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Control Engineering Practice 14 (2006) 121–136

CONTROL ENGINEERING PRACTICE

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Adaptive control of automotive electronic throttle

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Received 16 June 2003; accepted 19 January 2005
Available online 3 March 2005

Abstract

An electronic throttle is a DC servo drive which positions the throttle plate, thus providing drive-by-wire control of engine torque. This paper presents an electronic throttle control strategy consisting of a PID controller, and nonlinear friction and limp-home compensators. The emphasis is on the development of an adaptive control strategy, which is aimed to enhance the control strategy robustness with respect to process parameter variations, caused by production deviations, variations of external conditions, and aging. The adaptive strategy consists of auto-tuning and self-tuning algorithms. The auto-tuner provides automatic tuning of the control strategy parameters during vehicle assembly, or uses specific drive modes during normal use (e.g. each time the engine is turned off). The self-tuning algorithms are based on the permanent, on-line estimation of those process parameters which can vary within a single engine run (e.g. the DC motor armature resistance). The presented adaptive control strategy has been verified experimentally.

Keywords: Servomotors; Automotive control; Electric throttle control; Friction; Nonlinear control; Auto-tuner; Self-tuning control

1. Introduction

In conventional vehicles the driver gas pedal is mechanically linked to the throttle plate. This system is being replaced in modern vehicles by an electronic throttle, where the link between the gas pedal and the throttle plate is realized by means of a DC servomotor. In this way, the engine control unit can correct the throttle position reference value for specific engine operating modes, thus improving drivability, fuel economy, and emissions, and also providing the implementation of engine-based vehicle dynamics control systems including traction control (Huber, Liebenroth-Leden, Maisch, & Reppich, 1991). The electronic throttle consists of an electronic throttle body, a chopper, and a position control strategy. A photograph of an electronic throttle body is shown in Fig. 1a, and its internal structure is depicted in the lower right part of Fig. 1b. The electronic throttle servo system does not usually include an inner current controller. The throttle motion is constrained by a dual return spring which returns the throttle in the so-called limp-home (LH) position in the case of power supply failure.

It has been demonstrated in (Deur, Pavković, Perić, Jansz, & Hrovat, 2004) that DC drive transmission friction and the dual return spring nonlinearity at the LH position significantly affect the performance of the electronic throttle control system. A nonlinear control strategy is proposed in the same reference in order to compensate for friction and LH nonlinear effects, thus providing a linear system-like behavior for a wide range of throttle operation. The step response of control system is characterized by the settling time of approximately 70 ms and the steady-state accuracy better than 0.1°. The control strategy has been tuned based on the

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doi:10.1016/j.conengprac.2005.01.006

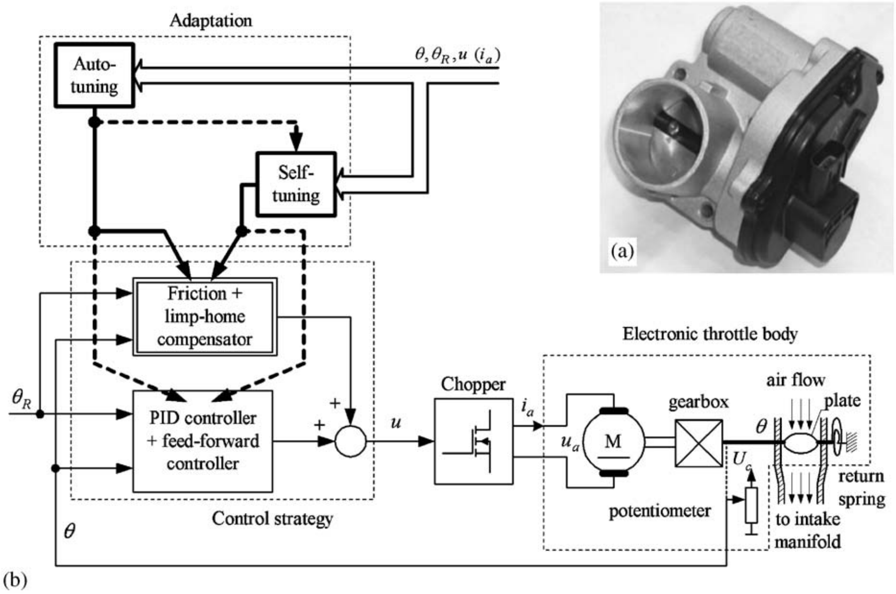

Fig. 1. Photograph of electronic throttle body (a), and principal schematic of adaptive electronic throttle control system (b).

results of off-line experimental identification of electronic throttle process model (see Pavković, Deur, Jansz, & Perić, 2003).

It can be expected that the performance of an electronic throttle with constant controller parameters will deteriorate in the presence of process parameter variations. There are three sources of process parameter variations (see Pavković & Deur, 2002; Hashimoto, Ishiguro, Yasui, & Akazaki, 2003):

(a) *Production deviations.* Different ETBs from the same production series can have different parameters. Static curves $u(\theta)$ in Fig. 2a illustrate that the friction level characterized by the width of the static curve hysteresis, and the LH voltage step can be quite different for different ETBs.
(b) *Aging.* Fig. 2b indicates that the friction and LH voltages increase with aging of ETB. The LH position has been found to vary with aging as well. Aging may also decrease the DC motor voltage and torque constants due to the weakening of the motor permanent magnets.
(c) *Variations of external temperature and battery voltage.* The DC motor armature resistance can vary in the range 1:2 as the consequence of temperature variations (Hashimoto et al., 2003). This has direct implications on the friction and LH voltage parameters, as illustrated by the static curves in Fig. 3. The battery voltage variations have similar influence on the process static curve parameters.

In order to deal with process parameter variations, two control concepts can generally be applied: (i) robust control and (ii) adaptive control. The former concept assumes that the process model uncertainties can be captured by means of a specific control structure. A sliding mode electronic throttle control structure is often proposed either in its standard form (see e.g. Hashimoto et al., 2003; Rossi, Tilli, & Tonielli, 2000; Yokoyama, Shimizu, & Okamoto, 1998) or in a more advanced neural network-based form (see e.g. Barić, Petrović, & Perić, 2002, 2004). The effectiveness of such an approach can be limited by high level of noise in the controller output signal (chattering), and/or the requirements on very low sampling time and powerful processor. The latter concept of adaptive control assumes on-line tuning of controller parameters based on the results of on-line process identification. Such a concept has not been well investigated in the available literature, with an exception of Hashimoto et al. (2003), and Gagner and Bondesson (2000), where adaptive LH compensators are presented.

This paper proposes a more comprehensive adaptive electronic throttle control strategy compared to those given in Hashimoto et al. (2003), and Gagner and Bondesson (2000), and presents the results of thorough experimental tests. The adaptation mechanism tunes the control strategy from Deur et al. (2004) with respect to wide-range variations of all process parameters. The overall adaptive control strategy can be implemented on a low-cost automotive microcontroller system with integer arithmetic only and typical electronic throttle sampling time in the range from 2 to 5 ms. The adaptation strategy consists of auto-tuning and self-tuning algorithms (Fig. 1b).

The auto-tuner tunes the controller parameters for each single ETB in the stage of vehicle production. It can also be executed during specific vehicle drive modes