Methods Research about Accuracy Loss Tracing of Dynamic Measurement System Based on WNN

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Abstract. The paper presents a method of achieving accuracy loss of the dynamic measurement system according to change of errors on different period of the system. WNN, used to trace the accuracy loss of dynamic measurement system, traces the total precision loss during a certain period to every part of the system, and the accuracy loss of every part can be get, so retaining the accuracy and optimum design of the system is possible. Take tracing the accuracy loss of a simulated system for an example to testify the method.

1. Introduction

With time going on, Dynamic measurement system, especially the mechanical one, has accuracy loss, even without considering the influence of environment, as a result, its measuring accuracy gradually drops inevitably. The modern science and technology development demands measurement, especially dynamic measurement, more and more highly, and personnel working in project measuring and instrument designing continuously focuses their mind on how to improve accuracy of dynamic measurement. The paper offers a new method to improve accuracy of dynamic measurement, after obtaining the total accuracy loss of dynamic system, trace it to every part of the system. According to the accuracy loss of every part and its change rule with time, relevant measure can be taken to resume the accuracy of the system, especially retaining the accuracy of the important part, so the capacity of resuming and retaining the accuracy of the system and its accuracy can be improved obviously.

WNN(Wavelet Neural Networks) is a new method of signal processing based on Wavelet Analysis. Neural Networks, with the capacity of self study and mode identify, can make input and output be a nonlinear relation. And Wavelet Analysis becomes the main tool of signal analysis for the automatic flex and parallel move character of its basal function. At present there are two main means for combination of Wavelet Analysis and Neural Networks [1]:

1. incompact combination, put Wavelet Analysis ahead of Neural Networks and make the result of Wavelet Analysis as the input of Neural Networks;
2. compact combination, interfuse Wavelet Analysis and Neural Networks directly, wavelet function and scale function as the motivation function of Neural Networks.
In the paper, incompact combination is used to do research on tracing accuracy loss of dynamic measurement system.

2. The theory and model of tracing accuracy loss of dynamic measurement system

2.1. Fundamentals of accuracy loss of dynamic measurement system

Accuracy is the difference in number between measuring result and true value, related to the errors, so accuracy can be signified by errors, changing with errors [2]. In this paper change of errors is used to signify accuracy loss of dynamic measurement system, so if errors become smaller, the accuracy loss of the system will be smaller. Also if errors increase, the accuracy loss of the system becomes bigger.

Theory of tracing accuracy loss, a new accuracy theory based on dynamic accuracy theory of whole system, is an antidromic problem of accuracy theory. In response to change of the total errors of the whole system during different measuring period, create total accuracy loss model of the system. With transfer chain of the whole system and modern signal analysis methods, trace the total precision loss during a certain period to every part of the system, and the accuracy loss of every part can be gotten, so retaining the accuracy and optimum design of the system is possible.

2.2. Simulation and modeling of accuracy loss of dynamic measurement system

Representative dynamic measurement system usually is a series and parallel system, figure 1 is a simple series and parallel. Based on the modeling principle of dynamic accuracy theory of the whole system, the transfer chain function of the whole system can be described as follows [3]:

\[
F(f_1, f_2, f_3, f_4) = f_1(f_2f_3 + f_4)
\]  

(1)

Figure 1. Configuration figure of series and parallel system.

Note: \(f_i(\cdot)\) as the transfer function of every part, \(i=1,2,3,4,\)

The whole output errors \(e_j\), in different phase (phase can be a period, such as a series of measurements in a short time), can be described as follows:

\[
e_j = (e_{1j}(t)f_2 + e_{2j}(t))f_3 + e_{3j}(t)f_4 + e_{4j}(t)
\]  

(2)

Note: \(e_j(t)\) as the errors of every part at \(j\), concluding the disturbance, \(i=1,2,3,4,\ j=0,1,2…n.

Dynamic errors of steady state measurement \((j=0)\) of the system as the basis, accuracy loss of dynamic measurement system during other period can be described as equation 3:

\[
E_j = e_j - e_0 - [(e_{1j}(t)f_2 + e_{2j}(t))f_3 + e_{3j}(t)f_4 + e_{4j}(t)]
\]

\[
-[(e_{10}(t)f_2 + e_{20}(t))f_3 + e_{30}(t)f_4 + e_{40}(t)]
\]

\[
= [(e_{1j}(t) - e_{10}(t))f_2 + (e_{2j}(t) - e_{20}(t))]f_3 + (e_{3j}(t) - e_{30}(t))
\]

\[
+ (e_{1j}(t) - e_{10}(t))f_4 + (e_{4j}(t) - e_{40}(t))
\]  

(3)
Note: $j=0,1,2…n$, equation 3 shows the accuracy loss of system and gives a series of $E_j$.

A dynamic simulation system as figure 1, has four segments: second-order segment, linear segment, gain segment and periodic segment. Their transfer characters can be described as follows:

$$
f_1(t) = 2e^{-2t} \sin(10\pi t + 3\pi / 4) ; \quad f_2(t) = 0.5t + 2 ; \quad f_3(t) = 4 ; \quad f_4(t) = \sin(t)
$$

According to equation 1, transfer chain function of the system can be showed as equation 4:

$$
F(f_1, f_2, f_3, f_4) = f_1(f_2 f_3 + f_4) = 2e^{-2t} \sin(10\pi t + 3\pi / 4)((0.5t + 2)\cdot 4 + \sin(t)) = 2e^{-2t} \sin(10\pi t + 3\pi / 4)(8 + 2t + \sin(t)) \quad (4)
$$

Suppose the errors ($j=0$ and $j=n$) of every segment as follows, to study accuracy loss of the system ($j=n$), compared with the state ($j=0$). Note that errors of the third segment $e_3(t)$ is a random signal and average value of the random signal is 0.

$$
e_{10}(t) = 0.1t ; \quad e_{20}(t) = \sin(0.3t) ; \quad e_{30}(t) = n_{w0}(t) ; \quad e_{40}(t) = \sin(0.03t + \pi / 4)
$$

$$
e_{1n}(t) = 0.3t ; \quad e_{2n}(t) = 2\sin(0.3t) ; \quad e_{3n}(t) = n_{wn}(t) ; \quad e_{4n}(t) = 2\sin(0.03t + \pi / 4)
$$

Suppose that the system is out of disturbance, change of accuracy of the system can be described as follows:

$$
E_n = 0.4t^2 + 1.6t + 4\sin 0.3t + 0.2t \sin t + \sin(0.03t + \pi / 4) + n_{wn}(t) - n_{w0}(t) \quad (5)
$$

The result of the random signal $n_{wn}(t) - n_{w0}(t)$ is a random signal, so equation 5 can be replaced by equation 6.

$$
E_n = 0.4t^2 + 1.6t + 4\sin 0.3t + 0.2t \sin t + \sin(0.03t + \pi / 4) + n_w(t) \quad (6)
$$

Figure 2 is the graph of equation 6 in MATLAB with 100HZ sampling frequency to sample the total error.

3. Research on tracing accuracy by WNN

After analyzing graph 2, it can be found that the original errors contains quadratic term errors, so the quadratic term must be separated from the whole errors before Wavelet Analysis. Fit multinomial by the least square method in MATLAB to separate quadratic term errors. A smoothness graph like...
figure 2, its quadratic term coefficient is 0.4, and its once term coefficient is 1.6. So its expression as follows:

\[ s = 0.4t^2 + 1.6t + 0.8 \]  

(7)

The signal without quadratic term errors can be separated. Next, analyze it by 5 tiers decomposition based on db3 wavelet in WNN [4]. Figure 3 and figure 4 is the result. Figure 3 is 5 tiers wavelet decomposition approaching signal and figure 4 is 5 tier wavelet decomposition detail signal. The signal described in figure 3 and figure 4 will be analyzed as follows.

According to d2 and d3 in figure 4 and a2 in figure 3, it can be found that the original signal has white noise \( e_3(t) \) with average value 0. Wavelet tool box in the MATLAB has a Graphical User Interface GUI, it can be used to amplify the signal that is to be analyzed. In response to d3 and a2, the system has a signal \( 0.2\sin t \); from d1 and a1, a periodic signal (its periodicity is 200s) can be found in the total accuracy loss signal, and considered with a4 its expression can be \( \sin(0.03t + \pi/4) \); in addition, take further studied on figure 3 and figure 4, and their partial enlarged drawing, another periodic signal, which has periodicity 20s, is in the total accuracy loss signal. In brief, the total accuracy loss signal contains a kind of quadratic term errors, three kinds of periodic signal, and a kind of white noise.

According to the analysis above, the unknown part can be signified by Neural Networks. The transfer characteristic (the same as transfer chain function) and error characteristic of every segment of the system are known. Take the second segment which is a linear gain segment for example, suppose its expression as follows:

\[ f_{20} = a_1t + b_1 \]  

(8)

Its errors characteristic is periodic, like the expression:

\[ e_{20} = k_2 \sin(2\pi t + \phi) \]  

(9)

Take the unknown parts as input of a 3 tier BP Neural Networks and take the output errors of the system as the input of networks, its structure like figure5, networks can be trained based on the capacity of self study and self organize of the BP networks and Levenberg-Marquart optimized algorithm. The training errors is \( 10^{-4} \), and the power of the networks are the unknown parts as follows:

\[ f_1(t) = 1.998 e^{-2t} \sin(10 \cdot \pi t + 3\pi / 4) \]  

(10)

\[ f_2(t) = 0.499t + 2.003 \]  

(11)

\[ f_3(t) = 4.001 \]  

(12)

\[ f_4(t) = 1.002\sin(t) \]  

(13)
\begin{align*}
e_1(t) &= 0.202t 	ag{14} \\
e_2(t) &= 0.996\sin(t) 	ag{15} \\
e_3(t) &= n_i(t) 	ag{16} \\
e_4(t) &= 0.999\sin(0.03t + \pi/4) 	ag{17}
\end{align*}

$e_i(t)$ are errors of the every part of the dynamic measurement system while $i$ equals to $n$, compared with while $i$ equals to 0, and $e_i(t)$ can be considered as accuracy loss of every segment. The result accords with characteristic of the every part of the original system. According to the analysis, tracing accuracy loss can be carried out by WNN. By now, accuracy loss of every segment of the system is known. The first segment has the biggest accuracy loss, as accords with the errors characteristic of the first segment; the second segment and the forth segment also have accuracy loss to a certain extent. And refer to the result of the wavelet analyses, the random signal has effects on accuracy loss of the system.

4. Conclusion

In this paper, accuracy loss of a simulated dynamic measurement system is studied base on WNN. According to change of errors of the system, accuracy loss of the system is analyzed, and put forward that the total errors of the system is used to achieve the accuracy loss function and accuracy loss of every part of the system, to identify the part which has the biggest accuracy loss. Based on the analysis, the method is feasible for study on accuracy loss of dynamic measurement system, and it can be a theoretical gist for the further research on accuracy loss of actual system, so it will play an important part in designing, maintenance and measurement of a system.

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