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CORRECTION OF SIGNAL DISTORTION CAUSED BY SENSOR’S DYNAMIC CHARACTERISTIC

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Abstract:* *The main cause of dynamic errors is due to limitation of sensor’s working frequency bandwidth. One way of solving this problem is designing an effective inverse filter. The method based on Particle Swarm Optimization (PSO) integrated with Functional Link Artificial Neural Network (FLANN) for correcting dynamic characteristics of sensor is presented to reduce sensor’s dynamic error caused by its systems limitation. The feasibility of dynamic compensation method is tested, Simulation results from simulator of sensor show that the results after being compensated has given a good description to input signal.

Keywords:* *Particle Swarm Optimization (PSO); Functional Link Artificial Neural Network (FLANN); dynamic error; dynamic compensation;.

1. INTRODUCTION

In test system ， if the sensor’s working frequency bandwidth is narrower than tested signal frequency bandwidth, the spectral components outside working frequency bandwidth will be distorted and the measured results can not describe the tested signal [1] [2]. At present the compensation method is using a dynamic compensator to process the output signal [3]. The method based on FLANN has been used widely, but the FLANN has some problems in different environment such as the local minimum problem, the unwanted study problem and so on [4]. PSO has also been used widely, but its optimized results easily effect by initial conditions[5]. Combines the advantages and disadvantages of two optimization algorithms, the method based on PSO integrated with FLANN is presented in this paper, the feasibility and field of application of method are also discussed.

2. DYNAMIC COMPENSATION OF SENSORS BASED ON PSO INTEGRATED WITH FLANN

The principle of dynamic compensation of sensors is shown in Figure 1. As shown in Figure 1, x(t) is the dynamic excitation signal; y(k) represents sensor dynamic response signal; r(k) is the expected sensor dynamic response result; z(k) is sensor responses after compensation and e(k) is the dynamic compensation error.

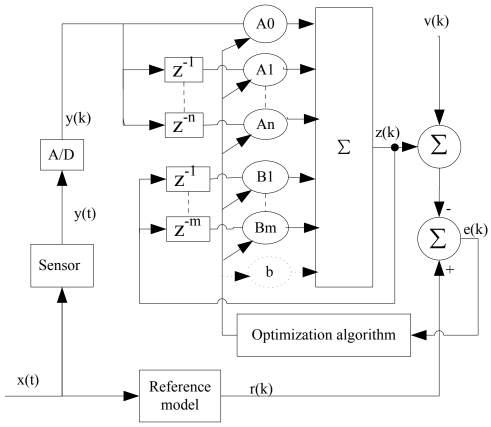


Figure 1.Principle of dynamic compensation of sensors

The principle of dynamic compensator [6] [7] [8] [9], therefore, is that the correctional result z(k) after compensation should approach the required ideal responses r(k) as close as possible and keep the loss function of the residual error sequence e(k) minimum. According to Figure 2, z(k) can be expressed by following equation

$$\begin{aligned} z(k) &= (A_0 + A_1 z^{-1} + \cdots + A_n z^{-n}) y(k) \\ &- (B_1 z^{-1} + \cdots + B_m z^{-m}) z(k) + v(k) \end{aligned} \quad (1)$$

Where $v(k)$ denotes a uniformly random noise, m and n are the steps of compensator, $A_0 \cdots A_n$ and $B_0 \cdots B_n$ are the coefficients of the compensator.

The vector form of coefficients can be expressed by following equation

$$W = [A, B]^T = [A_1 \cdots A_n, B_1 \cdots B_m]^T \quad (2)$$

The mean square error (MSE) between z(k) and r(k) is：

$$J = \frac{1}{N} \times \sum_{k=0}^{N} e(k)^2 = \frac{1}{N} \times \sum_{k=0}^{N} (r(k) - z(k))^2 \quad (3)$$

Here N denotes the sampling number.

The search speed of optimization method based on FLANN is high. However, it will fall into local minimum easily during network training. Although PSO algorithm has high global search capability, its optimized results easily effect by initial conditions. Combines the advantages and disadvantages of two optimization algorithm, the method based on PSO Integrated with FLANN is presented. With this method, the initial conditions of PSO can be determined by FLANN.

The steps of optimizing compensator’s coefficients by PSO algorithm integrated with FLANN are as follows:

Step 1: Set initial parameters of FLANN, including inputs X(k), learning factor α, threshold b, desired value of MSE and training times.

Step 2: Training the neural network till training times or desired value of MSE is attained. Then save last coefficients W.

Step 3: Set initial parameters of PSO algorithm, including population size, dimension, inertia weight, acceleration coefficients, position space and velocity space.

Step 4: Initialize every particle's position and velocity in parameter space through coefficients W in step2.

Step 5: Calculate the fitness function F(W) using formula as follow:

$$
\begin{aligned}
F(W) = J &= \frac{1}{N} \times \sum_{k=0}^{N} e(k)^2 \\
&= \frac{1}{N} \times \sum_{k=0}^{N} (r(k) - z(k))^2
\end{aligned} \tag{4}
$$

Step 6: Initialize the current particle's position as the individual extreme $pbest$, and the position of particle with minimum fitness among all individual extreme as $gbest$.

Step 7: Update the particle's position and velocity according to formula as follow:

$$
\begin{aligned}
v_{id}(n+1) = wv_{id}(n) + c_1 r_{1d}(n)(p_{id} \\
- x_{id}(n)) + c_2 r_{2d}(n)(p_{gd} - x_{id}(n)
\end{aligned} \tag{5}
$$

$$
x_{id}(n+1) = x_{id}(n) + v_{id}(n+1) \tag{6}
$$

Step 8: Calculate the fitness function F(W) again.

Step 9: Judge whether to update the particle's individual extreme $pbest$ and the global extreme $gbest$ of particle swarm.

Step10: Repeat step5 to step7, till meeting precision demand or reaching iteration times. output gbest, to obtain the coefficients of compensator.

3. THE FEASIBILITY ANALYSIS ON DYNAMIC COMPENSATION OF SENSORS BASED ON PSO INTEGRATED WITH FLANN

Various important types of sensors like accelerometers or load cells can be modeled by amass-spring system resulting in a second-order model [10] of the kind:

$$
H(s) = \frac{s_0 {\omega_0}^2}{s^2 + 2\delta\omega_0 s + \omega_0^2} \tag{7}
$$

Where s_0, δ and ω_0 denote static gain, damping and resonance frequency.

In order to simulate dynamic performance of those sensors, a second-order analog filter has been designed and its circuit is shown in Figure 2. We can simulate the characteristic of sensor through changing the parameters of resistance and capacitance.

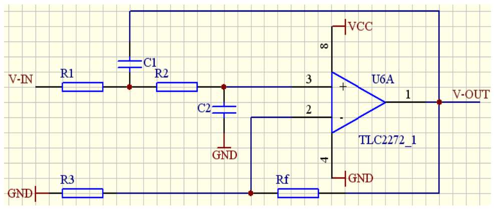


Figure 2 .The circuit of analog filter

In order to validate feasibility of the compensation method based on PSO integrated with FLANN, a square wave whose frequency is 200Hz has been used as the analog filter's input. Then, the input and response of analog filter has been measured by test system. Use the input and response, we can get the coefficients W of compensator through the dynamic compensation algorithm. Take the W and response into formula (1) then we can get the compensated result which showed in Figure 3.

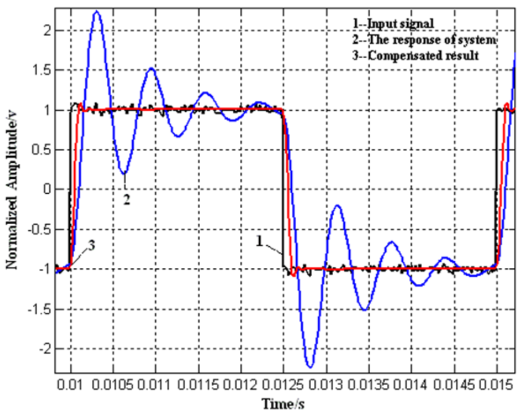
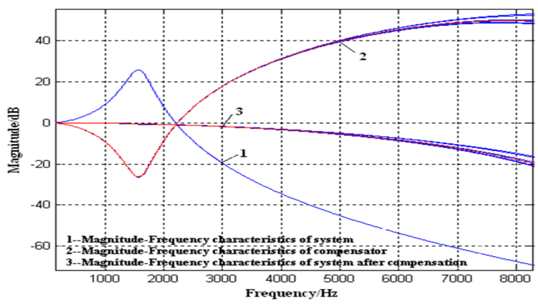


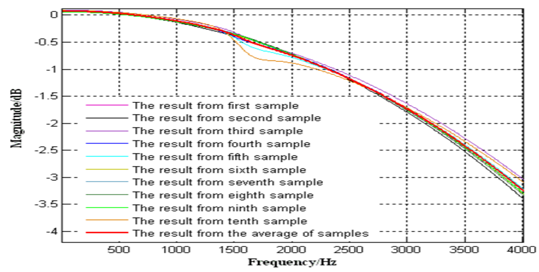
Figure3 The results of compensation

In Figure 3, the amplitude has been normalized, sampling period of test system is 0.02 ms .From the compensated result we cam see that the system response after compensation approached the input signal commendably, the speed of the dynamic response enhanced, the noise reduced.

In order to analyses the effect of training samples on coefficients W, ten groups of input and response of analog filter have been sampled by test system and average of input and response have been calculated. Then, the compensators have been obtained by compensation algorithm through those samples and average, the frequency response of those compensators and error analysis show in Figure 4 and Figure 5.

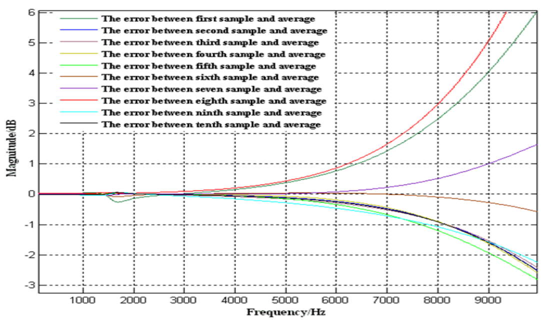


(a) Frequency response of analog filter and compensators

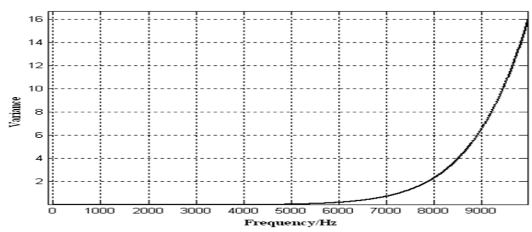


(b) Frequency response of system after compensation

Figure 4.Comparation of frequency response



(a) Frequency response error between samples and average



(b) Frequency response variance of samples

Figure 5.Error analysis of samples' frequency response

4. CONCLUSIONS

The primary outcome of the paper is the development of a dynamic compensation algorithm based on PSO integrated with FLANN to correct sensor's dynamic error caused by its systems limitation. The dynamic compensation algorithm can realize dynamic compensation without knowing the model of sensor, with this algorithm, we can avoid extra error cause by dynamic modeling of sensors. The algorithm has been demonstrated with a second-order system. It has been shown that the dynamic compensation algorithm based on PSO integrated with FLANN provides an accurate compensator in the relevant frequency region. Experimental results, showing the viability of the proposed algorithm, were presented.

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