measuring system (LCMS) came forth. The vision measurement system is typical one of LCMS [1]. Accounted for the advantage of large measuring size, high accuracy, non-contact, flexibility and dynamic measurement, LCMS have become substitution of traditional CMMs in the field. It is meaningful to research how to evaluate the measurement accuracy of the system in work field.

The accuracy evaluation is a continuous comparison chain linked with standard instrument with higher accuracy. Finally, the precision evaluation needs trace to the national standard [2,3]. The accuracy evaluation of CMM is relatively perfect. Usually, the higher precision instrument is used as the standard object, such as standard ruler, stop gauge. Currently, many countries have researched the precision evaluation of LCMS. The vision measurement system had been used in America widely [4]. For example, the famous Boeing Company was the primary client. In 1996, How to trace the origin was a hot topic in LCMS conference, and the laser tracker was the focus. German began to research the LCMS in early year [5], and proposed a draft for the attribute evaluation of theodolite. The evaluation method based on aluminum alloy standard bar with 1m distance. In china, the vision measurement system was used by many manufacture factories widely. The 30m length guide way was used to calibrate the laser tracker [6] in China Institute of Metrology. The reference [7] tried to use laser tracker to evaluate the precision of the vision system. Accounted for the different coordinate system, they compared the flatness degree of the object measured by the vision system and laser tracker. The state key lab of precision instrument of TianJing University researched uncertainty of LSCMS by Monte-Carlo method [8]. Meanwhile, they researched others method [9,10]. It had taken many researchers’ attention how to evaluate the accuracy of vision measurement system instantly. But up to now, there are not standard issued.

As mentioned above, the way to evaluate the accuracy of vision measurement included control point’s statistical method, standard bar method, or other method based on standard instruments. Those methods could be used to evaluate the accuracy of the vision measurement, but there are some shortages. The accuracy of the vision measurement is affected by the environment, such as the camera position, distance, light intensity, and photo number. So it was unreasonable to use the criterion made in lab. And it was impossible to reproduce the real measurement environment in lab. Some tasks required evaluating the accuracy instant. Meanwhile there were many target points in the vision measurement system, and the accuracy was different at different point. So the relative error of the standard can not reflect the whole status of the accuracy. The method based on points statistic usually needed coordinate system transformation and it was difficult to measure the same points by two kinds of instruments.

According to those problems, the fitting point method based on distance constraint is proposed. The variance of the fitting point is used to describe the evaluation of the measuring accuracy. Because the distance is invariant in different coordinate system, the method avoids the transformation. And it is easy to measure the distance by different measurement instruments. The method does not find out the specific factors of the uncertainty, and synthetically considered the operator, environment factor, the camera position etc.

2. Common method

2.1 The point statistical method

In order to evaluate the accuracy of the measurement, the engineers will place some control target points in the view field. Then they use higher precision instrument to get the coordinate of the target points as true value. The measurement values from vision system are compared with the value from higher precision instrument. Then the measurement variance of vision measurement could be evaluated. Usually, those coordinate values belong to different coordinate systems, so the transformation is needed. For example, used the laser tracker as higher precision instrument and compared with the vision measurement system.

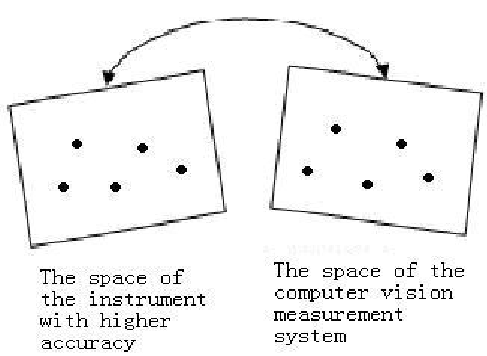


Fig.1 The transformation between two instrument spaces

The control target points from the higher precision instrument are denoted as $\{m_i \mid i = 1,...,n\}$. R denotes as the rotation matrix, and the translation vector is denoted by t. The control target points from the vision measurement system are denoted by $\{m_i^{'} \mid i = 1,...,n\}$. Because there are measurement errors η_i, the result can be denoted by:

$$m_i^{'} = Rm_i + t + \eta_i \tag{1}$$

In order to evaluate the spread of the measurement, firstly, the control target points is measured by the higher precision instrument and the vision measurement system. Then those points in two coordinate systems are matched to get the rotation matrix and translation vector. The value from higher precision instrument would be the true value. Then the data from the higher precision instrument would be compared with the data from the vision measurement system. Lastly, we would get the statistical variance.

In order to calculate the rotation matrix and the translation vector, usually quaternion algorithm would be used. This algorithm applies the least square method to minimize the following equation:

$$F(R,t) = \sum_{i=1}^{n} \omega_i \| m_i^{'} - (Rm_i + t) \|^2 \tag{2}$$

Then, the matrix (R,t) would be known. This implied that the optimal match between those target points in two coordinate systems should be required. In fact, errors η_i exist.

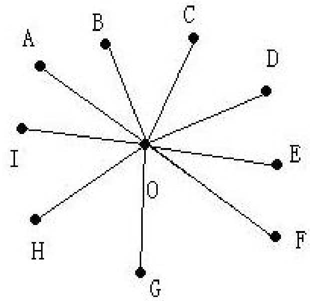
As mentioned above, this method has its advantages, but there are some shortages in practice. According to equation (1), errors η_i will cause the calculating error of the matrix (R,t). Because of the matrix (R,t) errors, the coordinate transformation is inaccuracy. Meanwhile, in practice project, if we use the laser track as higher accuracy instrument, it is no easy to measure the same target point by laser tracker and vision measurement system.

2.2 The method based on standard bar

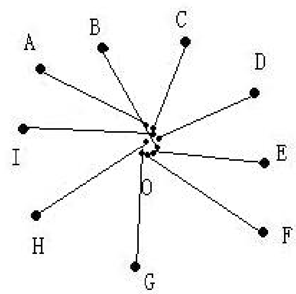
It is popular method using the standard bar to evaluate the vision measurement system. The principle is easy to understand. After measured the bar many times, the relative error would be evaluated by $\Delta l / l$. Here, l is real distance and Δl is the measurement error. The relative error becomes the evaluation criterion. The method is easy way, but the shortage is obvious. There are many target points in the view field and the accuracy is changed by the position. The uncertainty of three coordinates can not be reflected.

3. The method based on the variance of fitting point

According to above problems, the new definition named the variance of fitting point is proposed and attempts to describe the uncertainty of vision measurement. The special attributes of vision measurement system are that many target points would be measured in one task. The accuracy of those target points is different by their position. How to evaluate the accuracy and how to evaluate the accuracy of some one point must be resolved.



(a) no error



(b) with error

Fig. 2. The principle of the variance of fitting point (Fig. a the measurement with no error. Fig. b the measurement with error.

Supposed that there are $n+1$ target points in fig.2 and laser tracker is the higher precision instrument. The distance from some n points to the last one are measured by laser tracker. The equation group based on distance constraint can be made. It is obvious that this equation group is compatible. Through this group, we could fit a point accurately. But when the control points $(A, B, C, D, ... | n)$ contain error, the equation group will become incompatible. Usually, we use the least square method to fit the point and the variance of the fitting point to describe the accuracy of the measurement. The method is named as "the variance of the fitting point". Because the length is invariant in different coordinate system, the fitting point method don't need the transformation of coordinate, and the variance of fitting point can reflect the error of all target points.

Supposed that there are target points $i = (A, B, C, D, E, F, G, H, I, O)$ in view field (Fig.2), and the laser tracker is used to measure the distance. The distance value is denoted by l_{io}. Meanwhile, l_{io} denote the distance measured by vision measurement system, as Fig.2 (b) shown. The distance error is denoted by $\Delta l_i = l_{io} - l_{io}$. By the distance formulation, we can know that:

$$l_{io} = f(x_i, y_i, z_i, x_o, y_o, z_o) = \sqrt{(x_i - x_o)^2 + (y_i - y_o)^2 + (z_i - z_o)^2} \quad (3)$$

The coordinate of fitting point is denoted as $(x_o + \Delta x, y_o + \Delta y)$. Here, $(\Delta x, \Delta y)$ is the bias estimate between the fitting point and (x_o, y_o) .According to Taylor rule, If the equation is unfold at $(x, y) = (x_o, y_o)$ in vision measurement system, the nonlinear equation can be unfolded as:

$$l_{io} = f_0 + \frac{\partial f}{\partial \Delta x}\Delta x + \frac{\partial f}{\partial \Delta y}\Delta y + \frac{\partial f}{\partial \Delta z}\Delta z \quad (4)$$

The equation can be written as

$$l_{io} = \tilde{l}_{io} + \frac{x_i - x_o}{\tilde{l}_{io}}\Delta x + \frac{y_i - y_o}{\tilde{l}_{io}}\Delta y + \frac{z_i - z_o}{\tilde{l}_{io}}\Delta z \quad (5)$$

Here, l_{io} expressed the real value measured by laser tracker and l_{io} expressed the value measured by vision measurement system. For vision measurement system, Taylor formula can be unfolded as following,

$$\Delta l_i = \frac{x_i - x_o}{\tilde{l}_{io}}\Delta x + \frac{y_i - y_o}{\tilde{l}_{io}}\Delta y + \frac{z_i - z_o}{\tilde{l}_{io}}\Delta z \quad (6)$$

The equation (6) is the error equation, and the principle showed in fig.2. There, nine lines exist in fig.2 from $A, B, C, D, E, F, G, H, I$ to O. So we can get nine equations, and the equation group can be denoted by matrix,

$$\tilde{L} = AO \quad (7)$$

Here, $O = (\Delta x, \Delta y, \Delta z)^T$,

$\tilde{L} = (\Delta l_{AO}, \Delta l_{BO}, \Delta l_{CO}, \Delta l_{DO}, \Delta l_{EO}, \Delta l_{FO}, \Delta l_{GO}, \Delta l_{HO}, \Delta l_{IO})$,

A express the coefficient of equation(6).

The variance of distance can be obtained by the error vector of distance. If the equation group is redundant, according to the adjustment theory, the variance of fitting point can be express as:

$$Q_O = (A^T P A)^{-1} Q_\Delta \quad (8)$$

Above equation, if the condition is heteroscedastic, the coefficient matrix is denoted by P . Q_O Can be rewritten as:

$$Q_O = \begin{bmatrix} Q_x & Q_{xy} & Q_{xz} \\ Q_{yx} & Q_y & Q_{yz} \\ Q_{zx} & Q_{zy} & Q_z \end{bmatrix} \tag{9}$$

The variance of measurement can be express as error ellipsoid, and the specific formula can be found in reference [13]. As mentioned above, we can obtain the variance of measurement, here are some notices. The result described the whole evaluation of measurement not as some one point, and the result was affected by all target point. In order to improve the accuracy of evaluation, usually we need multi-bar (bar means distance).

On second thoughts, the condition that those bar crossed at one point is indispensable. If those lines don't cross, the principle is same. The only difference is that the unfolded point of Taylor formula is different. The unfolded points should be select as fig.3 shown. In this case, the fitting point is a virtual point.

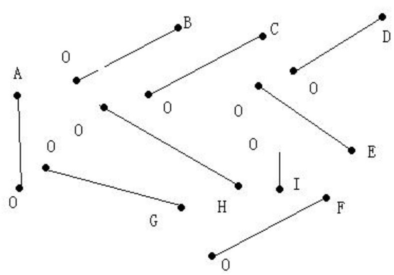


Fig.3 The principle of fitting point with no cross point

The advantage of the fitting point with cross point is able to evaluate the error of some one target point. For example, in fig.2, we attempt to evaluate the error of I target. Firstly, we calculate the mean value of relative error of distance by $\sigma_l = \frac{\Delta l}{l}$, then the distance error can be obtained by $\sigma_l \cdot l_{oi}$; lastly, the coordinate error can be evaluated by decomposed distance error.

4. Measurement experiments

4.1 Simulation

In order to verify the evaluation rationality of fitting point, the simulation was done. The random error was added to the control target points, and the tendency of evaluating variance was observed.

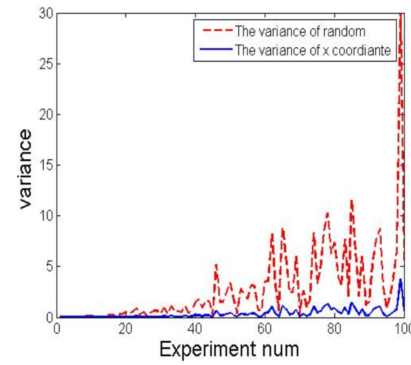
(1) Disposed 41 control target points in the view field, and make one point as the O point in the principle. Did the fitting work.

(2) Calculated the distance value and considered the value as real data.

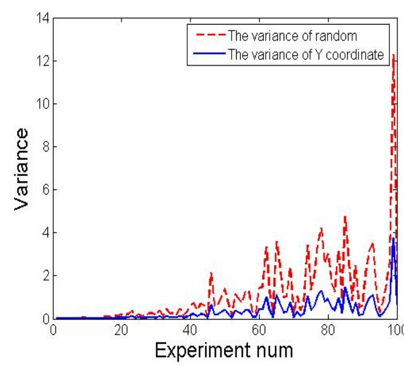
(3) Added the random error to the control target point and calculated the distance again.

(4) Calculated the matrix A and vector L according to the equation (6).

(5) Fitted the point O, evaluated the fitting variance and showed the result.



a



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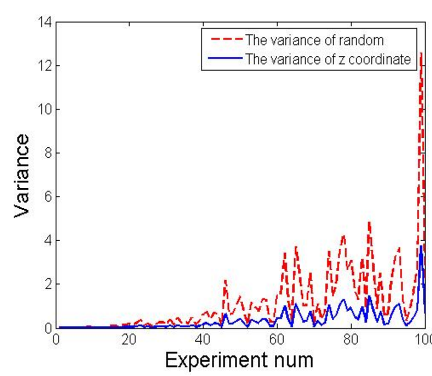

c

Fig. 4 The additional random variance and the variance evaluation of fitting point (The dashed line represents the additional random variance, and the solid line represents the variance evaluation of coordinate. The variance evaluation of x-coordinate is showed in fig (a). The variance evaluation of y-coordinate is showed in fig (b). The variance evaluation of z-coordinate result is showed in fig(c).)

The experiment result was showed in fig.4. The dashed line represents the variance of random added to the target points, and the solid line represents the value of evaluated variance of coordinate. The simulation experimental results indicate that the variance of the fitting point can reflect the variance of added random.

4.2 Experiment

In order to verify the practical efficiency, the comparison experiment was designed and the field was showed by fig.5. Before the experiment, the frame stability test had been done. The stability of experiment frame would ensure the reliability of measurement result. Firstly, the target points were measured by laser tracker and the distances were calculated. Then the target points were measured by vision measurement system. We considered the measurement value of laser tracker as real value. The uncertainty would be evaluated by point statistical method and the fitting point method respectively. The comparison between two methods would be done. The coordinate transformation was required by point target statistical method. In order to ensure the transformation with no error, special transforming accessory was used. The accessory can ensure the target point measured by two instruments was the same point. In practice task, usually the point statistical method can not be applied easily.

Fig. 5 The experiment field.

The instrument include: laser tracker, Nikon camera system. The laser tracker is API Tracker2 made in American: LTS_1100. And the vision measurement system is the product of American GIS Company. The experiment field was showed by fig.5, and the rebuild field was showed by Fig.6.

According to the principle, the variance of the fitting point was affected by the control target points. So the choice of fitting point would not affect the variance. In order to verify the principle, 88 points was measured and fitted. Ten fitting point of the result were selected randomly and was showed by table.1.

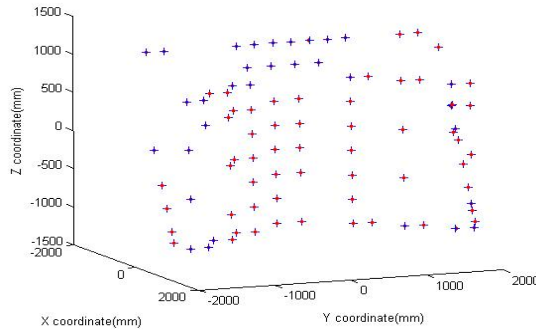

Fig.6 The reconstruct of the experiment field.

Table 1. The comparison between the statistical value and the fitting point evaluating value (Unit: mm).

Statistical value	0.1876	0.1479	0.1894
Fitting point 1	0.2054	0.1237	0.1330
Fitting point 2	0.2380	0.2048	0.2059
Fitting point 3	0.2379	0.1116	0.1475
Fitting point 4	0.1845	0.1230	0.1417
Fitting point 5	0.2573	0.1248	0.2037
Fitting point 6	0.1989	0.2156	0.2437
Fitting point 7	0.2068	0.1269	0.1404
Fitting point 8	0.1938	0.1432	0.1535
Fitting point 9	0.2068	0.1905	0.1922
Fitting point 10	0.2171	0.1329	0.1620

The RMS of the evaluation of the datum in table.1 can reflect the stability of the method. The data in talbe.1 is part of the experiment data randomly. The RMS of evaluation variance can reflect the stability of this method and the result is (0.0506, 0.0329, 0.0400).

The experiment result indicated that the variance of fitting point is stable. This method can reflect the uncertainty of vision measurement and the evaluating value was more than the statistical value slightly because of removed item of Taylor formula.

5. Conclusion

This paper researched the evaluating accuracy method of vision measurement system for large scale on work field. The variance of the fitting point is proposed to describe the measurement accuracy. In order to get the variance, point was fitted by the distance constraint. This method avoids the coordinate transformation. By distance constraint, all point errors are transferred to the fitting point. The variance of fitting point can reflect the uncertainty of vision measurement. Another advantage of this method is that the distance can be measured easily. Meanwhile, standard bar can be use to evaluate the accuracy based on this method on field. Experimental results indicate that this method is stability and can reflect the uncertainty of vision measurement. The RMS of evaluation variance can reflect the stability of this method and the result is (0.0506, 0.0329, 0.0400).

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