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Support vector regression based friction modeling and compensation in motion control system

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ABSTRACT

Friction has been experimentally shown to be one of the major sources of performance degradation in motion control system. Although for model-based friction compensation, several sophisticated friction models have been proposed in the literatures, there exists no universally agreed parametric friction model, which by implication has made selection of an appropriate parametric model difficult. More so, accurate determination of the parameters of these sophisticated parametric friction models has been challenging due to complexity of friction nonlinearities. Motivated by the need for a simple, non-parametric based, and yet effective friction compensation in motion control system, an Artificial Intelligent (AI)-based (non-parametric) friction model using ν-Support Vector Regression (ν-SVR) is proposed in this work to estimate the non-linear friction in a motion control system. Unlike conventional SVR technique, ν-SVR is characterized with fewer parameters for its development, and requires less development time. The effectiveness of the developed model in representing and compensating for the frictional effects is evaluated experimentally on a rotary experimental motion system. The performance is benchmarked with three parametric based (Coulomb, Tustin, and Lorentzian) friction models. The results show the ν-SVR as a viable and efficient alternative to the parametric-based techniques in representing and compensating friction effects.

1. Introduction

The inherent presence of friction in motion control system has been the major sources of performance degradation in terms of slow responses, steady state accuracy, and or limit cycles near the reference position (Armstrong-Helouvry, 1991). Hence the need for its accurate compensation has become important in high precision position control. Various techniques have been developed to eliminate the effects of the friction such as presented in (Dupont and Armstrong-Helouvry, 1993; Armstrong-Helouvry et al., 1994; Wahyudi, 2003; Tjahjowidodo et al., 2004; Canudas de Wit et al., 1986). Among the successful methods is the well-known model-based friction compensation. In this method, the effect of the friction is canceled by applying additional control signal which generates a torque/force. The generated torque/force has the same value (or approximately the same) with the friction torque/force but opposite in direction. This method requires the precise modeling of the characteristics of the friction to provide a good performance. Therefore, in the context of model-based friction compensation, identification of the friction is one of the important issues required for high performance motion control.

However, in literatures, many types of friction model have been identified. They are classified either as static or dynamic friction models. Among the static models are, Classical Coulomb friction model, Tustin model, Leuven model, Karnop model, Lorentzian model, while Dahl model, Lugre model, Seven parameters model, the most recent Generalized Maxwell-Slip model, are among the dynamic friction models (Armstrong-Helouvry et al., 1994; Canudas de Wit et al., 1995, Makkar et al., 2005). These models are characterized either as discontinuous or piecewise continuous functions. Intuitively, each model has its own merits and demerits, which has made the choice of the model problem dependent. The static friction model is simple and easy in the identification process, however using such model for friction compensation requires extensive refinement especially when the friction parameters are unknown. On the other hand, the accuracy of the dynamic friction model is anchored on the dependency of friction on an immeasurable internal state. Since friction model selection is an important factor in the model-based friction compensation, it is important to find the most appropriate friction model for realizing high performance motion control. This has been the basis for the continuous search for more efficient and yet simple model for friction identification and compensation in motion control system applications.

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In addition, the recent development in artificial intelligent approaches makes it adaptable for system modeling base on the data training and expert knowledge. It has been shown that the major AI-paradigms (Neural Network, Fuzzy Logic, Neuro-fuzzy, Support vector machine etc) have the capability of approximating any nonlinear function to a reasonable degree of accuracy, and have been applied in several engineering applications (Cheng et al., 2005; Kemal Cılıza and Tomizukab, 2007; Wen-Chuan et al., 2009). To this end, AI techniques have been identified and proposed as appropriate alternative for friction model and compensation in motion control systems, (Gao and Ovaska, 1999; Huang et al., 2000; Bi et al., 2004; Kemal Cılıza and Tomizukab, 2007; Gomes et al., 2005; Wahyudi and Tijani, 2008). Therefore, non-parametric models base on artificial intelligence approaches can be used as an alternative for friction identification so that the difficulty in friction model selection can be avoided. In addition, the use of artificial intelligence based friction model may also reduce both the complexity and time consumed in the friction modeling and identification. With recent advancement in statistical learning theory, support vector Regression (SVR) proposed by Vapnik (1995) has been identified as effective modeling tools in machine learning.

Support Vector Regression is generally an extension of the well developed theories of Support Vector Machine (SVM) to regression problems with introduction of ε-insensitivity loss function by Vapnik (1995). Unlike traditional learning algorithm for function estimation such as Neural Network that minimizes the error on the training data based on the principle of empirical risk minimization, SVR embodies the principle of Structure Risk minimization which minimizes an upper bound on the expected risk. Hence, it is characterized by better ability to generalize, and at the same time less prone to the problems of overfitting and local minimal. It has was applied for long-time prediction of discharge in (Lin et al., 2006), for forecasting of the daily metrological pollution in (Osowski and Garanty (2007)) and recently in fault detection in industrial environment (Gryllias and Antoniadis, 2012). Due to these unique advantages, it has been proposed and employed for non-linear function approximation, and recently for friction identification in Haptic Display system (Bi et al., 2004, Ahmed and Lee, 2008). However, besides the problem of specifying the trade-off between empirical error and model capacity (i.e. Model Selection), there also exists the problem of optimal choice of the ε-insensitivity cost function parameter, ε, in conventional ε-SVR. This has led to the formulation of other version of SVR known as ν-SVR with the introduction of another parameter ν. By the introduction of parameter ν in the objective function, ν-SVR provides automatic computation of the optimal ε-insensitivity cost function parameter, ε, and besides having the advantage of being able to automatically determine ε, it can be used to pre-specify the number of support vectors (Smola and Scholkopf, 2001; Schölkopf and Smola, 2002).

To this end, this study proposes the development of ν-SVR based friction model to overcome the problem of friction model selection and development in motion control system. And in addition, the difficulty in ε-SVR development is addressed with simplicity of ν-SVR model development. Hence, a non-parametric friction model using the novel ν-Support Vector Regression (ν-SVR) with Gaussian Kernel function is proposed in this study to estimate and compensate the non-linear friction dynamics in a Direct Current (DC) motor driven motion control system. The effectiveness of the proposed SVR-based friction model to compensate the frictional effects in positioning control is evaluated experimentally on a rotary experimental motion system for both Point-to-Point (PTP) and Tracking Positioning control. According to Armstrong-Helouvry et al., 1994, control tasks involving regulator and tracking positioning are mainly affected by stiction, stribeck, and kinetic frictions. Thus, an improved performance can be achieved with a friction model accounting for these main friction characteristics. Hence, this work is focused on identification of friction in sliding regime, and the performance of the proposed AI-based models is benchmarked with three no table parametric models- Coulomb, Tustin, and Lorentzian friction models. Coulomb friction model is chosen based on it's historically roles in the study of friction, and its simplicity in representing the friction. The remaining two parametric models represent the major static friction models that account for the friction effects in sliding regime. (Tustin, 1947) was the first model that explains the nonlinear negative viscous friction in the analysis of feedback control, while on the other hand Lorentzian model developed after Tustin model was known with better performance over other similar models (Armstrong-Helouvry, 1991).

The rest of this paper is organized as follows: Section 2 gives the brief information on the experimental plant and system model as used in this study, the concept of ν-SVR in system model is explained in Section 3. In Section 4, the experimental friction measurement and ν-SVR model development are detailed together with the estimation of the parametric models. The experimental implementation of the models in friction compensation is reported in Section 5. Section 6 gives the results and discussion. The paper is concluded in Section 7.

2. Plant descriptions and modeling

Since most of the motion control system uses a DC or Alternating Current (AC) motor, in this research only motion control system driven by a DC motor is considered. Fig. 1 shows the experimental set-up of the DC motor driven rotary motion system used in this paper. It consists of servo motor driven by an amplifier and position encoder attached to the shaft as the feedback sensor. The schematic representation of the complete

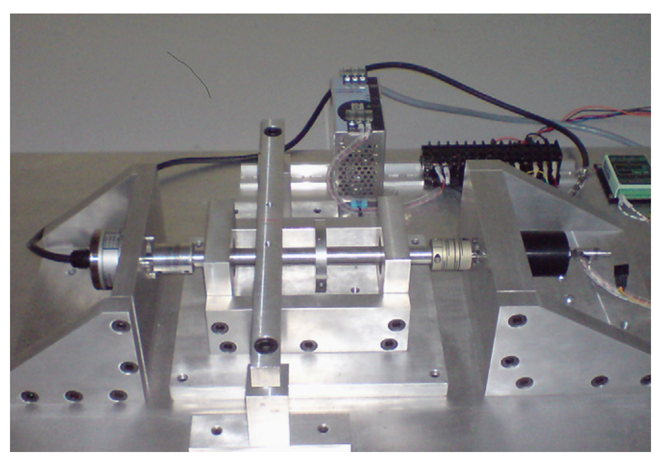

Fig. 1. DC-motor driven rotary motion system.

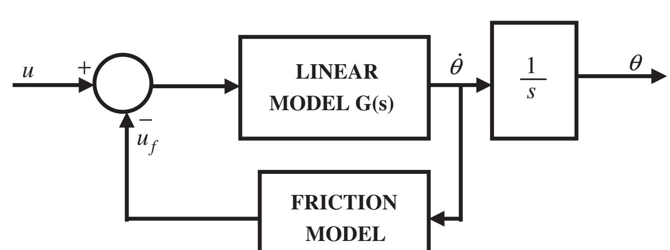

Fig. 2. Complete system model.