

THE DYNAMIC MEASURING ERROR MODEL AND FORECAST OF NATURAL STANDARD AND STANDARD DATA INSERTION¹

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Abstract: In the paper, a dynamic measuring system is set up on basis of the precise angle-measuring instrument. The paper analyzes the dynamic characteristic of the test data and the measuring system and establishes the forecasting model of the dynamic error data of the system by use of the theory of time serial and fuzzy neural network. During training the model, the insertion correction method of a limited number of standard data is used to get model parameter. During using the model, based on the circular self-sealing feature of the angle measuring system, the paper puts forward that the forecasting model is studied itself and revised itself with natural standard. It makes the suitability of the established model better and the established system more economical.

Keywords: Natural Standard, Standard Data Insertion, Dynamic Error Model

1 GENERALIZATION

Dynamic measurement system means that measurands or comparative parts have dynamic alternating factors. Features of dynamic measurement appear on its dynamic randomness, pertinence, and temporal and spatial alternation. From the data flow of making a system, at least one sector has or is introduced alternating dynamic variables. From the result, the output of a dynamic measurement system is a stochastic process. Similarly, the measuring error is a stochastic process.

With the incessant improvement and development of measurement technique and means, the task of dynamic measurement is more and more, and the demands are also higher and higher. At the present time, the international measurement fields are in the period of turn from static measurement to dynamic measurement. On the one hand, many excellent static measurement technique and methods are being improved and renovated continually. On the other hand, more attention is being put in dynamic measurement. Much beneficial work has been done in theory and practice such as discussing and drafting the measure specifications, evaluating the dynamic measuring error, calibrating the dynamic characteristics of measurement system, and so on. However, it should be noticed that there are many new problems in dynamic measurement because there isn't natural succession in dynamic measurement and static measurement, which requires man of recreating new measure specifications and theoretic system. At the same time, the infiltration of adjacent subjects is increasingly affecting and enriching the connotation of dynamic measurement.

2 DYNAMIC MEASUREMENT SYSTEM USING STANDARD QUANTITY INTERPOLATION

2.1 Error expression of static measurement systems

In general, the measuring error of a static system may be expressed as

$$\Delta = f(x, \Delta x) \quad (1)$$

Where x is a measurand, Δx is the measuring error of the measurand, and f is the error transfer function. To direct measurement $\Delta = \Delta x$. In the upper expression, f is usually explicit. For example, the measuring error expression of a certain universal toolmaker's microscope is

$$\Delta = \pm(0.5 + L/100) \text{ mm} \quad (2)$$

From the upper expression we can get that the measuring error of measurands using this instrument will be determined before measurement.

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2.2 Dynamic error of dynamic measurement systems

The truth-value is usually a stochastic variable or process when calculating the dynamic measurement error of a dynamic measurement system, because of its uncertainty. So we can only use statistical characteristic to characterize the truth-value. It determines the statistical characteristic of dynamic measurement error. From the error definition expression:

$$\Delta_t = y(t) - Y_0(t) \quad (3)$$

$y(t)$ and $Y_0(t)$ are usually correlative stochastic processes, and the characterization of statistical characteristic of Δt is determined by the statistical characteristic of $y(t)$ and $Y_0(t)$.

2.3 Dynamic measurement error separation and correction

Using error separation and correction technique can improve measurement accuracy and lower measurement costs while processing measured data. The method is widely and successfully applied in static measurement systems, similarly it can be used in processing dynamic measured data.

Dynamic measured data $y(t)$ can be divided into three parts as follows: definite part with explicit expression; stable part with stable statistical characteristic; other indeterminable or indefinite part. The first part can be regarded as static part of the dynamic measured data. The second is the object of dynamic error separation and correction. It is the premises of dynamic error correction to separate stable part with steady statistical characteristic and gain the mathematical model of its statistical characteristic via certain technique and means. It is the key of dynamic error correction how to determine these items and build a technical scheme of error correction. As to a dynamic measurement system, there are many error sources. It is the objective of dynamic error separation and correction to analyze main factors affecting error and main error terms, and determine their models. The specific steps may be summarized as follows:

1. Analyzing the dynamic measurement system and determining main objects researched (error sources);
2. Analyzing dynamic measured data, separating the characteristic of main objects researched and analyzing its stability;
3. Determining error separation and correction scheme, and building error model;
4. Doing practical correction and analyzing system accuracy.

Standard quantity relative method like static measurement is often used to separate dynamic measuring error in practice. It is essential to use measured data of the measurement system with higher accuracy as truth value—including dynamic measurement error, but its accuracy is superior to the system, so to gain the dynamic error of the dynamic measurement system, then to do dynamic error separation, modeling and error correction on the basis of it. The advantage of this method is that the dynamic error of measurement system is easy to separate and analyze. But there are still many problems in practice, especially in gaining dynamic measurement standard sources with high accuracy. It is obviously unpractical to require each dynamic measurement system of finding a system with higher accuracy. And it is impossible in most cases.

2.4 Introduction of dynamic standard quantity into gyration measurement systems

In order to research the technique of measuring error separation and correction of dynamic measurement systems, it is necessary to construct a dynamic standard quantity with high accuracy. The dynamic standard quantity must have high accuracy, high stability, and definite output characteristic. Definite expression of output at every point can be given, such as $30^\circ \pm 0.1^\circ$. Another basic requirement of constructed dynamic standard quantity system is that the system should be easy to realize, and its costs are low.

The dynamic standard quantity system, which is introduced in this paper while researching the characteristic of dynamic measurement error, is a dynamic standard quantity with a finite number of discrete values. Its principium is to introduce N number of standard quantities indicating values dynamically in the measurement range of 360° angle of gyration, and to gain the dynamic measuring error of the measurement system at these N number of points using these standard quantities, accordingly to gain error data which are necessary to further theoretic research and practical error correction.

2.5 About dynamic error forecasting

Introducing a finite number of discrete standard quantity values into a dynamic measurement system ensures the accuracy of large data, however, it is unable to directly process measured data between adjacent standard quantities. In this paper the constructed dynamic error model is used to do the next step of error forecasting, that is to say, the former dynamic error values and model are used to forecast the dynamic error of the coming value point of standard quantities. So we can use curve fitting method interpolation method and so on to do dynamic error correction of measurement points.

3 DYNAMIC GONIOMETRIC SYSTEM AND ERROR MODEL

3.1 Dynamic goniometric experimental system

The dynamic goniometric experimental system is converted from the original raster goniometer. A multiple-surface prism is fixed on the original mainshaft gyration system. The multiple-surface prism and photoelectric dynamic autocollimator fixed on the bed make the discrete standard quantity values forming system. During the course of measurement, photoelectric dynamic autocollimator will send a comparative signal once it aims at a flank of multiple-surface prism. Subtracting the standard angular value of multiple-surface prism from the current output of raster goniometer, then the dynamic measuring error of the measuring point, which is named as y_n (where subscript n is the n comparing signal), are gained.

3.2 Time series theoretical model of dynamic measuring error

Signal pre-process should be done before building sequential model. The contents of pre-process contain picking out coarse error, separating definite part (or system error), compensating for standard quantity signal, etc. Its objective is to gain stochastic part of the dynamic measuring error Δy_n . So we can regard the stochastic dynamic error set $\{\Delta y_n\}$ as second-order non-stationary random series with zero equalizing value and finite variance.

According to time series theory, time series $\{\Delta y_n\}$ can be characterized with ARMA(p,q) model if it is a second-order non-stationary random series with zero equalizing value and finite variance, that is:

$$\Delta \tilde{y}_n = -\sum_{i=1}^p f_i \Delta \tilde{y}_{n-i} + \sum_{j=0}^q q_j a_{n-j} \quad (4)$$

Where $\Delta_0=1$, f_i is the autoregressive coefficient, q_j is the moving average coefficient, and a_j is white noise.

Although in theory this type of random series can be characterized very well with the upper model, it is difficult to get nonlinear coefficients of the model. In engineering practice, its simplified model AR(p) is usually used to characterize the upper time series. The following is the expression of AR(p) model.

$$\Delta \tilde{y}_n = -\sum_{i=1}^p f_i \Delta \tilde{y}_{n-i} + a_n \quad (5)$$

The model order p and coefficients $\{f_i\}$ can be gained using the method of time series theory.

3.3 Dynamic measuring error forecasting, error correction and model modification

From optimal prediction principle of time series theory, when random distribution approximates to normal distribution, the upper model can forecast the next l steps well. Especially, small fiducial interval can be gained in high degree of confidence while forecasting the next step. This supplies theoretic foundation to dynamic measuring error forecasting using AR(p) model. It is noticeable what AR(p) model characterizes is only stochastic part of dynamic measuring error. So the influence of system error should be considered in dynamic error forecasting to get total measuring error and do dynamic error correction according to it.

Here, AR(p) model characterizes a non-stationary time varying system, so it should be refreshed after getting a new value point of standard quantity. At the same time, the model of system error, which is another part of dynamic measuring error, should be modified correspondingly, so the whole dynamic measuring error model can describe the characteristic of the system dynamically.

Figure 1 is practical correction example of dynamic goniometric device.

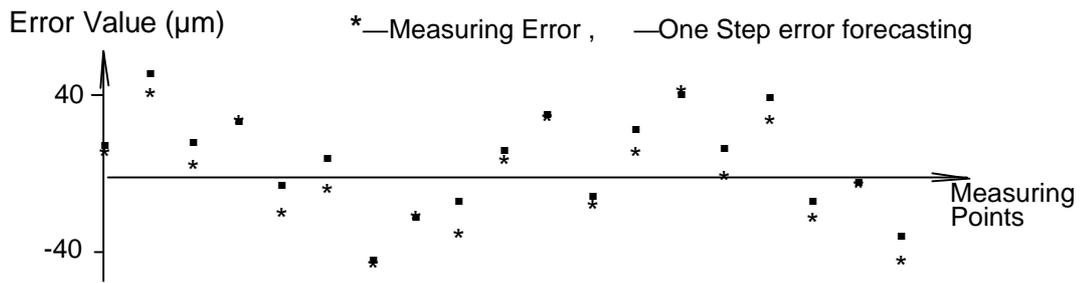


Figure 1. Dynamic measuring error forecasting based on AR(p) model

4 ERROR MODEL MADE UP OF FUZZY NEURAL NETWORK

Fuzzy rules are described as follows:

If x_1 is F_1^j , and x_2 is F_2^j ,, and x_n is F_n^j

then $y = f_j(X)$ (6)

Where $X = (x_1, x_2, \dots, x_n)^T$, $f_j(X) = \sum_{i=1}^n C_i^j x_i + C_0^j$

Apparently fuzzy system linearly splits up the input space, but to some nonlinear input spaces it is too complex. If using neural network to make membership grade function of nonlinear input space and join membership grade function together with fuzzy system, fuzzy rules will be simple and practicable. Fuzzy rules of current fuzzy system are described as follows:

If $X \in R_j$ then $y = f_j(X)$

Where $X = (x_1, x_2, \dots, x_n)^T$, R_j is parts of the split input space.

$f_j(X) = \sum_{i=1}^n C_i^j x_i + C_0^j$ (7)

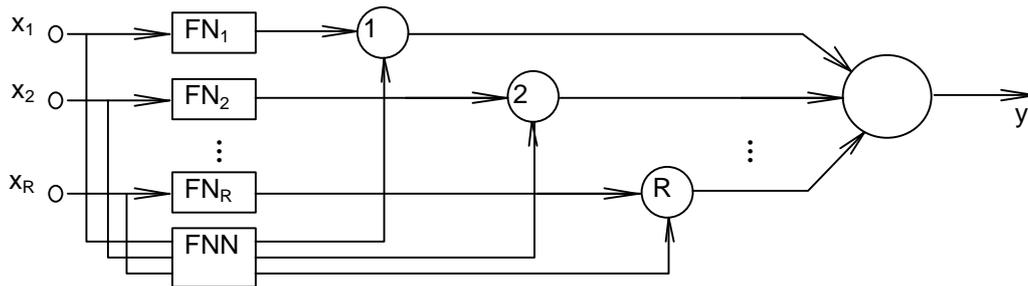


Figure 2. The structure graph of fuzzy neural network system

In the figure 2, FN_j is the j order fuzzy regular neuron corresponding to input space area, X_i is the input variable, FNN is the regular relevance grade neuron, and y is the output.

In the upper graph, dynamic error forecasting model that this paper requires will be built if the input is the previous n number of dynamic error term and the output is the next dynamic error forecasting term.

During the course of model training, by fuzzy rule optimization and selection, and neuron transfer function optimization, fuzzy rules and network parameter will be determined, and they will be regarded as error model to do dynamic error forecasting and correction. During the course of measurement, it is necessary to do real-time improvement and refreshment of error model. Compared with figure 1, more oncoming and better forecasting accuracy is gained by used of this method.

5 NATURAL REFERENCE OF GYRATORY ANGLE MEASURING PROCESS

In gyratory angular measure, the gyratory angle, which is formed once unit under test gyrates one circle, is 360° . In dynamic measurement, dynamic measuring error will be added to measure data because of the influence of many kinds of factors. Currently what we are doing is to set up another finite standard quantity generating system to calibrate finite angular node of gyratory angle measure and modify error-forecasting model at these reference points. This method can do error forecasting well to non-stationary dynamic measurement system, but much extra expense is required to set up the standard quantity generator. To stable systems and quasi-stationary dynamic systems that are stable in a short time, it can be used to build the original dynamic error-forecasting model. After building error model, we can use the natural reference of 360° to do model modification, so as to eliminate the influence of factors such as time drift, temperature drift, etc. It is relatively easy to determine single standard quantity value of the natural reference of 360° . And the expense is relatively small.

6 SUMMARY AND PROSPECT

Error forecasting and correction technique of dynamic measurement system is very important to supply of systematic measurement accuracy, research of systematic error characteristic and functional mode. It is certain that some technique and means can be used to get the features of dynamic measurement system and build error model by parts of work done for it. Dynamic error forecasting and correction can improve systematic measurement accuracy. The further extension and improvement of its theory and technique and its practical use is the main subject of the field in the future.

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