On-line Adaptive Scaling Parameter in Active Disturbance Rejection Controller

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Abstract. Active Disturbance Rejection Controller (ADRC) is considered one of the most famous model free controllers in the industry. This introduced scheme of control, do not require the exact modeling of the system equations and used to reject online any types of perturbations. However, the drawback of this tool is the hard task of tuning multi-parameters and takes a long time to achieve performances requirements. In this contribution, an optimization of a scaling parameter which has an important effect in the dynamic behavior of controlled system. There has been some research concentrate in estimate the parameters uncertainties from input and output signals of the body mass in vehicle system. This kind of estimation is based on differential algebra which is known by its simplicity of implementation, fast and robust to noise marring any measured signals. Furthermore, the combination of this algebraic methodology with aforementioned control low is easy. For the purpose of improving the effectiveness of ADRC controller, this paper use to predict this unknown variation and it was incorporated in the equation of control. Using this time varying parameter instead of an empirical one, simulations results show an amelioration of the energy consumption and an increase of the ride comfort.

Keywords: Model free control · On-line estimation · ADRC
Sprung mass variation

1 Introduction

Recently, controllers which are independent on the mathematical model spread in many filed such as Model Free Control (Fliess and Join 2013) and Active Disturbance Rejection Control (ADRC) (Han 2009).

The ADRC technique used to estimate endogenous and exogenous perturbations with a state observer. This estimated states can be injected in the equation of controller and cancel all unknowns' phenomena. Unfortunately, for obtaining the optimal control requires a lot of time and needs many essays. The main difficulty of the calibration task

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is to define properly the parameter that affect the denominator of controller. The range of variation of this scaling parameter is considered un-known and differ from an operator to another one.

This scheme of control was applied to control the passive quarter car system (Hasbullah et al. 2015; Li et al. 2016). Researchers have developed this method with a constant scaling parameter chosen by the operator and are approximate it to the inverse of sprung mass. However, our aim is to find a global approach by changing controller parameter in order to follow the sprung mass variation.

Recently, Alvarez-Sanchez (2013) provided an identification scheme framework to estimate the sprung mass variation based on algebraic rules of Fliess and Sira-Ramírez (2003). Using this approach, the range variation characteristic of body mass can be deduced based on the measured information of sprung mass displacement, un-sprung mass displacement and actuator force. Based on these mentioned principles, ADRC control using real-time identification for time-varying mass is proposed in this paper. A combination between online real-time identification and ADRC control can be used in order to escape the time-consuming in founding the optimal control.

The organization of the paper as follows. Section 2 describes the motion equations of quarter car model. Section 3 gives a simple description of estimator approach. The online estimation of sprung mass is discussed in Sect. 4. Results are presented in Sect. 5 and a conclusion is summarized in the last section.

2 Description of the System and Road Input

The motion equations of passive quarter car system are given below:

$$m_s\ddot{z}_s + d_s(\dot{z}_s - \dot{z}_u) + k_s(z_s - z_u) = F_A \tag{1}$$

$$m_u\ddot{z}_u - d_s(\dot{z}_s - \dot{z}_u) - k_s(z_s - z_u) + k_t(z_u - z_r) = -F_A \tag{2}$$

m_s is the sprung mass which represents the body of the car. m_u is the un-sprung mass. k_s is the suspension stiffness. d_s Represents suspension damping and k_t is the tire stiffness. The actuator force is denoted by F_A (Fig. 1).

A random road excitation is characterized by a constant of roughness that is given by:

$$\dot{z}_r(t) = -2\pi V n_0 z_r(t) + 2\pi\sqrt{G_0\, V\, w(t)} \tag{3}$$

where $z_r(t)$ is the random road displacement, V is the vehicle speed, the reference spatial frequency n_0, G_0 is the road roughness coefficient and the white noise signal is given by $w(t)$.

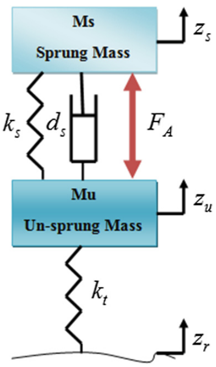

Fig. 1. Active quarter car model

Table 1. Parameters of suspension system

Parameters	Description	Value
m_s	Sprung mass	285 kg
m_u	Un-sprung mass	41 kg
k_s	Spring stiffness	17900 N/m
d_s	Damping constant	535 N/(m/s)
k_t	Tire stiffness	19125 N/m

3 Controller Design

The basic idea of ADRC is using an extended observer ESO without a priori information of the system. The attractiveness of this tool of control results from its capability to estimate on-line and reject unknown perturbations. Significant performances are achieved in the works of Hasbullah et al. (2015) and Pan et al. (2015).

In order to improve the response of suspension system described in Eqs. (1) and (2), the ADRC strategy used to reformulate these equations as,

$$\ddot{z}_s = h(t, \dot{z}_s, z_s) + \beta F_A + z_r \tag{4}$$

From practical point of view, the knowledge of h (.) and β is not straightforward. A non trivial approximation is used in other studies. Where, the constant β is chosen empirically and is approximated by $1/m_s$.

In real conditions, significant uncertainties of sprung mass can affect the behavior of this proposed controller. Estimation of this calibrating parameter can be a source of upgradability in energy consumption.

4 "β" On-Line Adaptation

An algebraic estimator used to find the car body mass of the quarter car system based on algebraic identification methods (for more details see Fliess and Sira-Ramirez 2003).

$$\begin{aligned} m_s(t)(2\int\int z_s - 4\int tz_s + t^2 z_s)dt + d_s(2\iint tz_s + \int t^2 z_s - 2\iint tz_u - \int t^2 z_u)dt \\ + k_s(\iint t^2 z_s - \iint t^2 z_u)dt = \iint t^2 F_A dt \end{aligned} \tag{5}$$

From the equation, it can be seen that only from the measured responses of vertical displacements and actuator force; we can obtain an approximation of sprung mass variation. This On-line estimation can be easily added to the controller structure where,

$$\hat{\beta}(t) = \frac{1}{\hat{m}_s(t)} \tag{6}$$

The structure of classical controller is changed with the variable $\hat{\beta}(t)$, the new design is given in this equations:

(1) the system's state:

$$\begin{cases} \dot{x}_1 = x_2 \\ \dot{x}_2 = x_3 + \hat{\beta}(t)F_A \\ \dot{x}_3 = \dot{f}(t, x_1, x_2, w) \end{cases} \tag{7}$$

where $x_1 = z_s$,$x_2 = \dot{z}_s$ and x_3 represents all the un-known perturbations.

(2) The linear Luenberger observer:

$$\begin{cases} \dot{z}_1 = z_2 - L_{01}\widehat{e} \\ \dot{z}_2 = z_3 - L_{02}\widehat{e} + \hat{\beta}(t)F_A \\ \dot{z}_3 = -L_{03}\widehat{e} \end{cases} \tag{8}$$

The observer gains $[L_{01}, L_{02}, L_{03}]$ depends to the location the desired close loop poles. The approximated error is $\hat{e} = z_s - z_1$.

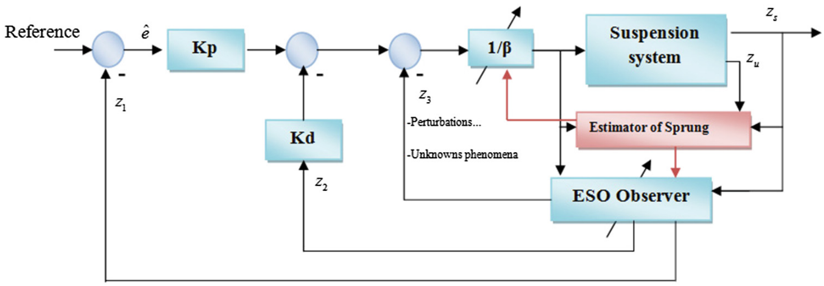

Fig. 2. Block diagram of the proposed control

The principle of combination between online real-time identification and ADRC control is described in Fig. 2.

The gains K_p and K_d are respectively, the proportional gain and the derivative gain, which are needed to implement the proportional-derivative (PD) feedback controller.

5 Results of Simulation

In the simulation algorithm a solver set to ODE5 and fixed integration step of 1 ms were used. The parameters of Suspension system are given by Table 1.

Figure 3 depicts the real value of mass and the identified masse $\hat{m}_i$ when using the "Eq. (5)". In reality, the on-line estimation process is characterized with few irregularities in the beginning. In order to eliminate this perturbation caused by the singularities; the implementation of identifier process is carried out at t > 0 s. It is observable that the estimation process is achieved after a short time t = 0.004 s. (In the rest of simulation, in the beginning β is chosen constant and independents of load variation. After that the estimation and the adaptive scheme start at t = 10 s).

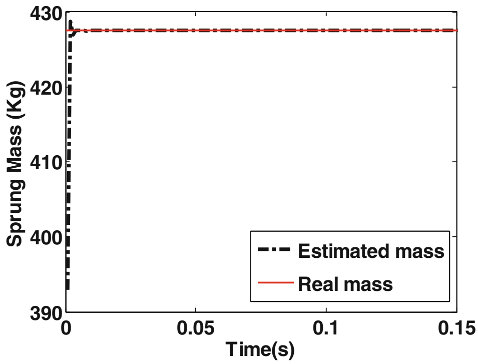

Fig. 3. On-line estimation of Sprung mass

Figure 4 shows the suspension deflection with the effect of sprung mass variation $m_s = +50\%\ m_{s\,initiale}$. The line at t = 10 s represents the instant where the identification started and applied to the controller equation. Before estimation of the constant from measured signals, the β is chosen empirically and it is not calibrated when the

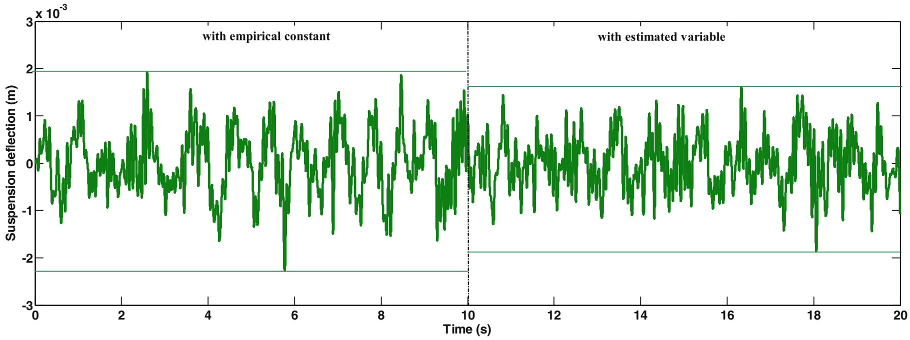

Fig. 4. Suspension deflection

body mass change. The ADRC controller with estimated $\hat{\beta}$ can produce more best tracking position than the ADRC without constant adaptation.

For quarter car control, the ride comfort is related to the body acceleration. In Fig. 5, we can see that the designed system conserve the best isolation of disturbance with a slight attenuation, for the reason that ADRC with adaptive $\hat{\beta}$ has the least RMS value among the sprung mass variation Fig. 6.

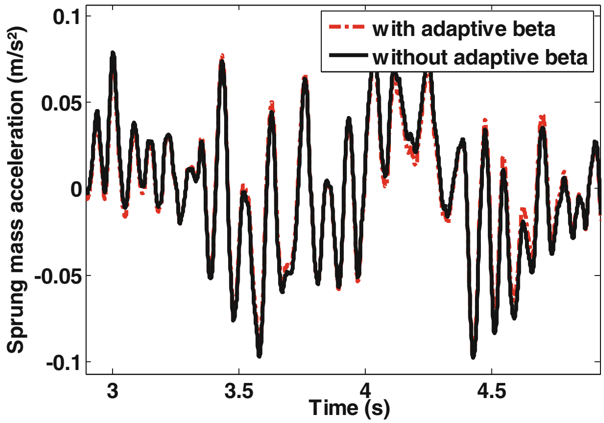

Fig. 5. Sprung mass acceleration variation

In Fig. 7 we observe a reduction of actuator force when we use the adaptive controller. According to this numerical results, the estimated $\hat{\beta}$ has an important role in the dynamic behavior of the suspension system. It is quite possible to obtain better sprung mass acceleration attenuation and the best tracking of reference trajectory for the ADRC controller with the lowest power demand.

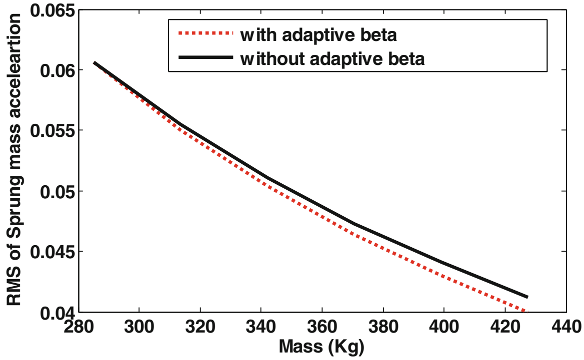

Fig. 6. RMS of Sprung mass acceleration

Furthermore, the Integral of the Square of the Error (ISE) performance was calculated with both of controller and with different masses. The results are depicted in Fig. 8.

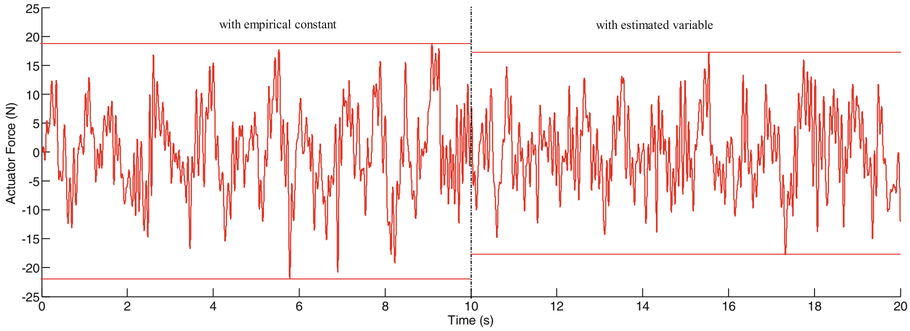

Fig. 7. The power demand of actuator

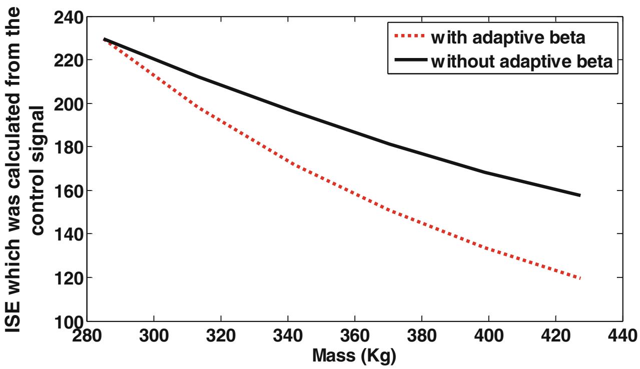

Fig. 8. ISE criteria was calculated from the power demand

6 Conclusion

The aim of this paper is to propose an adaptive ADRC controller using an On-line identification of Sprung mass which is intended to extended time-varying observer. This method can overcome time-consuming which are induced by nontrivial calibration. At the same time, this adaptive control provides high performances under sprung mass uncertainty. Lastly, this method applied to quarter car system permits to getting the best ride comfort and the best tracking with the minimum of power demand.

References

Alvarez-Sánchez, E.: A quarter-car suspension system: car body mass estimator and sliding mode control. Procedia Technol. **7**, 208–214 (2013)

Fliess, M., Sira-Ramírez, H.: An algebraic framework for linear identification. ESAIM: Control Optim. Calc. Var. **9**, 151–168 (2003)

Fliess, M., Join, C.: Model-free control. Int. J. Control **86**(12), 2228–2252 (2013)

Han, J.: From PID to active disturbance rejection control. IEEE Trans. Industr. Electron. **56**(3), 900–906 (2009)

Hasbullah, F., Faris, W.F., Darsivan, F.J., Abdelrahman, M.: Ride comfort performance of a vehicle using active suspension system with active disturbance rejection control. Int. J. Veh. Noise Vib. **11**(1), 78–101 (2015)

Li, P., James, L., Kie, C.C.: Experimental investigation of active disturbance rejection control for vehicle suspension design. Int. J. Theor. Appl. Mech. **1**, 89–96 (2016)

Pan, H., Sun, W., Gao, H., Hayat, T., Alsaadi, F.: Nonlinear tracking control based on extended state observer for vehicle active suspensions with performance constraints. Mechatronics **30**, 363–370 (2015)