MODELING, PARAMETER ESTIMATION AND NONLINEAR CONTROL OF AUTOMOTIVE ELECTRONIC THROTTLE USING A RAPID-CONTROL PROTOTYPING TECHNIQUE

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ABSTRACT—An electronic throttle consists of a DC motor, spur gears, a return spring, a position sensor, power electronics and an electronic control unit. Fast and precise position control of this electromechanical system is relatively difficult due to very high friction and the strong nonlinearity of the spring. Simple application of linear control, such as PID, fails. In this paper, two new controller structures suitable for different reference signal types are described. The key component of the position controller is the friction compensator based on either/both feedforward or feedback principles. The quality of the resulting behavior was measured using several criteria including the measure of control activity around the equilibrium position. The control activity directly influences the vibration, the noise and the wear of the servo system. The proposed controllers demonstrated superior behavior compared with other published structures.

KEY WORDS: Electronic throttle control, Nonlinear control, Friction compensation, Parameter estimation, Rapid control prototyping

1. INTRODUCTION

One important current area of research and development in the automotive industry is focused on the X-by-wire concept. The main idea is adopted from aircraft, where “fly-by-wire” is the standard approach used in military as well as civil aircraft. Computer control has replaced conventional mechanical controls; the actuator is connected to the pilot only by means of a “wire”. As a result, the mane-
verability of the aircraft increases significantly due to computer control of a naturally unstable design. Fly-by-wire is very often mentioned as a typical mechatronic solution.

In automotive design, there are many variants of this philosophy in use already or in development. Examples include steering-by-wire, where conventional mechanical steering is replaced by a sensor and an electrical servo-motor, brake-by-wire, where conventional hydraulic or pneumatic actuators are replaced by electrical ones, and (most commonly) throttle-by-wire, where a sensor and an electrical motor replaces a mechanical linkage between the accelerator pedal and the throttle. (Stence, 2006).

The throttle-by-wire system consists of a pedal sensor, the throttle body (with a DC motor, spur gears and a potentiometer as the position sensor) and an electronic control unit (ECU). Thus, the conventional mechanical linkage of pedal and throttle via a bowden cable is replaced by a mechatronic design.

Full ECU control of throttle plate behavior enables better fuel economy and emissions, and it provides the possibility of using advanced tracking control algorithms or other overall system improvements.

Due to mass production of automotive parts and the corresponding compromises between technical quality and manufacturing costs, high friction is a problem that plagues the throttle mechanism. Moreover, safety regulations require the return of the valve to a slightly open position—a so-called “limp home” (LH) mode—in case of system failure. This feature is implemented by a relatively strong spring near the LH position. However, using this spring stiffness through the full range of the valve would also produce an enormous motor load along with significant energy consumption and heating. In most throttles, a nonlinear spring is used to solve this problem (Pavković et al., 2006, Deur et al., 2003).

Here, we describe a solution to this problem by illustrating how the advanced control algorithm implemented in the ECU can significantly improve inexpensive electromechanical systems.

In the last decade, many authors have published interesting results using electronic throttle control; many of them have been directly related to automotive firms (Pavković et al., 2006). The high nonlinearity of the system disqualifies the use of simple linear controls (e.g., PID). It is well known that linear controllers cannot deal with the dry friction phenomenon because steady-state error arises in the case of a PD regulator and oscillations arise in the case of a PID controller.

The multi-model approach for throttle modeling has been successfully studied previously (Hadilebbal et al., 2007). In this approach, a nonlinear model is replaced by several linear models, and the algorithm switches between them. The work is highly inspired by the PWARX (Piece Wise Auto Regressive eXogenous) method. Other work (Trebi-Ollennu and Dolan, 2004) uses an adaptive fuzzy-control approach applied on unmanned ground vehicles. The whole drive system is modeled and controlled with the goal of low-speed control, and a detailed model of the throttle control is not provided.

Contreras et al. have identified throttle parameters (Contreras et al., 2002). In their approach, the dynamic friction model of LuGre is used with different inertial reduced moments of mechanical throttles, which are considered in terms of the closing or the opening direction. This model does not discuss its control scheme.

One highly inspiring set of papers has been published by Pavković, Deur, and Vasek (Pavković et al., 2006; Deur et al., 2003; Vašak et al., 2007). In these works, the controller architecture consists mainly of a friction compensator, a LH compensator, and a PID element. There are also other improvements including variable filtering according to the control error, feedforward elements, and gain scheduling of the PID. At a given moment, only one of the friction or LH compensators is used. Deur (Deur et al., 2003) describes the self-tuning of compensator parameters. Baotic, a collaborator of Deur, (Baotic et al., 2003) uses Model Predictive Control and a Karnopp friction model.

The key issue in effective throttle control is compensation for friction. Because friction is a nonlinear function of velocity, several authors deal with the compensators based on measured or reconstructed velocity (Olsson et al., 1998). The authors note that the approach is dependent on the precision of the velocity measurement or estimation. A much better alternative to this approach is the use of position error as the input for the friction compensator (Iserman, 1996; Yang, 2004; Pavković et al., 2006; Deur et al., 2003).

Sliding Mode Control (SMC) for ETC is also an active area of research. Beghi (Beghi et al., 2006) and Zhang et al. (2006) use SMC in conjunction with a Sliding Mode Observer and compare it with a Kalman filter.

Also, many researchers use the throttle model as a part of other complex models including the engine, the transmission, the wheels and tires, and the traction control system (Ryu et al., 2005; Jung et al., 2000; Ishikawa et al., 2007).