

Singularity Detection of ECU Speed Based on Lifting Wavelet

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Abstract. IPC(industrial personnel computer) emits the frequency signal to simulate the rotating speed through timer 8253. However, ECU(electronic control unit) sometimes cannot recognize the discontinuous frequency signal. Lifting wavelet is widely applied to locate the abrupt signal because it can simultaneously show the local characteristic of time domain signal and frequency domain signal. Fourier transform and lifting wavelet are used to detect the rotating speed change, respectively. The simulation results show that lifting wavelet can accurately and effectively detect the singularity of vehicle speed change such as speed decreasing and speed increasing, but Fourier transform fails to detect these singularities. Accurate singularity acquisition by lifting wavelet has potential application for further improving ECU performance.

Keywords: Lifting wavelet, Electronic control unit, Detect, Speed, Singularity

1. Introduction

Automatic transmission is the present trend of the vehicle transmission, which greatly improves the vehicle's economical and dynamic performances as well as alleviates the driver's working intensity [1]. ECU is the core of automatic transmission system. To simulate the real environment of the vehicle transmission, we designed the ECU simulation testing platform based on the automatic transmission of Santana 2000. Fig.1 shows the basic structure of ECU simulation testing platform. Simulation testing platform is composed of IPC, screen, ECU, electromagnetic valve, electrical source and all kinds of circuit board. IPC emits the needed signals such as analog signal, digital signal and frequency signal. However, ECU sometimes cannot recognize the discontinuous frequency emitted by IPC through timer 8253.

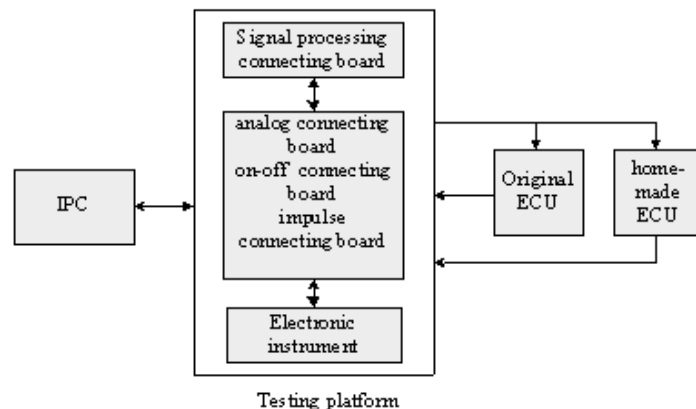


Fig. 1: Structure of ECU simulation testing platform.

Fourier transform is a useful method to detect the signal singularity [2-3]. In the Fourier transform, the signal is divided into complex sinusoidal functions [4]. Because sinusoidal basis functions are spread over the entire time domain and are not concentrated in time, the Fourier transform does not explicitly indicate how a signal's frequency contents evolve in time. The signal is only expressed in time domain or in frequency domain through Fourier transform. Wavelet analysis has different frequency in different plane

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position, which shows the general picture and detail signal at the same time. The lifting wavelet is based on lifting scheme [5]. The lifting scheme is a simple construction of the second generation wavelets, which is not necessarily translation and dilation of one fixed function. The lifting scheme allows one to design the filters needed in the transform algorithms and leads to a fast in-place calculation of the wavelet transform without increasing additional memory, which is very important for real-time operation in automotive ECU [6]. In this paper, Fourier transform and lifting wavelet are respectively used to detect the speed signal in the ECU simulation testing platform. The simulation results suggest that the lifting wavelet is a better tool than Fourier transform to detect the singular signal.

2. Wavelet Transform Based on Lifting Wavelet

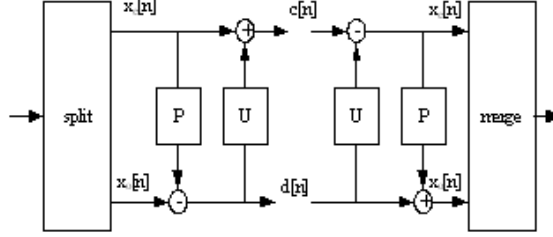


Fig. 2: Wavelet transform based on the lifting scheme.

The lifting wavelet, as a second generation wavelet [5], is a spatial or time-domain construction of biorthogonal wavelets. The basic idea behind lifting is that it provides a simple relationship between all multi-resolution analysis that shares the same low-pass filter or high-pass filter. The low-pass filter gives the coefficients of the refinement relation, which entirely determines the scaling functions where the coefficients are given by the high-pass filter. The lifting scheme consists of iterations of the following three basic operations, as shown in Fig.2. Firstly, the original data is divided into two subsets. The original signal is often split to the even indexed points and the odd indexed points, that is,

$$x_e[n] = x[2n] \quad x_o[n] = x[2n+1]$$

Secondly, this generates the wavelet coefficients $d[n]$ as the error by the predicting operator P:

$$d[n] = x_o[n] - P(x_e[n]) \quad (1)$$

The prediction and recording process is called a lifting step. The original signal is transformed from (x_o, x_e) to (x_o, d) . There is aliasing in the even samples due to the sub-sample. The lifting step is introduced to solve the problem. Finally, the update combines $x_e[n]$ and $d[n]$ to obtain the scaling coefficients $c[n]$ that represents the coarse approximation in the original signal. The updated operator U is used with the wavelet coefficients for $x_e[n]$.

$$c[n] = x_e[n] + U(d[n]) \quad (2)$$

These three steps form the lifting stage. The iterations of the lifting stage on the output samples create the complete set of discrete wavelet transform scaling and wavelet coefficients $c_j[n]$ and $d_j[n]$ at each scale j .

The lifting steps can be easily inverted. The following equations for invertible lifting are derived:

$$x_e[n] = c[n] - U(d[n]), x_o[n] = d[n] + P(x_e[n]) \quad (3)$$

From the above principle analysis, the lifting scheme is an efficient tool to construct the second generation wavelets, with advantages such as faster implementation, full in-place calculation, reversible integer-to-integer transforms, and so on [7].

3. Signal Detection of ECU Simulation Testing Platform

3.1. I/O Analysis of ECU Simulation Testing Platform

The working mechanism of ECU is as follows. Firstly, central microprocessor uses the sensors to collect the signals that represent the vehicle's present state. Secondly, the signal is stored and disposed. Thirdly, shifting law is transferred according to the moving state and the will of drivers. Finally, electromagnetic valve

drives the implementing framework that control automatically the transmission, arrester, clutch and hydraulic torque converter. Fig.3 presents the I/O signals of ECU system. The electronic control system of automatic transmission is a typical MIMO (multiple input multiple output) system. The input signal has three types: analog signal, on-off signal and impulse signal. The output signal includes three categories: sequential electromagnetic valve signal, PWM (pulse width modulation) signal and on-off signal.

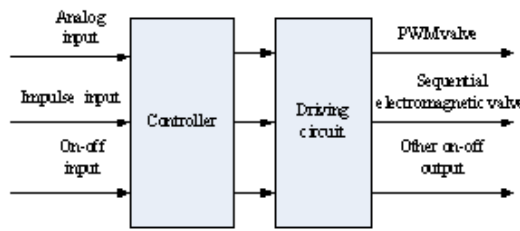


Fig. 3: I/O signals of ECU system

3.2. Singularity Detection of Speed Decreasing

ECU simulation testing platform emits frequency to simulate the rotating speed of Santana 2000. In fact, the field signal is the sine type in the normal condition. When the vehicle gears down, the rotating speed varies from high frequency to low frequency and the original signal of the sine type changes dramatically. The original signal, especially the dramatic signal point, is detected with Fourier transform and lifting wavelet, respectively, as demonstrated in Fig.4 and Fig.5. Fig.4 shows that Fourier transform fails to detect the singularity, while Fig.5 shows that the abrupt change is located accurately in the first layer of detail signal ($D1=500ms$). The simulation results suggest that the speed decreases at this point, which coincides with the above preferences.

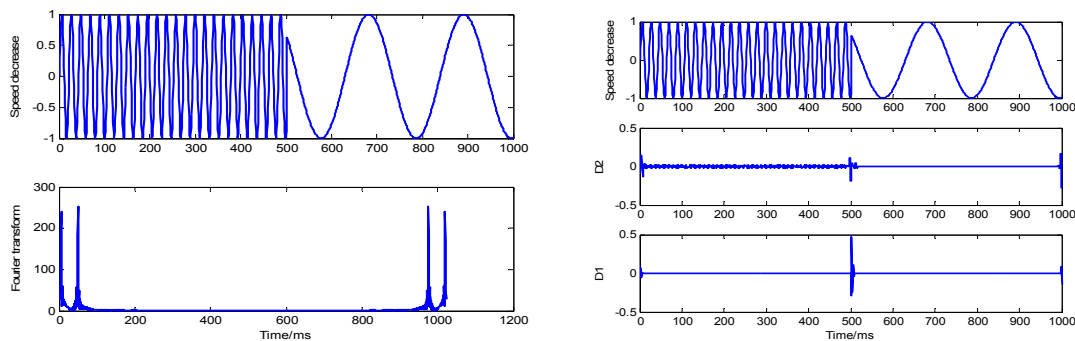


Fig.4: Detection of speed decreasing using Fourier transform Fig.5:Detection of speed decreasing using lifting wavelet

3.3. Singularity Detection of Speed Increasing

Analogically, the rotating speed varies from low frequency to high frequency when the vehicle gears up. Therefore, the original signal of the sine type can also dramatically change during the process of gearing up. The simulation results show that Fourier transform still can not detect the singularity of speed increasing (not shown). However, the singularity can successfully be detected with lifting wavelet, as demonstrated in Fig.6. The singularity of speed increasing is accurately located in the first layer of Fig.6 ($D1=600ms$). The detected fault point coincides with the predetermined parameters.

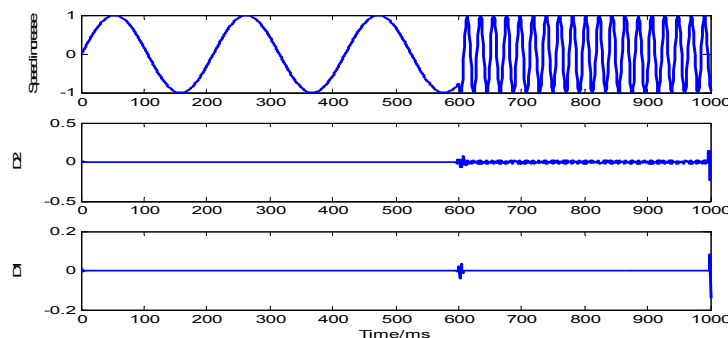


Fig.6. Detection of speed increasing using lifting wavelet

4. Conclusion

According to the above theory analysis and simulation results during the detection of vehicle speed change with Fourier transform and lifting wavelet, the conclusions can be drawn as follows.

1) Lifting wavelet can accurately and effectively detect the singularity of the rotating speed of ECU simulation testing platform, which provides effective support for further improvement of ECU.

2) Compared with Fourier transform, lifting wavelet can analyze the unstable signals. Therefore, it is more suitable to detect vehicle speed change.

5. Acknowledgements

This paper is supported by Leading Academic Discipline Project of Shanghai Municipal Education Commission (J51303).

6. References

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