Adaptive Neuro-fuzzy approach in friction identification

Muhammad Zaiyad Muda @ Ismail
Fakulti Kejuruteraan Mekanikal, Universiti Teknologi MARA, Shah Alam, Selangor, Malaysia.
zaiyad13@yahoo.com.my

Abstract. Friction is known to affect the performance of motion control system, especially in terms of its accuracy. Therefore, a number of techniques or methods have been explored and implemented to alleviate the effects of friction. In this project, the Artificial Intelligent (AI) approach is used to model the friction which will be then used to compensate the friction. The Adaptive Neuro-Fuzzy Inference System (ANFIS) is chosen among several other AI methods because of its reliability and capabilities of solving complex computation. ANFIS is a hybrid AI-paradigm that combines the best features of neural network and fuzzy logic. This AI method (ANFIS) is effective for nonlinear system identification and compensation and thus, being used in this project.

1. Introduction
Friction is the tangential reaction force that occurs when there is relative motion between surfaces [1]. Despite its importance in many applications, it also affects the attempts of designers in making an efficient system or machines. In industry, the uses of DC motors are quite common, for example in motion control, positioning and actuation system. Friction identification and compensation comes in place when there is need to improve the current motion accuracy especially when it involves precise machining and manufacturing processes.

This study includes the understanding of various number of classical friction models, namely Coulomb, static and Stribeck friction. DC motor mathematical model is briefly explained, which will be used to identify required data needed for friction modelling using ANFIS. Artificial Intelligent approach has been introduced in control system for friction identification due to complexity in friction models [2]. Generally, the objective of system identification is to estimate the dynamic model structure by means of observing the input and output data [3].

2. Friction model
Friction models are described by plotting the friction force and velocity [4]. Among the classical friction models that frequently studied are Coulomb, static and Stribeck friction. Another friction model known as viscous damping is the most utilized model; however, it is rarely found [5]. Coulomb friction, also known as dry friction [6], is a constant opposing torque for nonzero velocities [7]. The magnitude of kinetic friction according to Coulomb model depends on the magnitude of normal force and the direction of slippage, not the speed.
The phenomenon of Stribeck friction occurs due to the use of fluid lubrication, where the magnitude of friction is inversely proportionate to the velocity [8]. It occurs at the low velocity, and normally encountered in the lubricated servo-controlled machines. In the other hand, static friction is the friction when sticking [9]. The maximum frictional force is normally happen at the small distance from beginning point. The maximum static friction coefficient represents the maximum value of the friction force [10]. Figure 1 shows the various types of friction model.

![Figure 1. Friction models: (a) Coulomb; (b) Static friction; (c) Stribeck.](image)

3. DC motor mathematical model
DC motor is one of the most frequently used electromechanical systems. It consists of both electrical and mechanical elements [11]. Figure 2 shows a simplified DC motor model, and Figure 3 shows a block diagram for a DC motor that is obtained by using Laplace Transform.

![Figure 2. DC motor model](image)

The mathematical model of DC motor is described as follows:

\[ V_{in}(t) - Ri(t) - L \frac{d\theta}{dt} - K_b \omega(t) = 0 \]  \hspace{1cm} (1)

\[ J \frac{d\omega}{dt} + B \omega(t) - K_t i(t) = 0 \]  \hspace{1cm} (2)

Hence the transfer function is given by:

\[ \frac{\Delta \omega(t)}{V_{in}(0)} = \frac{B}{J s^2 + B s + K_t} \]  \hspace{1cm} (3)
The DC motor parameters are described as follows:
- \( V_{in} \) = input voltage
- \( R \) = motor resistance
- \( L \) = motor inductance
- \( K_b \) = back electromotive-force constant
- \( K_t \) = motor torque constant
- \( J \) = motor inertia
- \( B \) = motor friction

![DC Motor Block Diagram](image)

**Figure 3.** DC motor block diagram.

In determining the value of the motor frictional torque \( T_m \), the motor current \( I_m \) that has been measured in the experiment is multiplied with the motor torque constant \( K_t \) due to the equation:

\[
T_m = K_t I_m
\]

(4)

4. Methodology

Figure 4 shows the flowchart that summarizes the overall experiment. It starts with development of Simulink model, and then followed by data collection. The important data in this experiment are angular velocity and motor current. Next, the data is trained by using ANFIS toolbox that is available in MATLAB. The friction modeling is evaluated based on the difference between the actual and trained data.

![Experiment Flowchart](image)

**Figure 4.** Experiment flowchart.
4.1 Experimental setup

This experiment involves the use of the Modular Servo System (MSS) as shown in Figure 5. Three important components in this system are DC motor, tachogenerator and encoder. In the Modular Servo System, several modules are mounted at the metal rail and coupled with small clutches. The modules are arranged in the chain. The rotation angle of the DC motor shaft is measured using an incremental encoder. The tachogenerator is connected directly to the DC motor and used to generate a voltage signal proportional to the angular velocity.

![Figure 5. Modular Servo System configuration.](image)

Then, in order to generate the data required for friction identification, MATLAB Sofware which includes Simulink and Simscape is used.

4.2 Friction identification experiment

In this experiment, the objective is to find out the relationship between the angular velocity of the DC motor with the friction torque where the voltage is used as variable. The first step for this experiment is the system modelling using the MATLAB software, Simulink and Simscape. Figure 6 shows the model used in friction identification experiment. The model is developed by referring to the standard DC motor configuration available in mathworks, and then modified to suit the need of this project.

![Figure 6. Friction identification model in MATLAB.](image)
5. Result
The voltage input in the model is set to certain values before it starts to run. After that, the result of
the motor current and angular velocity is recorded in a table so that the process of analysing the data
will be easier. Furthermore, in the model system, the fixed parameter such as the motor inductance,
resistance, motor inertia and so on is applied in the system in order to get the results. The data is
studied in order to understand the relationship between the velocity and the frictional torque.

Figure 7 shows the relationship between the velocity and frictional torque.

![Figure 7. Frictional torque versus velocity graph.](image)

The angular velocity and frictional torque data are trained using the ANFIS method. These data went
through several training processes with 100 numbers of epochs. This process only allows 0.0001 error
tolerance provided by the trained data.

Based on the Figure 8, the training error during the data training process is 9.6428 based on the 100
epochs reading.

![Figure 8. Frictional torque and angular velocity data trained using ANFIS.](image)
6. Conclusion
The study carried out has successfully verified the experimental results of the friction identification using the Adaptive Neuro-Fuzzy Inference System (ANFIS). The difference between the real data and trained data is 9.6428%, which is acceptable since the target is below 10%. The friction model that has been built in this project can be used in the second phase of the project, which is friction compensation. The performance of DC motor is expected to be improved once the ANFIS based friction model is included into the system.

7. References

[1] Virgala I and Kelemen M 2013 International Journal of Mechanics and Applications 3(1) 26-30

[2] Tijani I B, Rini A and Momoh J E S 2011 Advances in Mechatronics 43-68

[3] Tolgay K and Sawsan A 2013 Proceedings on the 2013 International Conference on Systems, Control, Signal Processing and Informatics 233-240

[4] Chin-Jer L, Her-Terng Y and Yun-Cheng T 2013 IEEE/ASME Transactions on Mechatronics 18(4) 1385-1396

[5] Richard C and Cutkosky M R 1999 Proceeding of the 1999 ASME IMECE 14-19

[6] Popov V L 2010 Contact Mechanics and Friction

[7] Ciliz M K and Tomizuka M 2007 Engineering Applications of Artificial Intelligence 20 898-911

[8] Marton L 2006 Acta Polytechnica Hungarica 3(3) 45-58

[9] Olsson H, Astrom K J, Canudas de Wit C, Gafvert M and Lischinsky P 1997 European Journal of Control 1-37

[10] Sergio S M and Ricardo C 2013 Mathematical Problems in Engineering Volume 2013 1-8

[11] Virgala I, Frankovsky P and Kenderova M 2013 American Journal of Mechanical Engineering Volume 1 1-5

Acknowledgements
The author would like to thank Ministry of Education Malaysia and Universiti Teknologi MARA (UiTM) Shah Alam, Selangor for their support. This project is supported by the Ministry of Education Malaysia (MOE) under the Fundamental Research Grant Scheme (FRGS) (600-RMI/FRGS 5/3 (77/2013)).