Estimation of Road Disturbance for a Non Linear Half Car Model Using the Independent Component Analysis

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Abstract. The identification of the road profile disturbance acting on a vehicle was the objective of many recent researches. This estimation remains very interesting since it contributes to study the dynamic behavior of the vehicle in one side and to choose a control law later in other side. However most of the used techniques have many drawbacks such us those based on direct measurements of the profile which need costly profilometers or those based on neural network algorithm which are very complicated. So the purpose of this research is to use a new method named the Independent Component Analysis (ICA) to estimate the road profile. This method is based on the so-called inverse problem. So it necessitates only the knowledge of the dynamic responses of the vehicle to identify the road disturbance. Therefore the Newmark algorithm is used in this paper to extract the dynamic responses of the system under study which is a non linear half car model. Starting from these responses, the ICA algorithm is applied. The validation of the obtained results is done using some performance criteria which are the relative error and the MAC number. Finally a good agreement is found between the original profile and the estimated one.

Keywords: Non linear half car model · Road disturbance · ICA

1 Introduction

Vehicle dynamics is a domain of considerable interest for many years. It encompasses the intervention of many factors: driver, vehicle and loads (Rill 2004). Many models of vehicle are used in order to determine their dynamic behaviour. Such as E. Duni (Duni et al. 2003), in his studies uses a finite element method in order to simulate the dynamic response of a full vehicle model subjected to different types of road excitations. Others implement a bicycle model with four degree of freedom (Hunt 1989; Mavros 2008) and they concluded that the characteristics of the road profile influence on the dynamic

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response of the system. Pacejka (2005) also focuses on the study of the handling behaviour of a bicycle model with transient tyres. In this paper a non linear half car model is studied in order to identify the road disturbance. This identification was done using different techniques such as direct measurements (Kim et al. 2002), but its cost is very expensive. Other researchers use the estimation algorithms (Solhmirzaei et al. 2012), however they necessitate a long computing time (Fauriat et al. 2016). So in this study the proposed method of road profile estimation is the ICA. It is used to estimate the excitation force in many studies (Dhief et al. 2016; Hassen et al. 2017; Taktak et al. 2012). This method is simple to apply and permits to identify the road excitation in real time.

This paper is structured as follows: the first part present the studied system and its mathematical formulation. Then the results obtained by the ICA are presented in the second part and finally a good agreement between the original excitation and the estimated one is obtained.

2 Half Car Model

The dynamic model (Meywerk 2015) of the half car is presented in Fig. 1.

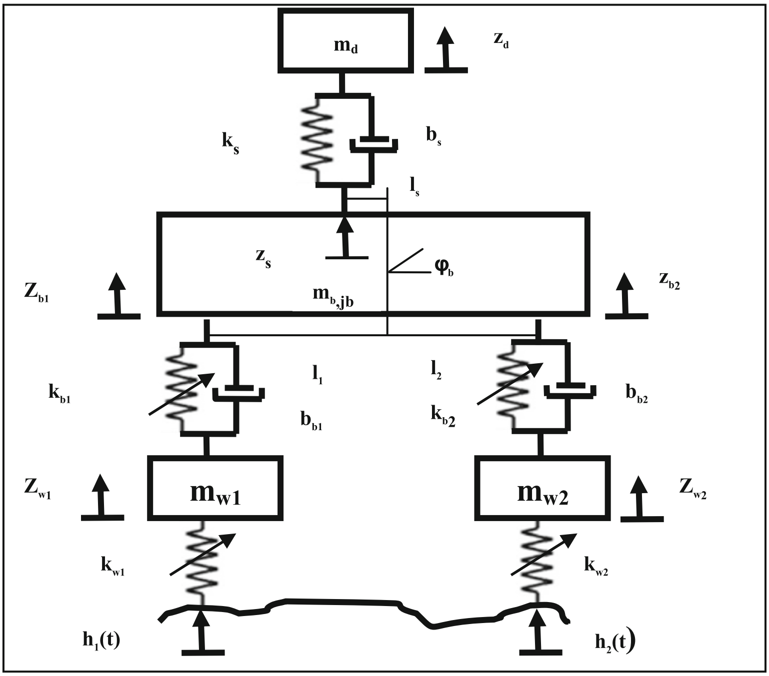


Fig. 1. Full vehicle model

This model has five degree of freedom:

m_{w1} and m_{w2} are the masses of the wheels. They are attached to the road via two non linear springs k_{w1} and k_{w2}. Their deflections are noted z_{w1} and z_{w2}.

The vertical displacement of the two suspension systems are noted respectively z_{b1} and z_{b2}. These suspension have a non linear behaviours due to the non linear stiffness k_{b1} and k_{b2}. The dampers are noted b_{b1} and b_{b2}.

Z_b and φ_b denote respectively the displacement of the center of gravity and the pitch angle.

The vertical displacement of the human's seat is noted z_d.

zb_1 and zb_2 can be expressed in function of the variable z_d as (Meywerk 2015):

$$\mathrm{z_{b1}} = \mathrm{z}_b - \mathrm{l}_1\varphi_b \tag{1}$$

$$\mathrm{z_{b2}} = \mathrm{z_b} + \mathrm{l}_2\varphi_b \tag{2}$$

And the coordinate z_s is expressed in terms of z_b as follow:

$$\mathrm{z_s} = \mathrm{z_b} - \mathrm{l_s}\varphi_\mathrm{b} \tag{3}$$

For the non linearity it's expressed by the following expressions:

$$F_{b1} = k_{b1}\Delta l + \beta_1 k_{b1}\Delta l^2 + \beta_2 k_{b1}\Delta l^3 \tag{4}$$

and

$$F_{b2} = k_{b2}\Delta l + \beta_1 k_{b2}\Delta l^2 + \beta_2 k_{b2}\Delta l^3 \tag{5}$$

With:

Δl is the difference between the two displacements z_{b1} and z_{w1} in Eq. (4)

And Δl is the difference between the two displacements z_{b2} and z_{w2} in Eq. (5).

β_1, β_2 are two non linear constants.

$\beta_1 = 0.1$ *and* $\beta_2 = 0.4$

The tire is modeled as a spring with a non linear stiffness k_2 in parallel with a linear damper c_2. The expression of the non linear tire stiffness is taken from Li et al. (2011) as:

$$F_{w1} = k_{w1}\Delta l + \beta_3 k_{w1}\Delta l^2 \tag{6}$$

And

$$F_{w2} = k_{w2}\Delta l + \beta_3 k_{w2}\Delta l^2 \tag{7}$$

With:

Δl is the difference between the displacement kw1 and the road excitation $h_1(t)$ in Eq. (6) and Δl is the difference between the displacement kw2 and the road excitation $h_1(t)$ in Eq. (7).

β_3 is the non linear tire coefficient. Its value is taken from (Li et al. 2011):

$$\beta_3 = 0.01 \tag{8}$$

To solve this non linear system, the implicit schema of Newmark coupled with Newton Raphson Method was used using the parameters presented in the following Table 1:

Table 1. Parameters of the full vehicle model

Parameters	Variable value	Variable unit
Mass of the chassis	$m_b = 960$	[Kg]
Mass of the tires	$m_{w1} = m_{w2} = 36$	[Kg]
Suspension stiffness	$k_{b1} = k_{b2} = 16000$	[N/m]
Tire stiffness	$K_{w1} = k_{w2} = 10^5$	[N/m]
Suspension damping	$bb_1 = bb_2 = 100$	[N/ms]
Driver's mass	$m_d = 90$	[Kg]
Moment of inertia	$Jb = 500$	[Kg/m^2]
Driver seat's rigidity	$k_s = 2000$	[N/m]
Driver seat's damping	$b_s = 10$	[N/ms]
l_1	$l_1 = 1.8$	[m]
l_2	$l_2 = 0.8$	[m]

Concerning the road excitation, we take in the first wheel a bump excitation and in the second the same excitation with a short delay as presented below:

$$h_1(t) = \left\{ \begin{array}{l} 0.05\ \frac{1-\cos(8\pi t)}{2}\ if\, 1 \le t \le 1.25 \\ 0.05\ \frac{1-\cos(8\pi t)}{2}\ if\, 5 \le t \le 5.25 \\ 0\ otherwise \end{array} \right\}$$

$$h_2(t) = \left\{ \begin{array}{l} 0.05\ \frac{1-\cos(8\pi t)}{2}\ if\, 1.25 \le t \le 1.5 \\ 0.05\ \frac{1-\cos(8\pi t)}{2}\ if\, 5.25 \le t \le 5.5 \\ 0\ otherwise \end{array} \right\}$$

The following figure presents the two excitations applied on the wheels (Fig. 2):

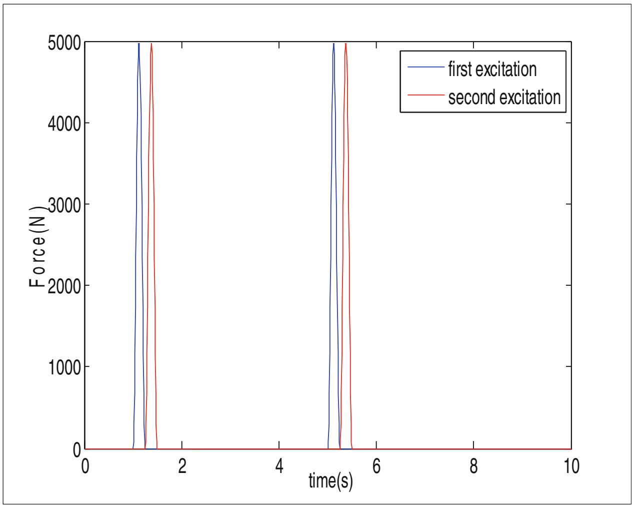


Fig. 2. Bump excitations

3 Description of the Applied Algorithm: ICA

The ICA is a method which aims to decompose a random signal X in independent components statistically (Abbes et al. 2011; Dhief et al. 2016).

The vector X can be written as (Hassen et al. 2017)

$$X(t) = [A]\{S\} \tag{9}$$

where:

A: Mixing matrix
S: Vector of source signals.

The task of ICA is to estimate A and S based only on the knowledge of the vector X. This estimation requires some assumptions:

- The components of the vector S must be statistically independent
- The number of the observed signals is equal to the number of the estimated sources.
- The components of the vector S must have a non-Gaussian distribution.

By validating these assumptions, the ICA define each column of the matrix A and after that compute the separating matrix W such as:

$$W = A^{-1} \tag{10}$$

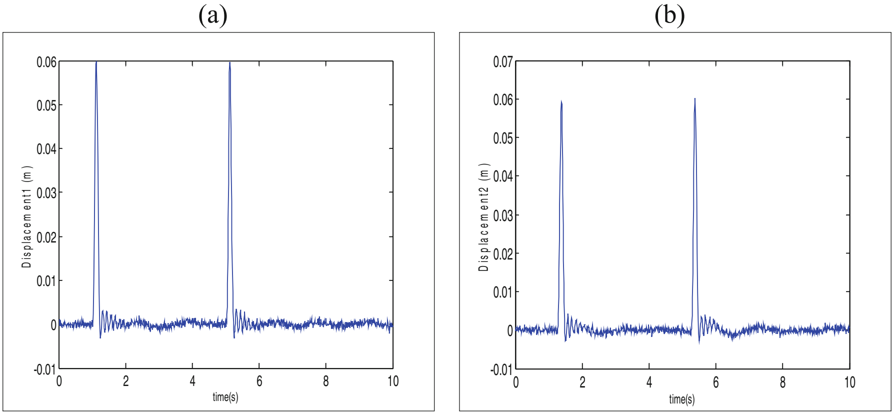
Then the ICA estimate the corresponding source signal defined by:

$$\{S\} = [W]\{X\} \tag{11}$$

Finally, the vector X undergoes some pretreatments (it must be centered and whitened) to have a successful separation.

4 Numerical Results

Starting from the observed signals presented by Fig. 3, the ICA is applied to the half car model in order to reconstruct the original excitations. We added a Gaussian random noise with zero mean value and a standard deviation σ equal to 0.5 (Akrout et al. 2012) on the observed signals in order to study the efficiency of the ICA.



(a)

(b)

Fig. 3. Observed signals (a) displacement of X1 (b) displacement of X2

The results of the ICA are presented by the following figures (Fig. 4).

We note that the ICA can identify the original signals. There is a small delay and perturbation due to the effect of the non linearity and the noise added to the sensors. But the obtained results remain in agreement with the original ones. The following table resumes the performance criteria (Table 2).

We can note that Mac value is near to one for the two studied signals, also the error has minimum value. These results confirm that the ICA is able to identify the original signal.

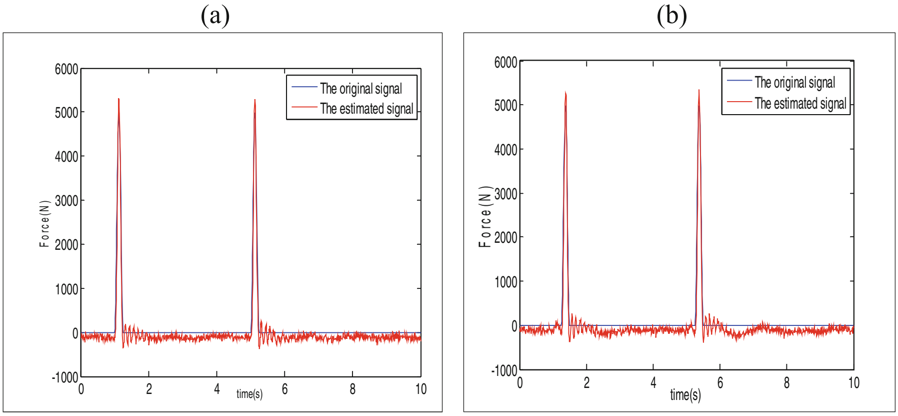


Fig. 4. Identification of the road profile by the ICA (a) excitation 1 (b) excitation2

Table 2. Validation of the results

	Mac	Relative error (%)
Profile 1	0.93	2.5071
Profile 2	0.92	2.5

5 Conclusion

This paper deals with the application of the ICA in order to reconstruct the road excitations. This method is applied to a non linear half car model. And the obtained results are in concordance with the original sources even with the non linear case.

This will be of a good importance to study the dynamic behavior of the system and to choose the adequate controller in future work.

References

Rill, G.: Vehicle Dynamics. University of applied sciences, Regensburg (October 2004)

Duni, E., Monfrino, G., Saponaro, R., Caudano, M., Urbinati, F., Marco, S., Antonino, P.: Numerical simulation of full vehicle dynamic behaviour based on the interaction between ABAQUS/Standard and explicit codes. In: Abaqus Users' Conference, June, Munich (2003)

Hunt, H.E.M.: Stochastic modelling of vehicles for calculation of ground vibration. In: Proceedings of the 11th IAVSD-Symposium-The Dynamics of Vehicles on Roads and Tracks, vol. 18. Taylor & Francis, London, August 1989

Mavros, G.: A study on the influences of tyre lags and suspension damping on the instantaneous response of a vehicle. Proc. Inst. Mech. Eng. Part D J. Automob. Eng. **222**(4), 485–498 (2008)

Pacejka, H.: Tire and Vehicle Dynamics. Elsevier, Amsterdam (2005)

Kim, H.J., Yang, H.S., Park, Y.P.: Improving the vehicle performance with active suspension using road-sensing algorithm. Comput. Struct. **80**(18), 1569–1577 (2002)

Solhmirzaei, A., Azadi, S., Kazemi, R.: Road profile estimation using wavelet neural network and 7-DOF vehicle dynamic systems. J. Mech. Sci. Technol. **26**(10), 3029–3036 (2012)

Fauriat, W., Mattrand, C., Gayton, N., Beakou, A., Cembrzynski, T.: Estimation of road profile variability from measured vehicle responses. Veh. Syst. Dyn. **54**(5), 585–605 (2016)

Dhief, R., Taktak, M., Tounsi, D., Akrout, A., Haddar, M.: Application of the independent components analysis in the reconstruction of acoustic sources in duct systems. Arab. J. Sci. Eng., 1–10 (2016)

Hassen, D.B., Miladi, M., Abbes, M.S., Baslamisli, S.C., Chaari, F., Haddar, M.: Application of the operational modal analysis using the independent component analysis for a quarter car vehicle model. In: Advances in Acoustics and Vibration (pp. 125–133). Springer, Berlin (2017)

Taktak, M., Tounsi, D., Akrout, A., Abbès, M.S., Haddar, M.: One stage spur gear transmission crankcase diagnosis using the independent components method. Int. J. Veh. Noise Vib. **8**(4), 387–400 (2012)

Meywerk, M.: Vehicle Dynamics. Wiley, London (2015)

Li, S., Lu, Y., Li, H.: Effects of parameters on dynamics of a nonlinear vehicle-road coupled system. JCP **6**(12), 2656–2661 (2011)

Abbès, M.S., Akrout, M.A., Fakhfekh, T., Haddar, M.: Vibratory behavior of double panel system by the operational modal analysis. Int. J. Model. Simul. Sci. Comput. **2**(4), 459–479 (2011)

Akrout, A., Tounsi, D., Taktak, M., Abbès, M.S., Haddar, M.: Estimation of dynamic systems excitation forces by the independent component analysis. Int. J. Appl. Mech. **4**(3), 1250032 (2012)