Dynamic Error Prediction Method of Simulation Turntable Based on ARMA-NN Model

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Abstract. The dynamic error correction of simulation turntable is an importance way to improve the turntable’s accuracy and reliability in the process of simulation. In this paper, an error modelling and prediction method combining ARMA (autoregressive moving average) model and NN (neural network) is proposed. In this method, an AIC criterion is used to determine the order of ARMA model, which can solve the problem to confirm the input and output variables of BP (back propagation) network. The dynamic error of simulation turntable is predicted and corrected online by this ARMA-NN model to get better performance. The validity of the method is illustrated by MATLAB simulation.

1. Introduction
The simulation turntable is a large time-delay system with many non-linear factors, which will inevitably produce system errors in the process of operation [1]. With the passage of time, the wear of the mechanical structure and the aging of the electrical equipment of the turntable will inevitably lead to the decrease of the control effect of the system and the increase of the system error, which will inevitably affect the operation accuracy of the system and reduce the performance of the simulation test. In order to effectively improve the control accuracy of the system, error correction technology must be used to reduce the error and improve the accuracy. With the development of on-line detection technology, real-time error correction is becoming more and more important. In the process of real-time error correction, it is available to model and predict dynamic error. Dynamic error prediction is the basis of error correction and plays a very important role in error correction technology. In this paper, a dynamic error modelling and prediction algorithm of simulation turntable based on ARMA-NN is presented. It solves the problem of selecting input and output of neural network, improves the prediction accuracy of dynamic error, and realizes online correction of dynamic error. At last, a simulation example is given to illustrate the effectiveness and advantages of the proposed method.

2. Dynamic Error of Simulation Turntable
The simulation turntable is a servo system, whose output changes according to the input instructions. In order to drive the test equipment and the inner and outer frame with considerable weight, permanent magnet DC torque motor is used. The control system is a typical three-loop servo control system including current, speed and position. In order to make the system rapid, a compound control is
designed on the position loop, that is, feed forward correction and lead emendation based on the given input compensation are added, which not only keeps the system stable, but also restrains the measurable disturbance.

However, because the simulation turntable is kind of large inertia equipment with complex control structure, involving many electrical devices and rotating components, it will inevitably come into being following errors, whose components are much more complex than that of static testing. For example, in the moving of system, the system errors with high frequency noise signal are mainly caused by the large inertia of the simulation turntable, such as response errors, servo system errors and geometric errors. When the system is positioned at a certain position, its error is mainly a random error signal similar to the stationary process as shown in Fig. 1 and Fig. 2, where the sinusoidal swing of 1°1Hz means that the turntable is swinging according to the sinusoidal oscillation with the frequency of 1Hz and amplitude of 1°, and the position of 1° means that the turntable is fixed at the position of 1°.

![Dynamic error curve of simulation turntable](image1)

(a) Error of sinusoidal swing 1°1Hz  
(b) Error of position 1°

Fig. 1 Dynamic error curve of simulation turntable

![Dynamic error's amplitude-frequency characteristic curve of simulation turntable](image2)

(a) Error of sinusoidal oscillation 1°1Hz  
(b) Error of position 1°

Fig. 2 Dynamic error’s amplitude-frequency characteristic curve of simulation turntable

From the above figures, we can see that the dynamic error problem is more obvious when the turntable is in motion. And with the increase of swing frequency and amplitude, the error becomes larger and larger. In the actual test process, when the swing frequency and amplitude of the turntable are large, its performance cannot meet the double-ten index. The increase of errors will inevitably affect the test results. Therefore, dynamic errors must be compensated in some high precision test occasions to improve the reliability of test appraisal.
3. ARMA-NN Modelling Method

Artificial Neural Network (ANN) is popular because of its powerful parallel processing information ability and fault tolerance, and it does not need the specific mathematical model of the control system to realize the “black-box” operation, that is, to estimate the model according to the input and output of the controlled system. BP network has good non-linear dynamic mapping capability, dynamic attractor and information storage capability, especially its ability to handle time-varying input and output. So it is very suitable for dynamic systems. However, the determination of input and output of neural networks is a problem to be solved. Thus, generally, the trial-and-error method is used, but the efficiency is very low [2–6]. Here, using the order of ARMA model to determine the input and output of the neural network can solve this problem well.

3.1. ARMA model

The dynamic error model describes a dynamic process with both regularity and randomness. According to the error data sequence of simulation turntable, n-order ARMA model can be established as follows:

\[ e_t - \phi_1 e_{t-1} - \cdots - \phi_n e_{t-n} = a_t - \theta_1 a_{t-1} - \cdots - \theta_m a_{t-m} \quad (1) \]

That is:

\[ \varphi(q) e_t = \theta(q) a_t \quad (2) \]

where \( \varphi(q)=1 - \phi_1 q^{-1} - \phi_2 q^{-2} - \cdots - \phi_n q^{-n} \), \( \theta(q)=1 - \theta_1 q^{-1} - \theta_2 q^{-2} - \cdots - \theta_m q^{-m} \), \( q^{-1} \) is backward shift operator, and \( a_t \) is normal white noise. This model can be used to model the time series of stationary stochastic process.

But the \( m \) and \( n \) in ARMA model is the most difficult part of the modelling process to determine. In this paper, AIC criteria are used to determine the \( m \) and \( n \):

\[ AIC(m,n) = \min_{l,m,n} AIC(m,n) = \ln \sigma^2 + 2(m + n + 1) / N \quad (3) \]

where \( \sigma^2 \) is the variance of the residual, and \( N \) is the length of the sequence \( y_t \). Paudit-Wu proposed a more convenient modelling scheme, namely, taking \( (m+1, n) \) as \( (m, n) \), so that the problem changed from the original need to determine two parameters to only one parameter, greatly simplifying the calculation process. In the process of modelling, the order of the model is increased step by step from a certain value. When the data are fitted, the criterion function tends to decrease. When reaches a certain order, the criterion function will gets a minimum, which is the best model order determined by the criterion function.The main steps of calculation are as follows:

- Given the upper limit of the model order and the initial value \( m = 2 \), the ARMA parameters \( \varphi(q^{-1}) \) and \( \theta(q^{-1}) \) of the model can be calculated by above formulas, and \( \sigma^2 \) and AIC can be obtained, too.
- Let \( m = m + 1 \), and the same as the previous step, calculate the ARMA parameters \( \varphi(q^{-1}) \) and \( \theta(q^{-1}) \), and \( \sigma^2 \) and AIC, until the upper limit of the model order is reached.
- Take the minimum AIC corresponding order and parameters to determine the final ideal model order and parameters.

3.2. BP network

BP network is suitable for forecasting problems because of its capability to infinitely approximate the mapping of non-linear functions. According to Kolomgorov theorem, a three-layer BP network can approximate any complex non-linear function with arbitrary precision, so in dynamic error modeling, generally speaking, it is enough to use three-layer BP network. Because the traditional BP algorithm of neural network has some inherent defects, such as easy to fall into local minimum, slow
convergence in learning course, etc., this paper adopts LM algorithm, that is, the weight adjustment of BP algorithm is as follows:

$$\Delta W = (J^T J + \mu I)^{-1} J^T E$$

(4)

where $W$ is the weight, $\Delta W$ is the weight correction, $E$ is the error, $J$ is the Jacobian matrix of the error to the weight differential, and $\mu$ is the scalar. $\mu$ can be adjusted adaptively, which determines whether the learning is achieved according to Newton method or gradient method. Practice shows that LM algorithm can effectively solve the shortcomings of traditional BP algorithm, shorten the learning time, and is suitable for solving medium and large-scale problems.

In neural network prediction, in order to reduce the influence of dynamic error size changes on data sequence, ensure the accuracy of calculation, reduce rounding errors and avoid overflows, the original error data sequence is standardized. Because dynamic errors vary in a certain range $(E_1, E_2)$, the original error data sequence $\{e_t^0\}$ can be processed as follows:

$$e_t = \frac{e_t^0}{E_2}$$

(5)

If $e_t^0 > E_2$, $e_t = E_2$. Similarly, if $e_t^0 < E_1$, $e_t = E_1$. And the predicted result must be multiplied by $E_2$ to get the final result.

From the above, we can get a dynamic error ANN model of data output by using input multiple historical data, but the number of data variables in the input layer cannot be determined. So we can use the estimation $(m, n)$ of ARMA model to get the number of input variables. For instance, if the sequence of measured data can be estimated as an ARMA(6,5) model, the input variables of the neural network can be determined as the nearest six historical values and the nearest six residual values of the second-order difference sequence $\{e_t^0\}$, and the next sampling value of $\{e_t^0\}$ is taken as the target output of the network to form a sample, and many groups of sample are selected to form a training sample set to train the network. At this time, the convergence speed of the network is obviously accelerated. The effect of measurement is improved obviously. The specific steps are as follows:

- AIC criterion is used to determine the order of input and output of ARMA model.
- The input and output orders of the neural network model are determined according to the input and output orders of the ARMA model.
- BP algorithm is used to model and predict the error data.

Using neural network for online prediction error, when it is found that the error of the trained model increases due to the change of system motion law, the model needs to be trained again. Because the predicted data have certain correlation with the previous historical data, it can be retrained on the basis of the existing weights to realize the rolling prediction of dynamic errors to obtain very good result. This method has a good real-time performance.

4. Examples and Analysis
Taking a random dynamic error data sequence as a sample, the order is determined by using ARMA model, and different system parameters $(m, n)$ and AIC values are obtained by simulation with MATLAB, as shown in Table 1. As can be seen from the table, the AIC value of the selected sample is the smallest when $(m, n)$ is $(2,1)$, so it can be determined that the neural network model should take two historical values and the last two residual values as input.

| $(m, n)$ | $\phi_1$ | $\phi_2$ | $\phi_3$ | $\phi_4$ | $\theta_1$ | $\theta_2$ | $\theta_3$ | $\theta_4$ | AIC    |
|--------|----------|----------|----------|----------|-----------|-----------|-----------|-----------|--------|
| (2,1)  | -1.258   | 0.2637   | -0.6449  |          | -0.01442  |           |           |           |        |
A neural network model of S-type function is established, and the dynamic error data of the stationary signal is used to predict. The predicted data of the neural network are compared with the data obtained by ARMA(2,1) model, as shown in Fig. 3.

From this figure, we can see that the method of ARMA-NN is better than ARMA model. From the error analysis, the maximum error of ARMA-NN model is 25.7%, the absolute average error is 9.3%, and the mean square error is 11.5%, while the maximum error of ARMA model is 37.43%, the absolute average error is 12.2%, and the mean square error is 15.4%.

The dynamic error data of the sinusoidal swing rollers of the turntable is simulated at 1° 1Hz. Because there is a lot of noise in the signal source, which affects the analysis and prediction of the regular variation of the system error, it is necessary to use the filtering method to filter the noise. The filtering method used here is the DB4 wavelet filtering method. The different system parameters and AIC values are determined by using ARMA model, as shown in Table 2. As can be seen from the table, the AIC value of the selected sample is the smallest at the same time, so it can be determined that the neural network model is input with three historical values and the last three residual values.

| (m,n) | \(\phi_1\) | \(\phi_2\) | \(\phi_3\) | \(\phi_4\) | \(\theta_1\) | \(\theta_2\) | \(\theta_3\) | \(\theta_4\) | AIC     |
|-------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|---------|
| (2,1) | -1.996      | 0.9963      |              |             | 0.6254      |              |             |             | -24.9262 |
| (3,2) | -2.965      | 2.935       | -0.97        |             | -0.5798     | 0.547        |             |             | -26.0347 |
| (4,3) | -2.1631     | -0.5532     | -1.391       | -0.781      | 0.2482      | 0.02511     | 0.4082      |             | -25.8766 |
| (5,4) | -3.966      | 6.019       | -4.241       | -1.017      | -0.01679    | 1.611       | 1.185       | -0.4308     | -0.08837 | -25.8188 |

The ARMA-NN model is used to predict the dynamic error data of the roll axis’s sinusoidal swing. The prediction data of the ARMA-NN are compared with the data obtained by the ARMA (3,2) model, as shown in Fig. 4.
Fig. 4 Prediction of sinusoidal swing’s dynamic Error

It can be seen from the figure that the predicted signal of the ARMA-NN basically coincides with the original signal, which effect is better than that of the ARMA model. The maximum error of the ARMA-NN model is 4.3%, the absolute average error is 1.3%, and the mean square error is 1.5%, while the maximum error of the ARMA model is 11.2%, the absolute average error is 5.1%, and the mean square error is 5.15%.

Thus, although the input variables of the ARMA model and the ARMA-NN method are the same, the result of ARMA-NN method is better than that of the ARMA model. The ARMA-NN method can learn the non-linear law of dynamic error, while the ARMA model cannot do this. So in theory, the prediction effect of the ARMA-NN method is better than that of the AMAR model. The experiments show that the absolute average error of the ARMA-NN model is reduced by 3% for stationary random signals and 4% for sinusoidal swing signals.

5. Conclusion
The dynamic error of simulation turntable will affect the simulation results. In this paper, a dynamic error prediction method based on ARMA-NN model is proposed to solve the problem of dynamic error modeling and prediction of turntable. The advantages of this method are as follows:

- Not only has a good effect on linear signals, but also has good prediction ability for non-linear signals.
- Only need to determine the input and output variables, the model prediction can be established;
- The convergence speed is faster, and the prediction effect is better;
- The real-time prediction and correction of dynamic errors can be realized, which can be further improved to meet the requirements of high precision of the turntable simulation.

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