Online Wavelet Denoising for a Quarter Car Model

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ABSTRACT

Noise impact cannot be ignored in control system. In online systems when the received data by sensor contains noise, may cause to a problem. Linear position sensor can be widely used to control of body motion in different types of suspension system. Sensor's resolution, accuracy and stability depend on its electronics design. For this purpose, in this paper an online wavelet denoising has been studied for a quarter car model. Vibrations due to the unit step input are controlled with PID controller. If the sensor contains noise, controller performance will be poor. Online wavelet denoising is used to eliminate the noise. Simulation results show that when the system has online wavelet denoising, controller gives better results and system is not affected by the noise. As a result, this type of control strategy can be applied to the semi-active suspension systems to improve driver comfort.

Keywords

Wavelet denoising, PID control, vehicle safety.

1. INTRODUCTION

The transportation safety has been an active area of research in recent years. When a human is driving the transportation system, it involves reaction time, delay and human error that adversely affect safe driving [1]. At the same time constructed controls systems for vehicle comfort, sensor noise impact cannot be ignored. Noise can affects the system negatively and it causes undesirable situations. Thus this paper focus on the noise and to design the system with online wavelet denoising to eliminate the noise.

Real world data rarely comes clean. In order to extract useful information from raw data, robust denoising method is often required [2]. Wavelet is used frequently in data compression, auto industry, chemical process engineering, mathematics, image process, computer science and etc.[3].

As a recent studies, references [4],[5],[6],[7] could be demonstrated. In this study a quarter car model is used with MatLab-Simulink.

PID controller is studied for the displacement control. A closed loop system performs according to the data which is taken by sensor. Data received from the sensor contains the noise in the application and it affects the response of the controller negatively.

It is known that position and its derivatives, velocity and acceleration can be measured by using a linear position sensor. Semi-active suspension systems have a damper and the linear position sensor for controlling MR (Magneto-rheological) fluid damper [8]. The linear position sensor can be widely used to control of body motion in different types of suspension system. Therefore noise, accuracy and stability of the linear position sensor are very crucial to control variable damping shock absorber in the semi-active suspension systems. Furthermore desired performance from the suspension systems in terms of minimum percentage

overshoot and rapid stabilizing time can be reached by using optimum controller and mathematical model [9],[10],[11]. The focus of this study is to improve a riding comfort and road handling for road disturbance by using online wavelet denoising.

This paper is divided into the following parts. In section 2, system model is presented. Section 3 is devoted to the description of the online wavelet denoising. In section 4 the simulation results are given.

2. SYSTEM MODEL

When the degrees of freedom increases for the vehicle, it makes the study complicated. In this study, online wavelet denoising is examined for 2DoF vehicle model.

A quarter car model is examined with PID controller for the displacement. The linear quarter car model is given in Fig. 1 [12],[13],[14],[15].

Fig 1: A quarter car model [12],[13],[14],[15].

The mass m_1 represents approximately the mass of the wheel plus part of the mass of the suspension arms, m_2 represents approximately $\frac{1}{4}$ of the body mass [15,16]. k_2 means spring coefficient of the suspension systems, k_1 represents spring coefficient of the rubber tires, c_2 and c_1 shows suspension damping coefficient and rubber tires damping coefficient, respectively. Vibration movements are shown with x_1 and x_2 . Road roughness is used as xy . The linear equations of motions of the system model are given in equation (1) [14].

$$\begin{bmatrix} m_1 & 0 \\ 0 & m_2 \end{bmatrix} \begin{bmatrix} \ddot{x}_1 \\ \ddot{x}_2 \end{bmatrix} + \begin{bmatrix} C_1 + C_2 & -C_2 \\ -C_2 & C_2 \end{bmatrix} \begin{bmatrix} \dot{x}_1 \\ \dot{x}_2 \end{bmatrix} + \begin{bmatrix} k_1 + k_2 & -k_2 \\ -k_2 & k_2 \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \end{bmatrix} \begin{bmatrix} x_y \end{bmatrix} + \begin{bmatrix} 0 \\ C_1 \end{bmatrix} \begin{bmatrix} \dot{x}_y \end{bmatrix} \quad (1)$$

3. ONLINE WAVELET DENOISING

With reasons such as vehicle vibration, excitation of road, the signal can be severely polluted. Various techniques have been used to process the signal, such as fast Fourier Transform and Neural Network [17]. In this study wavelet denoising method is used. Daubechies wavelet is chosen. Fig.2 shows the db7 wavelet.

Fig 2: db7 wavelet

In most cases, wavelet denoising is performed as offline processing for real-time signals [18]. A moving window technique is to solve this problem [3]. In this paper online wavelet denoising method is used for the system control.

At the first stage of online denoising, when sampled data are not long enough for a wavelet transform, the data is kept. As soon as the minimum length is reached, the first window initiates and online denoising begins. Subsequently, the window moves ahead step by step with the width fixed [18,19].

Fig.3 shows the designed of the system block diagram. cd and ca are the detail and approximation coefficients. H and L are the high-pass and low-pass filters, respectively. The filter coefficients for the decomposition and the reconstruction stages are seen in table 1.

Fig 3: The designed of the system block diagram

Table 1. The filter coefficients for the decomposition and the reconstruction stages

Decomposition low-pass filter	Decomposition high-pass filter	Reconstruction low-pass filter	Reconstruction high-pass filter
0.0004	-0.0779	0.0779	0.0004
-0.0018	0.3965	0.3965	0.0018
0.0004	-0.7291	0.7291	0.0004
0.0126	0.4698	0.4698	-0.0126
-0.0166	0.1439	-0.1439	-0.0166
-0.0380	-0.2240	-0.2240	0.0380
0.0806	-0.0713	0.0713	0.0806
0.0713	0.0806	0.0806	-0.0713
-0.2240	0.0380	-0.0380	-0.2240
-0.1439	-0.0166	-0.0166	0.1439
0.4698	-0.0126	0.0126	0.4698
0.7291	0.0004	0.0004	-0.7291
0.3965	0.0018	-0.0018	0.3965
0.0779	0.0004	0.0004	-0.0779

The technique contains of applying a discrete wavelet transform to the original data. The detail wavelet coefficients are thresholded and inverse transforming the thresholded

coefficients to obtain the denoised data [20],[21],[22]. Hard and Soft thresholding methods are generally used for the wavelet coefficients. References [23],[24] gives the details about the wavelet denoising. In this study hard thresholding is used. After the reconstruction stage a denoised signal is obtained. Using the denoised signal, system is performed successfully.

4. SIMULATION RESULTS

The simulation results are obtained using Matlab/Simulink. The numerical values for the quarter car parameters are shown in table 2. [15]

Table 2. The numerical values for the quarter car parameters

Parameter	value	Units
M2	229	kg
M1	31	kg
K2	20000	N/m
K1	120000	N/m

For this study the quarter car model is controlled with PID controller. Fig. 4 shows the PID control effects.

When the step function is applied to the quarter car model, the result includes the oscillation. If the system has a PID Controller, the result has no oscillation.

Fig 4: Step function response for the system

Data is taken by the sensor with the noise. Sensor noise is taken into consideration for the study. The noise has 0.15 variance. The data which has noise is shown in fig. 5 for the study.

Fig 5: The data with the noise

Fig. 6 shows the response of the system without online wavelet denoising. The sensor noise effects the PID controller badly, so the system response is not good for the control.

Fig 6: The response of the system without online wavelet denoising

Fig 7: The quarter car model with online wavelet denoising

Finally, the quarter car model with online wavelet denoising is constructed as shown in fig. 7. Fig. 8 represents the response of the system using online wavelet denoising. It is clear that although the system has a sensor noise, PID controller makes the control properly.

Fig 8: The response of the system with online wavelet denoising

5. CONCLUSIONS

In this study a quarter car model is used with MatLab-Simulink. Vibrations due to unit step input are examined to control with PID controller. A closed loop system performs according to the data which is taken by sensor. Data received from the sensor contains the noise in the application. To solve this problem online wavelet denoising is studied. It is observed that online wavelet denoising can be effectively used in real time control applications. Additionally some parameters are made adjustable according to the real time conditions such as wavelet basis, window width, thresholding type. Simulation results show that the effectiveness of the online wavelet denoising for controlling of body motion, improving the ride comfort. This study demonstrates that the noise effects can be minimized and the controller performances can be much better. The future scope of this study is to determine the parameters of online wavelet denoising using artificial intelligence techniques.

6. REFERENCES

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