Mechatronics 21 (2011) 614–624

Contents lists available at ScienceDirect

Mechatronics

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

Technical note

Energy-based approach for friction identification of robotic joints

M. Vakil, R. Fotouhi *, P.N. Nikiforuk

Mechanical Engineering Department, University of Saskatchewan, 57 Campus Drive, Saskatoon, Canada S7N 5A9

ARTICLE INFO

Article history:
Received 7 April 2010
Accepted 13 December 2010
Available online 1 February 2011

Keywords:
Robotics
Friction identification
Work-energy principle

ABSTRACT

In this paper a new open-loop (off-line) identification approach to determine the friction parameters in the joints of robotic manipulators is presented. These friction parameters are the Coulomb friction, Static friction, Stribeck velocity constant and Viscous damping coefficient, referred to as the CSSV.

The new friction identification approach introduced in this paper permits the CSSV to be determined by solving a nonlinear optimization problem which is derived using work-energy principle. The corresponding nonlinear optimization problem is solved using an efficient technique which does not require iteration or any initial estimate of the parameters. This new open-loop approach, compared to the available open-loop approaches, has the advantages that do not require the values of the manipulator's parameters; such as mass or mass moment of inertia of links. Moreover, since this new identification approach is open-loop, it has the superiority that does not require any controller, which is the vital component in the closed-loop identification approaches.

The new identification approach proposed here is applicable to the joints of earth-based robotic manipulators whose corresponding links move in the horizontal plane or the joints of space manipulators. The new approach was experimentally verified on a robotic manipulator available in the Robotics Laboratory at the University of Saskatchewan.

1. Introduction

One of the inherent nonlinearities in almost all robotic manipulators is friction [1]. Control of robotic manipulators, in the presence of friction, might suffer from phenomena such as steady tracking error [2], limit cycles [3,4] and stick–slip [5]. Therefore, to improve the performance of controllers, without resorting to high gain feedbacks, the friction force (torque) should be identified and compensated. Hence, a model which is capable of satisfactorily resembling the friction force (torque) in robotic joints should be first selected and its contributing parameters then identified [6–9].

In this paper the torque of friction, $\tau_{friction}$, in a revolute joint of a robotic manipulator is modeled as[1] [3]:

$$\tau_{friction} = \begin{cases} (\tau_c + (\tau_{st} - \tau_c)e^{-(\dot{\theta}/v)^2})\mathrm{sgn}(\dot{\theta}) + \sigma\dot{\theta} & \forall\ \dot{\theta} \neq 0 \\ \min(|c_m i|, \tau_{st})\mathrm{sgn}(i) & \forall\ \dot{\theta} = 0 \end{cases} \quad (1)$$

where $\dot{\theta}$ is the rotational velocity of the joint, i is the motor current, c_m is the torque constant which relates the motor current to the motor torque and τ_c, τ_{st}, v and σ are the Coulomb friction, Static friction, Stribeck velocity constant, and Viscous damping coefficient (CSSV), respectively. Moreover, $\mathrm{sgn}(\dot{\theta})$ is:

$$\mathrm{sgn}(\dot{\theta}) = \begin{cases} 1 & \text{for } \dot{\theta} > 0 \\ 0 & \text{for } \dot{\theta} = 0 \\ -1 & \text{for } \dot{\theta} < 0 \end{cases} \quad (2)$$

This model, Eq. (1), not only models friction during maneuver but also approximates the friction during the stiction [3].

Although there are different models for the friction such as the LuGre model [10], bristle model [11], modified sigmoid-friction (neural network) and polytopic model [12], or those in [13–15], in this paper the model in Eq. (1) is selected to represent the friction. This model, which is based on the widely used LuGre model [10], assumes that the average deflections of the bristles in the LuGre model are constant [16]. That is, the frictional memory and the rising static friction [1] are considered negligible. Even though, neglecting frictional memory and the rising static friction leads to an approximation, the model in Eq. (1) is computationally efficient and its application to predict the friction in robotic joints has been experimentally verified in many studies such as [16–20].

After selecting the model presented in Eq. (1), CSSV have to be determined. To determine these parameters, a new open-loop (off-line) approach is introduced in this paper. Based on this new approach the CSSV is determined by solving a nonlinear optimization problem. The nonlinear optimization problem is derived according

* Corresponding author. Tel.: +1 306 966 5453; fax: +1 306 966 5427.
E-mail address: reza.fotouhi@usask.ca (R. Fotouhi).

[1] For a prismatic joint the relation between the force of friction, $F_{friction}$, and the translational speed, $\dot{x}$, is similar to that presented in Eq. (1) with the difference that $\dot{\theta}$ and $\tau_{friction}$ in this equation should be replaced with $\dot{x}$ and $F_{friction}$, respectively.

0957-4158/$ - see front matter © 2010 Elsevier Ltd. All rights reserved.
doi:10.1016/j.mechatronics.2010.12.007