Mechanical Systems and Signal Processing 26 (2012) 294–304

Contents lists available at ScienceDirect

Mechanical Systems and Signal Processing

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

Nonlinear modeling and identification of a spark ignition engine torque

Necla Togun [a,*], Sedat Baysec [a], Tolgay Kara [b]

[a] Department of Mechanical Engineering, University of Gaziantep, 27310 Gaziantep, Turkey
[b] Department of Electrical and Electronics Engineering, University of Gaziantep, 27310 Gaziantep, Turkey

ARTICLE INFO

Article history:
Received 20 January 2010
Received in revised form
13 May 2011
Accepted 12 June 2011
Available online 26 July 2011

Keywords:
Spark ignition engine
Nonlinear modeling
Nonlinear identification
Hammerstein systems
Recursive least squares estimation

ABSTRACT

The identification of mathematical models typically nonlinear systems is vital in many fields of engineering. This study presents nonlinear modeling and identification of spark ignition engine torque from input–output measurement. Nonlinear models for the system are obtained for identification purposes. The Hammerstein nonlinear system approach is used for identification of the nonlinear system model. Identification of nonlinear system models is performed using the recursive least squares method. The nonlinear system identification with fifth order linear dynamics gives the best result. And also selection of the second order nonlinearity gives the best result. The results are numerically and graphically presented.

1. Introduction

System identification is the process of creating models of dynamic process from input–output signal. System identification is the art and methodology of making mathematical models from dynamic systems based on the input–output data [1]. System modeling and identification refers to a systematic way to determine and improve the mathematical models for proper representation of dynamic systems [2]. A large body of work on the topic is available in the literature [3,4].

Modeling and identification of mechanical systems constitute an essential stage in practical control design and applications. Controllers commanding systems that operate at varying conditions or require high precision operation raise the need for a nonlinear approach in modeling and identification. Most processes in industry are characterized by nonlinear and time-varying behavior. Most systems encountered in the real word are nonlinear in nature, and since linear models cannot capture the rich dynamic behavior of limit cycles, bifurcations, etc. associated with nonlinear systems, it is imperative to have identification techniques that are specific for nonlinear systems [5]. System identification has become an important area of study because of the increasing need to estimate the behavior of a system with partially known dynamics. Especially in the areas of control, pattern recognition and even in the realm of stock markets, the system of interest needs to be known to some extent [6].

Theory of system identification plays a significant role in many fields of science and engineering, including simulation, automatic control, fault tolerant analysis, prediction, etc. [7,8,3]. Several techniques have been proposed for identification of nonlinear systems. Among the various linear in the parameter structures available, nonlinear autoregressive exogenous

* Corresponding author. Tel.: +90 342 3172534; fax: +90 342 3601104.
E-mail address: nkara@gantep.edu.tr (N. Togun).

0888-3270/$ - see front matter
doi:10.1016/j.ymssp.2011.06.010

model (NARX)/NARMAX (Nonlinear Autoregressive Moving Average with Exogenous input) is one of the earliest and perhaps most widely used model types, with many successful industrial applications reported. For example, it has been used in the modeling and control of power systems, such as internal combustion engine (ICE) [7], automotive diesel engine [9] and dynamic modeling of three way catalysts [10]. Ref. [11] deals with the nonlinear identification of a turbocharged diesel engine. A combined use of NARMAX models and group method data handling method is proposed in an attempt to provide a systematic approach to identify nonlinear systems using relatively simple models well suited to computer handling. A nonlinear system identification procedure, based on a polynomial NARMAX representation, is applied to a variable geometry turbocharged diesel engine [12]. A nonlinear black box engine model is derived using the NARMAX models proposed. Input–output models allow the identification of black box models derived purely from experimental data, both online and offline [13].

An identification procedure for NARX models describing the pressure inside the intake manifold and the crankshaft speed of ICE has been handled in Refs. [14–16]. A number of methodologies for idle speed control design has been presented in literature [16,17].

A new approach to control air management process of a diesel engine has been proposed. Predictive control and model identification schemes for the Wiener and Hammerstein models have been shown [18]. Ref. [19] has described and compared two approaches to the experimental identification of dynamic nonlinear processes: the dynamic multi layer perceptron and the generalized Hammerstein model. A large number of research studies has indicated the superior capability and effectiveness of Wiener models in nonlinear dynamic system identification and control [20].

Tan and Saif have proposed a recurrent neural network for modeling the nonlinear dynamics of the intake manifold pressure for onboard diagnosis application [21]. Dynamics of air manifold and fuel injection of spark ignited (SI) engines are very fast, severely nonlinear and with constraints imposed on the states and inputs [21,22]. To model volumetric efficiency of internal combustion using parametric, nonparametric and neural network techniques are studied [22].

Advanced research on engine control often relies on model based control strategies. Model based engine diagnostics also is another area that relies on an engine model. Therefore, the development of simplified models of automotive engines appropriate for control/diagnostic system research and design is an important subject for research and development [21]. Ref. [23] deals with methods based on engine model linearization in order to apply linear control theory. Jones et al. [24] implemented a nonlinear least squares state estimator for an adaptive control schema. Least square support vector machines have been handled regression problems [25]. NARX models have already been used in engine modeling for control and diagnosis purposes [13]. Dynamic models in ICE have been applied to design, optimization or diagnosis [26], using geometric and dynamic engine characteristics. Several different methods have been proposed and investigated for pressure reconstruction, mathematical engine models [26,27]. A procedure for the identification of emission models for the design of optimal control of SI engine is presented [28].

Automotive engine control is one of the most complex control problems for control system engineers and researches. Due to the increasing requirements of governments and customers, car manufacturers always strive to reduce substantially emissions and fuel consumption while maintaining the best engine performance. To satisfy these requirements, a variety of variables need to be controlled, such as engine speed, engine torque, spark ignition timing, fuel injection timing, air intake, air/fuel ratio (AFR) and so on. These variables are complicatedly related to each other. Engine dynamics are highly nonlinear and multivariable because of these factors [21,29]. Among all the engine control variables, engine torque estimation has important applications in the automotive industry: for example, automatically setting gears, optimizing engine performance, reducing emissions and designing drivelines [30]. The coordinated overall torque reference value is realized by the manipulation of variables like throttle position, ignition timing, injection timing and others [31].

A number of such control strategies has been reported in the literature during the current decade. Most of these control schemes deal with manifold pressure control, AFR control and idle speed control [32]. The article deals with nonlinear modeling of AFR dynamics of gasoline engines during transient operation [33]. The influence identification scheme developed in Ref. [34] is applied to the system for the determination of the inputs that affect exhaust oxygen content and the appropriate time delays that the system imposes on each variable. Ref. [35] included the effect of exhaust gas recirculation in a nonlinear model to investigate engine dynamics. In another application, a finite difference model is used to represent engine nonlinear inverse dynamics between engine speeds and throttle duty cycle signals [36]. A detailed physically motivated simulation model is derived in Ref. [37]. An adaptive (online) identification algorithm, developed recently in Ref. [38] for continuous time single input single output (SISO) linear time delay system with uncertain time-invariant parameters, is tested in an experimental study of the transient fuel parameter identification in a port fuel injected ICE.

The engine torque is one of the most important performance variables of an ICE and, for this reason; a torque control system can improve substantially the performance of the overall vehicle [39,40]. Their modeling efforts were focused on an experimental method of system identification that captures the nonlinear engine torque characteristics for a large range of operating conditions [41]. In recent years considerable interest has been placed on the estimation of ICE torque both for control and diagnostic applications. Ref. [42] discusses a method for the identification of a nonlinear model of the dynamics relating combustion pressure to crankshaft angular velocity. A linear gray box approach to modeling the torque and NO_x dynamics in response to combined fuel quantity/timing excitations has been handled in Ref. [43].

This paper basically focuses on nonlinear modeling and identification of SI engine torque. In this paper, a procedure to provide the nonlinear model of the dynamics between the throttle valve command and torque in a gasoline engine directly