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Study on Application of Adaptive Neuro Fuzzy Inference System in Noise Cancellation

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Abstract. ANFIS(Adaptive Neuro Fuzzy Inference System) can identify unknown non-liner dynamic characteristic of the channel.This paper constitutes a principle mode with self-adapting noise-canceling by analysis and study the principle of ANFIS , and gives the experimental model and simulation results, which show that ANFIS can convert noise source to interference ingredients of detection signal and plays a good noise-canceling role in its application in noise cancellation.

Keywords: ANFIS, noise, filtering, simulation model.

1. Introduction

Filtering is one of the commonly used signal processing methods in modern communications and control engineering. Filtering is to filter out the interference in signal by processing a series of measured data with errors, thus restoring the information flow interfered by noise as much as possible. There are many kinds of filterings[1]. The simplest filter is the linear filter with fixed weight coefficient. To improve the filtering performance, the weight coefficient (transfer function) of a filter often changes with the input signal, which is referred to as adaptive noise cancellation (ANC). If the filter's input-output relationship has non-linear mapping properties, the corresponding filtering is referred to as non-linear filtering. In daily life, many actual signals contain the noise caused by nonlinearity of the system or the Non-Gaussian noise, so it is very necessary to study the non-linear filtering.

By using a non-linear adaptive system, the concept of linear adaptive noise cancellation can be extended into the non-linear field, in which the Adaptive Neuro-Fuzzy Inference System (ANFIS) [2][3] is used to identify the unknown dynamic characteristics of the non-linear channel, transforming a noise source into an interference component in a detected signal. Under certain conditions, the proposed method is sometimes more effective than noise elimination techniques based on frequency-selective filtering, because when the distorted noise signal considerably overlaps the original effective signal, it is very difficult to separate it from the detected signal by using the frequency domain filtering technique.

The basic idea of ANFIS is very simple. It provides a learning method capable of extracting corresponding information (fuzzy rule) from data set for the fuzzy modeling procedure. The learning method, very similar to that in the neural network, can effectively compute the optimal parameters of membership function, enabling the designed fuzzy inference system to best simulate the expected or actual input-output relationship, so ANFIS is a modeling method based on existing data.

2. Principle of Noise Cancellation with ANFIS

Figure 1 shows the principle of adaptive noise cancellation under ideal conditions. There are immeasurable signals and measurable noise signals in Fig. 1. The noise source produces distorted noise

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through unknown non-linear dynamic characteristics, and then added to it, producing the measurable output signal. Now the task is to restore the information signal $s\ (k)$ from the output signal $y\ (k)$, where $y\ (k)$ is comprised of the information signal s (k), the distorted signal of $b\ (k)$ and corresponding delay signals.

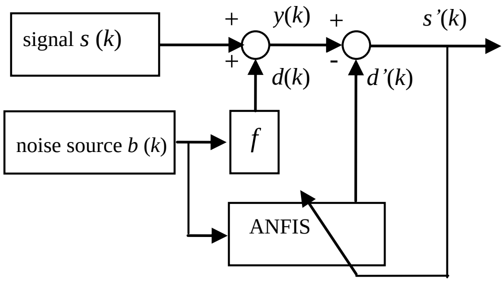

Fig. 1: Principle of noise cancellation with ANFIS

The detected signal is expressed as follows

$$y\ (k) = s\ (k) + d\ (k) = s\ (k) + f\ (b\ (k), b\ (k\text{-}1)\ , b\ (k\text{-}2)\ ,\ldots) \quad (1)$$

$f\ (\ )$ represents the dynamic characteristics of the channel through which the noise signal goes. If accurate $f\ (\ )$ is known, it is easy for us to restore the original information by subtracting $d\ (k)$ from $y\ (k)$ directly. However, $f\ (\ )$ is often previously unknown, and may be time variant with environmental changes. In addition, the spectrum of $d\ (k)$ may cover the important spectrum of $s\ (k)$, making the commonly used frequency domain filtering technique fail.

To estimate the distorted noise signal $d\ (k)$, we need to pick up the clear noise signal $b\ (k)$ independent from the information signal. However, we cannot directly obtain it because the distorted noise signal $d\ (k)$ is the additional component of the total measurable signal $y\ (k)$. But we can still detect the signal $y\ (k)$ as the expected output of ANFIS training if only the information signal $s\ (k)$ is a zero mean and is not correlated with the noise signal $b\ (k)$.

The ANFIS learning rule tries to minimize the error:

$$\begin{aligned} \|u(k)\|^2 &= \|y(k)\text{-}d'(k)\|^2 \\ &= \|s(k)+d(k)\text{-}d'(k)\|^2 \\ &= \|s(k)+d(k)\text{-}f'(b(k),b(k\text{-}1),b(k\text{-}2),\ldots)\|^2 \end{aligned} \quad (2)$$

where f' is the function realized with ANFIS. The information signal $s\ (k)$ is regarded as an uncorrelated noise component during the data fitting procedure, so ANFIS can do nothing for $s\ (k)$ unless it picks up the static trend of $s\ (k)$. On the contrary, ANFIS is good at minimizing the error component correlated with $d\ (k)$ or $\|\ d(k)\text{-}f'(b(k),b(k\text{-}1),b(k\text{-}2),\ldots)\|^2$, which is just the expected error measurement.

(2) can be extended into

$$\|u(k)\|^2 = \|s(k)\|^2 + \|d(k)\text{-}d'(k)\|^2 + 2s(k)d(k) \text{-} 2s(k)d'(k) \quad (3)$$

Take mathematical expectation on both sides of(3)and $s\ (k)$ is not correlated with $d'(k)$, we obtain

$$U[u^2] = U[s^2] + U[(d\text{-}d')^2] \text{-} 2U[sd']$$

If $s\ (k)$ is a zero mean random signal, ANFIS cannot establish a model for it, and when it is infinite, $\frac{1}{m}\sum_{k}^{1} s(k)d'(k)$ tends to zero, or $U[sd']=0$, we obtain

$$U[u^2] = U[s^2] + U[(d\text{-}d')^2]$$

where $U[s^2]$ will not be affected when ANFIS is adjusted to minimize $U[u^2]$. Therefore, the minimized total error of ANFIS is equivalent to minimized $U[(d\text{-}d')^2]$, making the ANFIS function $f'(\bullet)$as close to the dynamic characteristics $f'(\bullet)$of channels as possible in the least-square sense.

3. Modelling and Simulation of Non-Linear Dynamic Characteristics

Before giving the simulation results, we assume a few conditions making adaptive noise cancellation effective:

(1) The noise signal b (k) should be measurable and is not correlated with the information signal s (k).

(2) The information signal s (k) must be a zero mean.

(3) The order of dynamic characteristics of channels is known (or ANFIS filter input number determined).

In experiment, ANFIS is applied respectively to 2 order and 3 order non-linear dynamic characteristics of channels. Assume the unknown non-linear dynamic characteristics of channels to be

$$d(k) = f(b(k), b(k-1)) = \frac{4\cos(b(k))b(k-1)}{1+[b(k-1)]^2} \tag{4}$$

where b (k) is the noise source, and d (k) represents the results obtained from the non-linear dynamic characteristics of channels $f(\bullet)$based on b (k) and b (k-1). Unknown channel characteristics of interference is shown in Fig.2.

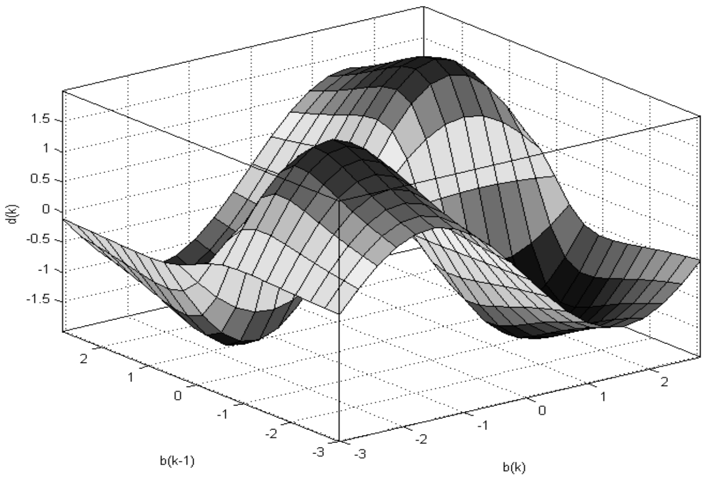

Fig. 2: Unknown Channel Characteristics of Interference

Assume the information signal s (k) is

$$s(k) = \cos\left(\frac{6000}{k+15}\right) \tag{5}$$

In (4) , d (k) is the distorted noise produced by the non-linear dynamic characteristics, y (k) is the measurable signal at the receiving end, or the sum of s (k) and d (k). Due to the non-linear dynamic characteristics of signals and the magnitude of d (k) of f ( ), it is difficult for us to correlate y (k) with s (k) in the time domain.

An analysis of 256 dot density distribution before s (k), b (k), d (k) and y (k) shows that the spectra of s (k) and d (k) considerably overlap each other, so it is difficult to cancel d (k) from y (k) with frequency domain filtering techniques.

In(5), k is the number of steps and the sampling time is 5μs. Figure 3 shows s (k) from 0 to1000 steps. In Fig. 4, assume the measurable noise source is a zero mean, unit-variance Gaussian distribution. Figure 5 shows the measurable signal y (k) at the receiving end, equal to the sum of s (k) and d (k).

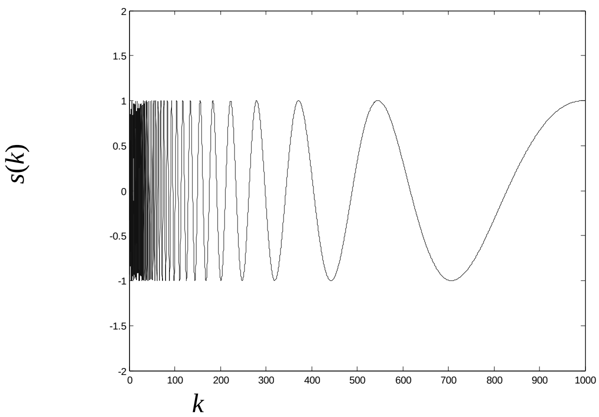

Fig. 3: Information signal s (k)

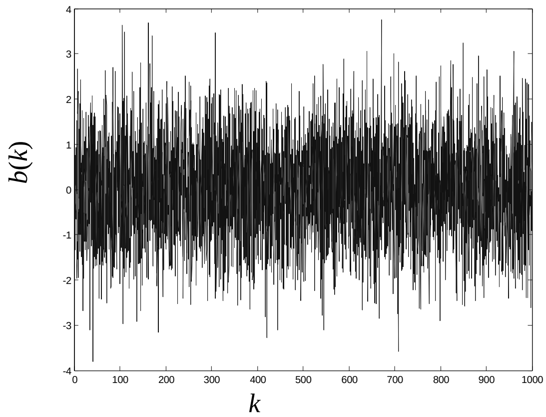

Fig. 4: Noise signal b(k)

Under those conditions, to apply ANFIS, we collected 500 pairs of training data as follows

$$[b(k),b(k\text{-}1)\ ;\ y(k)] \tag{6}$$

In(6), *k* runs from 1 to 500, we used a four-rule ANFIS to fit the training data, in which each of the input was assigned two generalized bell membership function [3][4]. Figure 6 gives the root-mean-square error curve from step 1 to 10. The starting point of the root-mean-square error curve shows the error when only LSE is used to identify the linear parameters. By using non-linear parameters, the error can be reduced further.

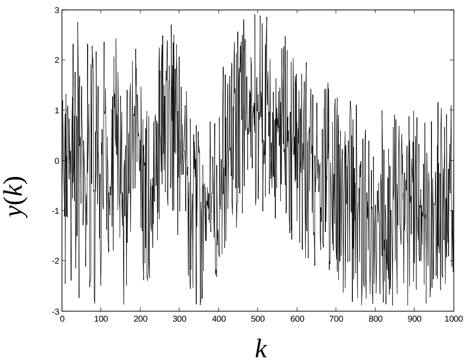

Fig. 5: Measurable signal y (k)

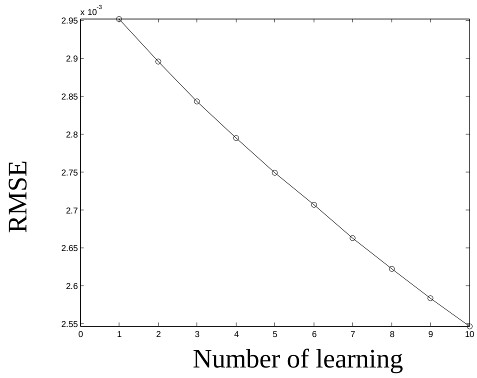

Fig. 6: Root-mean-square error curve (RMSE)

The result *d*' of channel estimated with ANFIS can be expressed as *d*'(*k*)=*f*'(*b*(*k*),*b*(*k*-1)). Thus the estimated signal derived from *y* (*k*)-*d*'(*k*) is *s*'(*k*). The estimated error of the difference of *s* (*k*) and *s*' (*k*) is shown in Fig. 7. It can be seen from it that *s*' (*k*) is fairly close to *s* (*k*). If more training data and training steps are used, it is expected to further decrease the estimated error. The original information signal *s* (*k*) obtained after noise is cancelled with ANFIS is shown in Fig.8, which is satisfactory compared to the information signal in Fig. 2.

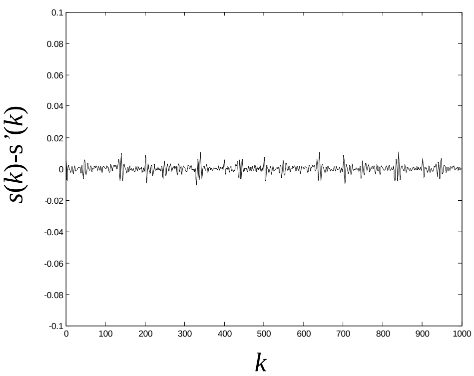

Fig. 7 Estimated error signal s (k)-s' (k)

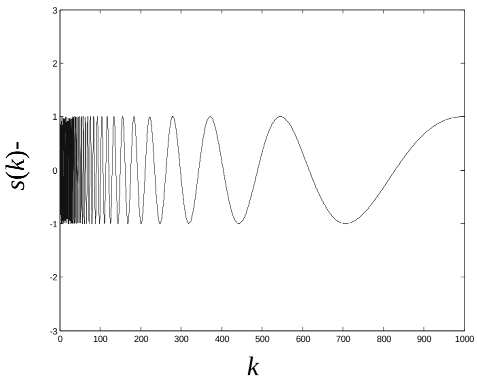

Fig. 8 Original information signal s (k)

4. Conclusions

Through the above analysis and study, when we use training data in a longer time interval, it is expected to improve the above results. But collection of data in a longer time interval often produces excessive data pairs, so to maintain reasonable training time, it often needs certain data inductions to obtain representative data pairs, and eliminate the redundant data. To sum up, we have found that ANFIS has better advantage in canceling the unknown distorted noise signal $d(k)$ from the measured signal $y(k)$. Particularly, when the information signal considerably overlaps the distorted noise signal, simulation, spectral analysis and actual measurement have shown that the use of ANFIS network for noise cancellation can effectively extract the original information signal, obtaining obvious effects, having better advantage compared to the frequency domain filtering technique.

5. References

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