Measurement 125 (2018) 526–534

Contents lists available at ScienceDirect

Measurement

journal homepage: www.elsevier.com/locate/measurement

Design of adaptive filter for the wheel force transducer[☆]

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A R T I C L E I N F O

Keywords:
Wheel force transducer
Wheel force model
Adaptive filter
Data test

A B S T R A C T

Wheel force transducers (WFTs) are widely used in the car and commercial vehicle industry to determine forces of vehicles in operation, relevant for multiple tasks within the development process of the manufacturers (Sankarganesh and Pawar, 2015). Due to the uncertainty and randomness of the wheel forces, it is crucial to design a suitable real-time filter for the WFT to obtain the high-accuracy forces data. Considering the diversity of the wheel forces, models for different dynamic ranges are established. And a two-step adaptive filter is proposed in this paper. In the first step, the wheel forces' actual dynamic is evaluated by the interacting multiple model (IMM) algorithm, then a suitable model is chosen to match the evaluated dynamic of the wheel force for data denoising in the second step. Simulations in different driving conditions are carried out to demonstrate the effectiveness of the proposed filter. Furthermore, the results of data test show that the adaptive filter can be successfully used in practice to get high-accuracy wheel forces.

1. Introduction

The wheel force is the result of the interaction of ground and wheel. The research on wheel force is an indispensable part of the vehicle design and test, which is necessary for improving the security and stability of the vehicle [4,7,8]. Therefore, it is crucial to acquire accurate wheel forces data for the development of high-quality products in a reasonable time frame for car maker companies and system & component supply companies [10,11]. The Wheel Force Transducer (WFT) as shown in Fig. 1 has been designed and proven to be a cost and time effective tool for the needs of wheel force data acquisition [1,12,15,16]. For the WFT, structural design and data processing are two important factors to guarantee the measurement accuracy [24,26]. The rational structure design would be of great help to reduce the structure coupling degree of wheel forces and outputs of the WFT [2,13,18,19]. The effective data processing method is adopted to calculate the real wheel forces from the outputs of the transducer [14,20]. Since the WFT is amounted on the wheel, the outputs of the transducer might be influenced by the magnetic field and vibration of the engine, which make a data filter essential to denoise and estimate the real wheel forces (see Fig. 2).

To obtain the effective signals in whole sampling rate, the wavelet method was used in the earlier WFT filter [32]. This filter is lack of real-time performance, because wavelet is an offline data processing method. To guarantee the WFT's real time accuracy, an improved denoising algorithm with Kalman filter is designed in [25]. It is well known that the capacity of the Kalman filter is largely dependent on the precision of the system modeling. But in the usage of the real-time filter, we found that the variation of the wheel forces cannot be characterized by one certain model in all time. To address this problem, the interacting multiple model (IMM) is an accepted scheme to provide good performance with efficient computation. The selected models must obey two principles in traditional IMM based filter. Firstly, every elemental model is good at any given time and none may provide incorrect, misleading, confusing, or any other erroneous information. Secondly, it could not be exposed to an environment where none of the existing elemental models fits. The above principles sometimes limit the selection of models, which also limit the capacity of the filter. In this paper, we propose a two-step filtering algorithm to obtain high accuracy wheel forces. The first step is to identify the wheel force dynamic range, where the IMM algorithm plays a role as the mode selector. In the second step, based on the calculated weight of the IMM algorithm, we set three filtering models corresponding to different wheel force dynamics, and the appropriate model according to the identified dynamic range would be adopted to implement filtering.

The organization of this paper is as follows. Section 2 reviews the useful models for the variation of the wheel forces. Section 3 describes the implementations of the proposed adaptive filter and the

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[☆] This work was supported by the Jiangsu Natural Science Foundation Project BK20170681, Anhui Natural Science Foundation Project 1608085ME109, and National Natural Science Foundation of China 51675005.

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https://doi.org/10.1016/j.measurement.2018.05.026
Received 30 October 2017; Received in revised form 4 March 2018; Accepted 4 May 2018

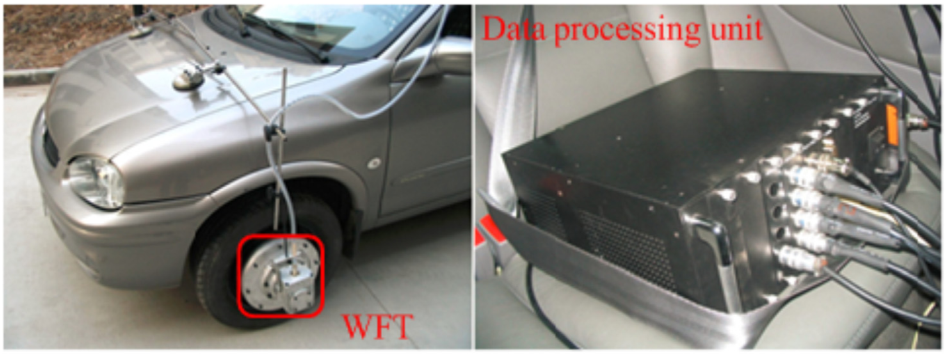

Fig. 1. The WFT designed by Southeast University.

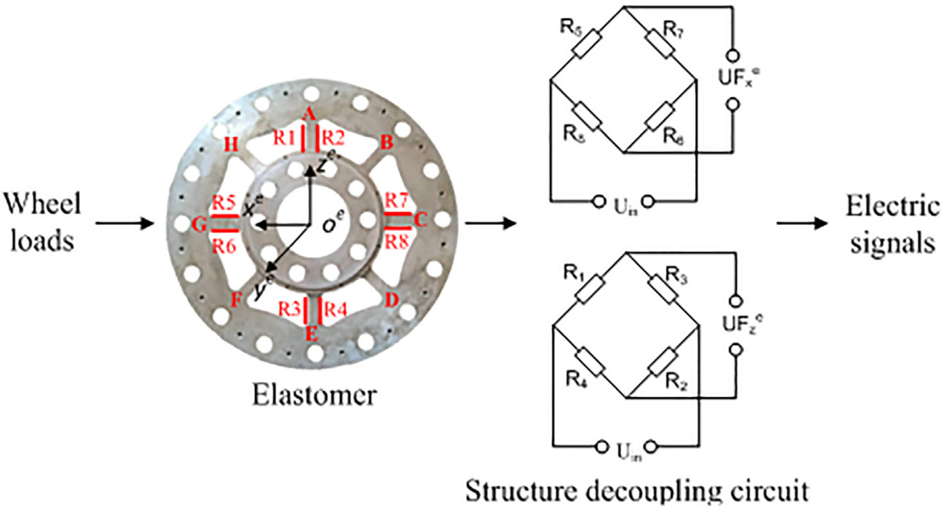

Fig. 2. Structure of the WFT.

determination of the parameters for each model. Section 4 presents the numerical simulations and data test with the proposed filter. Section 5 concludes the paper.

2. Dynamic models

The key to successful filter design lies in the optimal extraction of useful information about the system state from the observations. Most filtering algorithms are model based because a good model-based filtering algorithm will greatly outperform any model-free filter algorithm if the underlying model turns out to be a good one, and a good dynamic model of the system will certainly facilitate the filtering accuracy to a great extent. For the WFT, the dynamic of the wheel forces is random, which makes us choose different models to fit different dynamic ranges [23].

2.1. Coordinate definition

Because of the rotation of the wheel, the outputs of the WFT and the real wheel force are defined in the wheel coordinate ($\{o^e x^e y^e z^e\}$) and the vehicle body coordinate ($\{o^v x^v y^v z^v\}$), respectively. In the initial condition, this two coordinates coincide with each other. The origin o^v is located in the center of the wheel, the axis $o^v x^v$ is pointing forward in the longitudinal, the axis $o^v y^v$ is along the lateral, and the $o^v z^v$ axis is normal to the road surface to constitute a right-handed reference frame, as shown in Fig. 3. When the vehicle is in motion, the wheel coordinate rotates around the axis $o^e y^e$, and the angular displacement is symbolized by the angle θ. the outputs of the WFT (F_x^e,F_z^e) and the real wheel force (F_x^e,F_z^e) satisfy (1).

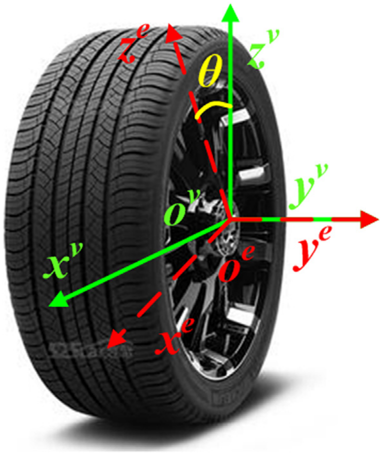

Fig. 3. Coordinate definition in the WFT.

$$\begin{cases} F_x^v = F_x^e cos\theta + F_z^e sin\theta \\ F_z^v = -F_x^e sin\theta + F_z^e cos\theta \end{cases} \tag{1}$$

2.2. Singer model

The WFT is designed to calculate the longitudinal force ($F_x{}^v$) and vertical force ($F_z{}^v$). Meanwhile, the WFT is rotating with the wheel in operation so that the rotation angle (θ) is another major variable to decouple the transducer's outputs. However, these variables are