DC Motor Friction Identification With ANFIS and LS-SVM Method

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ABSTRACT

Friction has been an old age problem for any motion system to accomplish its optimum performance. Friction compensation has been identified as an effective strategy to enhance the performance of a motion system. To be able to compensate the friction in motors, the friction itself needs to be identified. Through the latest development in Artificial Intelligent, it has been obvious that the major Artificial Intelligent-paradigms are able to resemble any nonlinear functions precisely and hence, being used as one approach in friction modeling and identification. In this paper, a DC motor is selected as the representative of simple motor. A real-time experiment involving a DC motor is required in getting the best velocity to friction torque relationship. By using MatLab, the friction modeling data is trained with two different methods, which are Adaptive Neuro-Fuzzy Inference System (ANFIS) and Least Squares Support Vector Machine (LS-SVM). The performance of both methods is compared and analysed.

Keywords: *ANFIS; LS-SVM; DC Motor; Friction Modeling*

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1. Introduction

1.1 Background

Any work related direct or indirectly with motor will face the unchanged problem as old as time which is the deterioration of motor's performance because of friction occurrence. To be able to achieve an accurate control of mechanical systems without being unhindered by the encumbrances of friction is crucial in many industrial uses. Therefore, the need for friction compensation is increasing in the area of motion control.

The pioneer for advanced friction compensation is the group working at Lund and Grenoble [1]. They are famous for their contribution namely the use of an integrated friction model for synthesis to enhanced controller that able to achieve efficient friction compensation for a simple motor. However, although it manages to reduce the friction problems, there is still susceptibility with the current available friction models. It still lacked the ability to describe friction well enough for a much more precise model with the elastic part specifically. Friction compensation requires detailed friction identification and the modelling process must be done as precise as possible. Among the abundance of Artificial Intelligent method out there, there are not yet definite answer as to which has the best and the most accurate friction identification. Support vector machine (SVM), fuzzy logic (FL), neural network (NN) and adaptive neuro-fuzzy inference system (ANFIS) are among the common artificial intelligent methods that are being repeatedly applied in positioning control system. Among these, two methods are selected and analysed.

With the inspiration to further enhance motion system performance with the elimination of friction, compensation method need to have an accurate friction modeling to be able to achieved the optimum performance.

In this project is there are quite a few tasks that need to be executed in order to get the best result as to be able to further boost DC motor performance. The scopes of this project are:

i. Constructing a complete model system for the friction identification experiment. During the motion control experiment use the appropriate real time DC motor experiment. The experiment should be similar to a typical DC motor application. In this stage, the arrangement for the experiment will be carefully analyzed and design in order to get the system work with the incorporation of relationship of angular velocity and frictional torque.

ii. Model the DC motor friction during the motion control experiment. This involves the work done during the experiment period and the gathering of the data that are necessary in the process of the real-time experiment. The method to model the friction are ANFIS and LS-SVM. The constants and manipulated parameters are analyses before modeling with both method.

iii. Observe the friction as well as train data using the artificial intelligence application known as the adaptive Neuro-fuzzy inference system (ANFIS) and Least Squares Support Vector Machine (LS-SVM). The data that composed in the friction identification experiment will be practice in order to model the DC motor friction using the artificial intelligence based technique and then carry on with the comparison between the two approaches.

2. Literature Review

2.1 Understanding DC Motor

The main advantages of the DC motors are easy position and speed control and also wide modifiable range to follow a pre-determined speed or position trajectory under load. These have been broadly used in quite a few industrial applications. The mathematical model of DC motor [2] is expressed by following equations:

$$J\frac{d\omega(t)}{dt} + B\omega(t) = T_m(t)$$

$$L\frac{di_a(t)}{dt} + Ri_a(t) = v_a(t) - v_b(t)$$

$$v_b = K_e\omega(t)$$

$$T_m(t) = K_t i_a(t)$$

In the above, R is the armature resistance, L is the armature inductance, J is the moment of inertia, K_t is the motor torque constant, K_e is the back emf constant, B is the viscous friction and T_m is the motor torque.

By means of Laplace transformation we can obtain transfer function of DC motor:

$$\frac{\Omega(s)}{V_a(s)} = \frac{K_t K_e}{(Js + B)(Ls + R) + K_t K_e}$$

The mathematical model can be expressed by block diagram in **Figure 1** below:

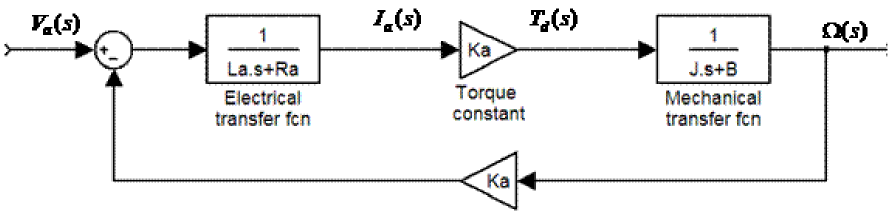

Figure 1: Block diagram of a typical DC motor

Accurate model building is a decisive stage in hands-on control problems. For a dependable designed control a sufficiently developed system model is critical. It may be hard to acquire a model for the system when the plant has hesitations or time dependencies, or just basically cannot be parameterized. The system constraints should be find out by using system identification methods for such system. The experiment for friction identification can easily be done if all the variables of motor are known.

3. Methodology

3.1 Construction of Complete System

A real-time experiment was conducted to mimic a typical simulation of a DC Motor system. With this experiment, a similar output of a DC motor characteristic can be obtained. Several option of circuit diagram were considered before conducting the experiment. The experiment is carried out by manipulating the input voltage to the system in order to identified what will happen to the resulting current and velocity of the DC motor. The experiment done for both clockwise and anticlockwise rotation of the DC motor. The resulting current and voltage were recorded and will be discussed further.

In the complete set up of the model system, its includes power source to adjust the voltage input, multimeter to measure the current, tachometer to detect the speed of the DC motor as the voltage change and finally the most essential hardware needed DC motor. A 24 volt low inertia DC servo encoder unit with series number 284-3168 were use. So all parameter use in the system will be based on this type of DC motor. In this experiment, the relationship between the velocity with the friction torque is discovered when the voltage is used as a variable.

4. Results and Discussion

4.1 Friction Identification

It is crucial to have a mathematical model of friction which can be obtain through the friction identification experiment [3]. A friction model should be able to precisely predict the experimental friction characteristics, however be simple enough to do the friction compensation.

Data Tabulation and Calculation

From the experiment of friction identification, as stated in the methodology, the outcomes of the experiment are current and angular velocity. Based on these data, the relationship between current and frictional torque will be identified. The equation used to find the frictional torque is stated in the equation below:

$$F_t = k_m i \tag{1}$$

Where,

F_t = Frictional torque

k_m = Motor torque constant

i = Current

As can be seen in the equation (1), to be able to acquire the frictional torque the step needed is to multiply the value of current at each value of manipulated voltage with the motor torque constant. In this project the value of the motor torque constant is 0.09 Nm. The value for the frictional torque for this experiment for each value of voltage, after done calculating the value then were tabulated. Results obtained from the experiment are then used to plot graph to determine the type of the friction model the DC motor produced. The graph of frictional torque versus the velocity is shown in Figure 2.

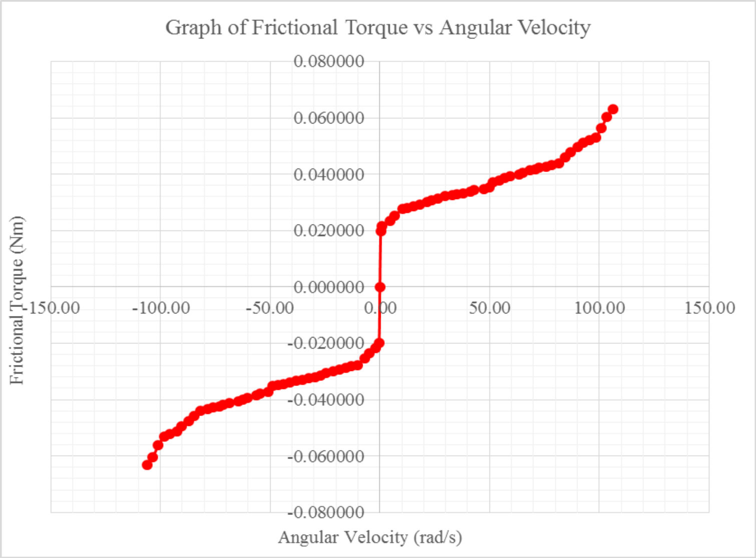

Figure 2: Graph of Frictional Torque vs. Angular Velocity

Graph of frictional torque versus angular velocity from the conducted experiment displays a Stribeck friction model. The graph is replicated as a function of relative velocity and is presumed to be the combination of Stribeck, Coulomb, and viscous components. At the vicinity of zero velocity of the graph the straight line can be seen when the velocity only make a small insignificant change, this is often referred to as the breakaway friction.

Theoretically, a Stribeck effect is a kind of friction which occurs when a solid oils or liquid is used for the contact surfaces of a mechanical parts that is moving like a lubrication. This causes diminishing of friction with an opposing of increasing velocity. Stribeck friction model is an uninterrupted drop in the friction force for small velocities [4], which can be clearly seen from the plotted graph where after an increase of velocity, the frictional torque makes a less significant change. Stribeck friction model are able to cause non-linearity in model in comparison with viscous friction model but gives more precise result.

4.2 Data Training

Training the data is done in two selected artificial intelligence method which in this project with ANFIS and LS-SVM.

<u>Data Training Using ANFIS</u>

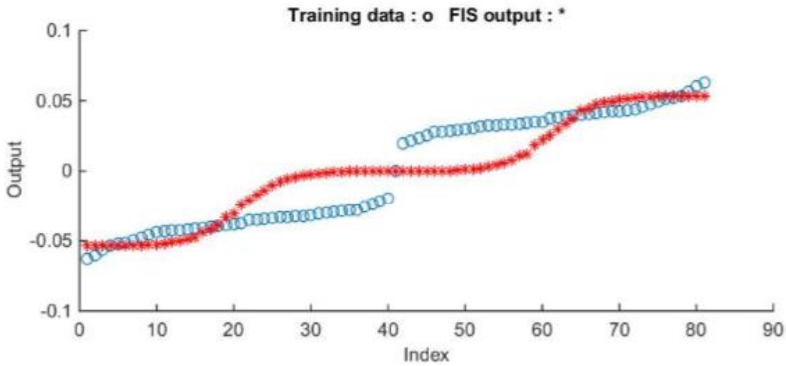

Figure 3: ANFIS Data Training

The blue dot is the data that was attained from the friction identification experiment meanwhile the red star is the data created by the ANFIS output, as shown in Figure 3. From the ANFIS friction model, it can be seen that frictional torque with less error of tolerance were achieved. The training error is actually the difference between the training data output value, and the output of the fuzzy inference system parallel to the equivalent training data input value which is the one that is associated with the training data output value. The training error of ANFIS, records the root mean squared error of the training data set at each epoch. The epoch selected is 100 but the ANFIS training completed early at epoch 2.

Data Training Using LS-SVM

The proposed and compared models were trained and tested with datasets from the previous friction identification of friction torque and angular velocity, which is similar to ANFIS. LS-SVM time series prediction applies function estimation in the parameter tuning, training procedures and prediction, [5] by using a random number code. For this purpose, the coding is run several times and finally, an average of error is extracted. The error is calculated automatically in MatLab, and finally given a results of 0.1774. The error is obtain by subtracting the mean of the predict value obtain with the mean of target produce.

The coding from the LS-SVM toolbox is typically used to predict a set of data by studying the behaviour. Plots of graph are generated as shown in Figure 4.

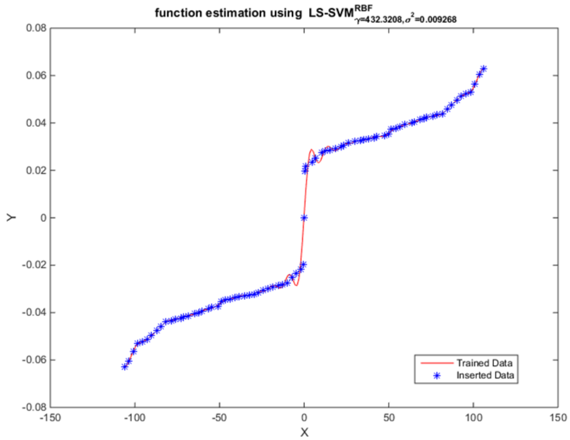

Figure 4: LS-SVM Data Training

The graph are plotted from input into the *plotlssvm* function. Besides that, after the previous tuning shown at methodology, the *trainlssvm* command is executed to create alpha and b, which are translated as input. The estimated function, Y in terms of the inputs is shown above. From the graph, the first is to be plot is the actual data points of the subset inserted into the coding of LS-SVM which in blue stars then are compared to the estimated function of the trained data to predict those points which is the red line, as can be seen from figure above. This graph is a fixed size LS-SVM which was chooses from a range number of subset from the data to estimate the implied mapping to the features space. Theoretically, the regularization parameter which is used inside the regression in primal space is enhanced here by using Bayesian framework.

4.3 Comparison of ANFIS and LS-SVM

Based on the data training with both method ANFIS and LS-SVM, the friction modeling done is indeed able to assist friction compensation. By distinguishing the results of the two data training, it can be seen that ANFIS produced a slightly much better friction model with a much smaller error compare to the error attain from LS-SVM method. However, this is when taking error as the only parameters to compare.

Both of the data training using ANFIS and LS-SVM predictions is used based on the data acquired from the experimental friction identification which is the friction torque and angular velocity. LS-SVM algorithm is recognized as to be proficient with resource.

In addition, because ANFIS only operates on Sugeno-type systems, it has a limitation of output membership function. The only choices available for the output membership function are constant or linear [6]. Not only that, due to the nature of the fuzzy rules an ANFIS can only have one output, which limits its capability to train data problems with one solution at a time. This is where LS-SVM differs, since to train data with LS-SVM is by using source code, any condition of the inputs data can be manually adjusted at the coding. As for its output, the algorithm of LS-SVM might take a very long time to process more than a few thousand data points, but it definitely can handle the option of multiple outputs for the intended train data.

As for the model accuracy, LS-SVM model actually works better compared to ANFIS model in term of prediction [7]. It can be seen in the results that LS-SVM model perform better output in the case of unseen data set. This may conclude that the LS-SVM are better than ANFIS in generalization, but at the same time, it also depends on the kind of input and output the project intent to achieve.

5. Conclusion

The friction identification by using artificial intelligence is in no doubt a reinforcement to the current classic friction modeling. Both ANFIS and LS-SVM method have difference expediency as well as its own drawback. The artificial intelligence method that has the upper hand is ANFIS. The reason for this is because the input for the friction modeling is only two, angular velocity and frictional torque which means that ANFIS are able to train the data swiftly. In terms of speed, both methods did not take much time to train the data. Last but not least, the error produce at the end of each data training proving that ANFIS are able to obtain a lesser error compared to LS-SVM. Although ANFIS performs better, as discussed earlier, that may not be the determinant as generalization which of the two are predominant, because after all it all depends on the project expected outcomes and the available parameters.

6. Acknowledgment

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7. References

[1] C. Canudas de Wit, H. Olsson, K. J. AstrÄom, and P. Lischinsky. A new model for control of systems with friction. IEEE Trans. Autom. Control, 40(3):419-425.

[2] Miqoi, S., Ougli, A.E. and Tidhaf, B. "Application of Fuzzy Logic on a PV water pumping system", *3rd International Symposium on Environmental Friendly Energies and Applications (EFEA*), (2014).

[3] Brian, A. H., Dupont, P.,and De Wit, C. C., "A survey of models, analysis tools and compensation methods for the control of machines with friction", *Automatica* 30 (7), 1083-1138.

[4] Tran, X. B. and Yanada, H., "Dynamic Friction Behaviors of Pneumatic Cylinders", *Intelligent Control and Automation* 4, 180-190.

[5] Zhang, N. and Williams, C. "Water Quantity Prediction Using Least Squares Support Vector Machines (LSSVM) Method", *SYSTEMICS, CYBERNETICS AND INFORMATICS*, 12(4), 53-58, (2014).

[6] Minghui, W., Yongquan, Y. and and Wei, L., "Adaptive-Neural based Fuzzy Inference System Approach Applied to Steering Control", *Advances in Neural Network*, 1189-1196, (2009).

[7] Azeez, D., Ali, M.A.M.,Gan, K. B. and Saiboon, I., "Comparison of adaptive neuro-fuzzy inference system and artificial neutral networks model to categorize patients in the emergency department", *Springer Plus 2013, 2 (416), 1-10* (2013).