Self-organization combination measuring system for large geometric parameters measurement based on wireless sensor networks guiding

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With the continuing development of the manufacturing industry, the dimension of products has extended to tens of or even hundreds of meters. It means that the measuring range will accordingly expand, and the demand for Large Geometric Parameters Measurement becomes practical. The Large Geometric Parameter Measurement could be indirectly fulfilled by measuring the spatial coordinates of some target points, or locating those target points.Owning to the favorable characteristics of the laser itself, laser-based system used in the Large Geometric Parameters Measurement have unparalleled advantages in terms of accuracy. In this paper, based on wireless sensor networks guiding, a self-organization combination measuring system for Large Geometric Parameters Measurement is proposed. In this system the laser absolute distance meter, which is precisely controlled by a two-dimensional rotary servo, is integrated with the beacon of wireless sensor networks as a whole to constitute a single Measurement Station. Similarly the target mirror which can also be precisely two-dimensionally rotated is integrated with a wireless sensor networks node. In actual measurement, Measurement Stations should be calibrated first, and then utilize wireless sensor networks to locate the target mirror, so that the target mirror could be tracked by controlling the two-dimensional rotary servo, thereby the laser absolute distance meter can complete re-positioning of the target mirror with a high precision. Due to the self-organizing capability of wireless sensor networks, the flexibility and scalability of whole system are enhanced. In addition, a novel self-calibration method of this system named Without-mobile-point self-calibration method, is also proposed.

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NOMENCLATURE

σ^i_x = standard deviation of coordinates in the direction of X axis for the *i*th measurement stationin
σ^i_y = standard deviation of coordinates in the direction of Y axis for the *i*th measurement stationin
σ^i_z = standard deviation of coordinates in the direction of Z axis for the *i*th measurement stationin

1. Introduction

Large geometric parameters measurement (LGPM), or large scale metrology (LSM), generally "can be defined as the metrology of large machines and structures. ... the metrology of objects in which the linear dimensions range from tens to hundreds of meters" [1]. With the continuing development of manufacturing industry, some products such as large aircraft, huge ships, not only the size has reached tens or even hundreds of meters, but also the demand for manufacturing precision becomes higher and higher.

Currently there are as many as ten techniques and methods applied to LGPM, which almost indirectly fulfill their tasks by measuring spatial coordinates of target points, namely by positioning these target points. These techniques or methods have their advantages and shortcomings. For instance, laser trackers are captable of high accuracy, but it needs to re-establish tracking once the laser beam is broken. Some researchers suggest using multiple laser trackers to realize system self-restore when the laser beam is broken [2], however, it would greatly increase the system cost, and the system is still in the experimental stage. Another example is the indoor global position system (iGPS). It has advantages of measurement range, which could achieve uncertainties of ± 0.1 mm in a 2 ~ 40m measurement volume [3], but it is very expensive.

Owning to the favorable characteristics of the laser itself, laser-based system used in range-finding have unparalleled advantages in terms of accuracy. Performances of both the laser interferometer (IFM) and the laser absolute distance meter (ADM) are already in the micrometer range. In the Faro tracker, the level of accuracy achievable with an ADM (typically 10um+0.4um/m) is already approaching what can be achieved with the sort of conventional displacement-measuing interferometer fitted to laser trackers (typically 0.5umum/m) [4]. Consequently, if the laser multilateration, which does not need measuring angles, is used in LGPM, the measurement accuracy will be very high in theory [5], but it is difficult to track targets. Oppositely, wireless sensor networks (WSN) applied to positioning has the advantage of trackability, but its accuracy can't meet the requirement of LGPM. Taking the above discussion into consideration, a self-organization combination measuring system for LGPM based on WSN guiding is proposed. And the characteristic of self-organization, which derives from that WSN is capable of self-organization [6], can be defined as that increasing or decreasing target stations or measurement stations even during the measuring process, the system can work normally by organizing into a new measuring network.

This paper is organized as follows: in section 2 mathematical models including measurement and self-calibration models for the system are introduced; in section 3 the system structure and measuring process are described; in section 4 simulation of the novel self-calibration method proposed in section 2 is presented ; in section 5 the conclusion are summarized.

2. Mathematical models

2.1 Mathematical model of measurement

The measurement principle of the system is the multilateration, which is illustrated in Fig. 1. And in Fig. 1, green points represent measurement stations, while black points represent target stations, or measured targets. "M1,M2,...,MN" means that the total number of measurement stations is N; d_i (i=1,2,...,N) which can be measured by a certain ranging method, is the distance between the ith measurement station and the target station T.

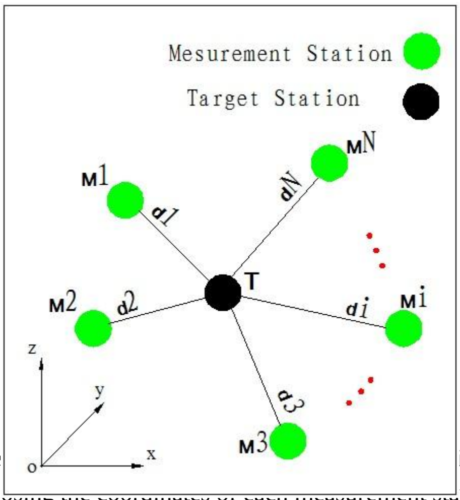


Fig. 1 Re nciple

Supp tion are (x_i , y_i , z_i) (i=1,2,...,N) and the coordinate of target station T is (a,b,c)，then equations (1) from the distance formula between two points is：

$$\begin{cases} (x_1-a)^2+(y_2-b)^2+(z_1-c)^2=d_1^2 \\ (x_2-a)^2+(y_3-b)^2+(z_2-c)^2=d_2^2 \\ \dots \\ (x_n-a)^2+(y_n-b)^2+(z_n-c)^2=d_n^2 \end{cases} \quad (1)$$

Obviously, N measurement stations can gain N equations, so when N$\geq$3, the coordinate of target station T can be calculated.

2.2 Mathematical model of self-calibration

In part 2.1, the coordinates of each measurement station are assumed known. In the actual measurement, nevertheless, it involves how to get the coordinates of each measurement station, and this is the system calibration problem.

For equations (1), when N > 3, adding every a measurement station, equations (1) will add a redundancy equation, i.e. the system realizes the redundant measurements. If the system realizes the redundant measurements, not only the system performance will be improved, but also the system self-calibration come true. According to reference [2], system self-calibrationcan be implemented by adding mobile-points (target stations). However, it also can be implemented just using measurement stations, which is defined as the without-mobile-point self-calibration method.

Supposing that, there are N (N > 3) measurement stations in total, and the coordinate of the kth measurement station is (x_k, y_k, z_k) (k=1,2,...,N). Then the number of unknown parameters for all measurement stations are 3×N-A, where A is a constant determined by establishment ways of the coordinate system, detailed in Tab. 1. d_{ij} (i=1,2,...,N; j=1,2,...,N; $i\neq j$), which also can be measured by a certain ranging method, is the distance between the ith measurement station and the jth measurement station, and the number of distances between random two measurement stations is N×(N-1)/2. Then equations (2) is:

$$\begin{cases} (x_2-x_1)^2+(y_2-y_1)^2+(z_2-z_1)^2=d_{21}^2 \\ (x_3-x_1)^2+(y_3-y_1)^2+(z_3-z_1)^2=d_{31}^2 \\ \dots \\ (x_n-x_1)^2+(y_n-y_1)^2+(z_n-z_1)^2=d_{n1}^2 \\ (x_3-x_2)^2+(y_3-y_1)^2+(z_3-z_1)^2=d_{32}^2 \\ \dots \\ (x_n-x_2)^2+(y_n-y_2)^2+(z_n-z_2)^2=d_{n2}^2 \\ \dots \\ (x_{n-1}-x_n)^2+(y_{n-1}-y_n)^2+(z_{n-1}-z_n)^2=d_{(n-1)n}^2 \end{cases} \quad (2)$$

Equations (2) also can be written as follows:

$$(x_s-x_t)^2+(y_s-y_t)^2+(z_s-z_t)^2=d_{st}^2 \quad (3)$$

Where: t > s, s=1,2,...,N-1, t=2,3,..,N. And in actual self-calibration, define $d_{st}=(d_{ij}+d_{ji})/2$ (i=s; j=t).

To realize the system self-calibration, the number of equation in equations (2) must be not less than the number of unkonwn parameters, that is:

$$N\times(N-1)/2 \geq 3\times N-A \quad (4)$$

According to inequality (4) and establishment ways of the coordinate system, the minimum number of measurement stations can be calculated, which is shown in Tab. 1.

3. System description

3.1 System structure

As shown in Fig. 2, the system consists of three units: measurement stations, target stations and data processing system.

<1> The measurement station is composed of a beacon node of WSN, ADM, a target mirror and a two-dimensional rotary servo. The beacon node can send or receive the wireless signal, and controlled by the data processing system, the two-dimensional rotary servo is able to make ADM or the target mirror rotated in horizontal or vertical direction.

<2> The target station is composed of a target node of WSN, a target mirror and a two-dimensional rotary servo. There is no differences in hardware and function between the beacon node and the target node, and it is similar to the measurement station that the two-dimensional rotary servo is able to make the target mirror rotated in horizontal or vertical direction controlled by the data processing system.

<3> The data processing system, which takes a computer with mainstream configurations as the core, is responsible for the initialization of measuring models, the sending of control commands and data processing.

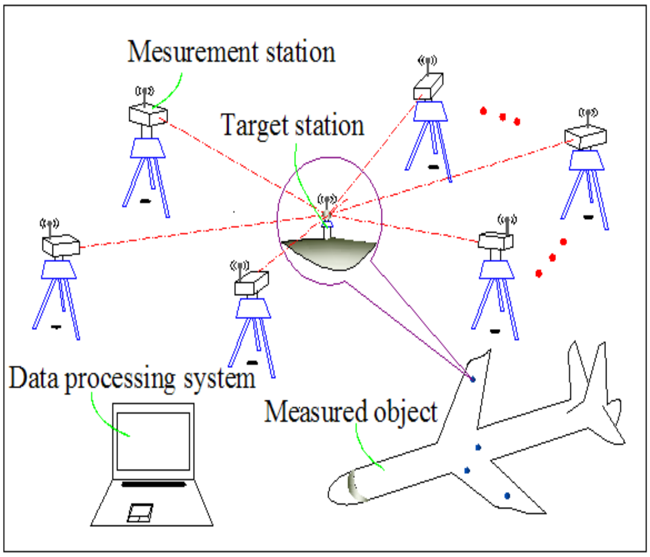
3.1 System measuring process

Before measuring, the spatial position relation of the beacon node, ADM and the target mirror in the measurement station as well as the spatial position relation between the target node and the target mirror in the target station should be calibrated. In actual measurement, measurement stations is to be arranged in the measurement volume according to the designed system arrangement scheme, while target stations is to be correspondingly placed on the feature spots of the measured object. The whole measuring process is as follows:

<1> Finish the system self-calibration by using the without-mobile-point self-calibration method. Firstly, all distances between random two measurement stations is obtained by beacon nodes using RTOF (Roundtrip-Time-Of-Flight) or other methods [7], and define these distances as the coarse distances. Secondly, the coarse coordinates of beacon nodes can be calculated according to equations (2) and the coarse distances. Thirdly, because the spatial position relation of the beacon nodes, ADMs and the target mirrors in each measurement station has known by calibration, the coarse coordinates of ADMs and the target mirrors can be gained according to the coarse coordinates of beacon nodes, then the two-dimensional rotary servo will be controlled by the data processing system to make all distances between random two measurement stations obtained by ADM, and define these distances as the accurate distances. Lastly, according to equations (2) and the accurate distances, the accurate coordinates of beacon nodes, ADMs and target mirrors are to be calculated.

<2> Locate the target stations to obtain coordinates of the feature points. This process is similar to step <1>, hence no more illustration here.

<3> After acquiring the coordinates of all feature points by step <2>, the measurement results are to be given by a certain algorithm according to the different geometric parameter to be measured.



4.

From the system measuring process, it could be found that the positioning accuracy of WSN is the critical factor for this system, and it could meet the requirement as long as the positioning accuracy of WSN could ensure the realization of system self-calibration. The range accuracy of WSN can reach ±15mm in theory if the time-to-digital converter TDC-GP2 is utilized [8], and for the common target mirrors, the guiding function of WSN can be realized as long as the positioning accuracy of WSN could reach ±15mm.

Consequently, this simulation of the without-mobile-point self-calibration method aims to verify that the positioning accuracy of WSN can reach ±15mm or not when the range accuracy of WSN is ±15mm.

In the simulation, there are several definitions as follows:

<1> The establishment way is set as establishment way 1 (see

Establishment ways of the coordinate system	0 No limitations;	1 The 1^{st} station is at the origin;	2 The 1^{st} station is at the origin; The 2^{nd} station is on the X axis;	3 The 1^{st} station is at the origin; The 2^{nd} station is on the X axis; The 3^{rd} station lies in the X-Y plane;
A	0	3	5	6
Min. numbers of stations	7	6	5	4

Table. 1 Minimum numbers of measurement stations for the without-mobile-point self-calibration method

Tab. 1).

<2> The total number of measurement stations N=6, and the coordinate of the first station = (0,0,0).

<3> Define the coordinates of all measurement stations from the designed system arrangement scheme as the designed value, which is the initial value of iteration.

<4> The range error is set to ±15mm, which is given according to the normal distribution.

<5> Replicate the test 30 times, and define the mean of the results of these tests as the calculated value.

<6> Define σ^i_{xyz} (i=1,2,...,N) which can be calculated by equation (5) as the self-calibration accuracy of the ith measurement station.

$$\sigma^i_{xyz} = \sqrt{(\sigma^i_x)^2 + (\sigma^i_y)^2 + (\sigma^i_z)^2} \quad (5)$$

The result of the simulation is shown in Table 2. And from the data in Tab. 2, it could be found that the self-calibration accuracies of each measurement station are not more than ±7mm, which is less than ±15mm. It means that the guiding function of WSN still can be realized when the range accuracy of WSN is ±15mm. Besides, the self-calibration accuracy of the first measurement station is obviously higher than other measurement stations.

Self-calibration schemes	Measurement Station (N=6)		Designed Value (mm)	Calculated Value (mm)	σ^i_x (mm)	σ^i_y (mm)	σ^i_z (mm)	σ^i_{xyz} (mm)
Without-mobile -point self-calibration scheme	1	*x1*	0	2.514×10^{-7}	1.856×10^{-7}	2.650×10^{-7}	2.170×10^{-7}	3.895×10^{-7}
		y1	0	6.694×10^{-8}				
		z1	0	2.025×10^{-8}				
	2	*x2*	10000	9989.151	2.754	4.261	3.909	6.405
		y2	0	4.172				
		z2	0	6.690				
	3	*x3*	10000	9994.066	4.071	3.800	3.245	6.445
		y3	10000	9992.503				
		z3	0	12.772				
	4	*x4*	10000	10002.582	3.718	4.225	3.766	6.772
		y4	10000	9995.715				
		z4	10000	9989.904				
	5	*x5*	20000	19987.315	2.901	2.907	2.575	4.848
		y5	10000	10002.631				
		z5	10000	9991.694				
	6	*x6*	20000	19995.163	5.318	2.180	2.306	6.192
		y6	20000	19988.311				
		z6	10000	9996.140				

Table. 2 Result of the simulation

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5. Conclusion

A combination measuring system for LGPM based on WSN guiding is described and performed through academic discussion. By discussion it can be concluded that the hybrid system has advantages of a sound flexibility and scalability because of its characteristics of self-calibration and self-organization.

Furthermore, a novel self-calibration named the without-mobile-point self-calibration method is also proposed. And the result of the simulation shows that the positioning accuracy of WSN completely meet the requirement of the system, but the self-calibration accuracy of the measurement station which is set as the origin of the coordinate system is obviously higher than other measurement stations, which perhaps is not unexpected. Therefore in a research perspective, a without-mobile-point self-calibration method with the equal accuracy will be investigated.

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