International Journal of Electrical and Computer Engineering (IJECE)
Vol. 4, No. 3, June 2014, pp. 366~371
ISSN: 2088-8708

Performance Comparison between Classic and Intelligent Methods for Position Control of DC Motor

Navid Moshtaghi Yazdani*, Arezoo Yazdani Seqerloo**
* Departement of Mechatronics Engineering, University of Tehran
**Departement of Computer Engineering, University of Tehran

Article Info

Article history:

Received Dec 14, 2013
Revised Mar 24, 2014
Accepted Apr 6, 2014

Keyword:

DC motor
Machine learning
PID controller
XCSR

ABSTRACT

Controlling DC motors is mainly done by controlling either voltage or field of their armature. Numerous methods have been proposed so far for this purpose. Some intelligent methods such as XCSR and machine learning systems are used to control position of a separately excited DC motor. Having set output position of the motor to its basic position, voltage of armature becomes zero and the motor stops working. Characteristic features of the methods in this paper are resistance against changing friction and moment of inertia. Meanwhile, time to reach stability in this type of controllers is considerably lower than that of PID controller with no oscillations being observed in the responses.

Corresponding Author:

Navid Moshtaghi Yazdani,
Departement of Mechatronics,
University of Tehran,
Tehran, Iran.
Email: navid.moshtaghi@ut.ac.ir

1. INTRODUCTION

DC electric motors operate using basic concepts of electromagnetic such that a classic DC motor has a winding in rotor and a permanent magnet in stator. A rotary switch called commutator reverses the direction of electric current twice during each cycle. Thereby, a flow of current is created in the armature and the electromagnet attracts and repulses the permanent magnet out of the motor. Speed of DC motor depends on a set of voltages and currents passing through windings of the motor as well as motor load or braking torque. In other words, speed of the DC motor is dependent on voltage while its torque is dependent on current. Speed is usually controlled using a variable voltage which is generated by current passing through motor winding or by a variable source of voltage. It is because this type of motor can produce relatively great torque at low speeds. The permanent magnets in the outer stator are replaced with electromagnets in other models of DC motors known as solenoid motors. The ratio of speed to torque can be altered by changing current of the solenoid on the electromagnet. If the solenoid is connected series with the armature winding, a low-speed high-torque motor will be obtained. On the other hand, a high-speed low-torque motor will be achieved if the solenoid is connected in parallel. It is even possible to reach higher speeds by reduction of the field current though at the expense of a smaller torque. Application of this technique can lead to make equipments of a mechanical gearbox unnecessary. Universal DC motors are able to work with either direct or alternating current. They are designed based on the following principle: When a solenoid DC motor is connected to AC, the current changes simultaneously at both solenoid and armature winding. Thus the created mechanical force will always remain unchanged. That is why impedance and reluctance must be taken into account in design to make compatibility with alternating current. The finally produced motor often has a performance lower than an equivalent DC motor. Advantage of the universal motors is that AC source can be used on motors with typical specifications of DC motors, especially since these motors have a considerably high operation torque as well as a very compact design for high-speed operations. The only disadvantage of these motors is related to their repair and maintenance and also reliability issues which are caused by existence of the commutator. Therefore, these motors can be rarely seen in industrial applications. Series-wound motor is the most desirable alternative below 1 KW power with full load speed of 4000 to 10,000 rpm. The series motor with the capability of using DC or AC source show a high speed at large range and a high starting torque (approximately 500% of the nominal value). It is thus accounted for an ideal drive in different applications having power of several to several hundred watts. Maximum short-term torque limits power of this motor to 400% of the nominal value. Although this motor is very similar to shunt-wound motor, its armature and field are connected in series and not in parallel with the line. This feature allows the series-wound motor to be designed for being operated with alternating or direct current. Moreover, compound-wound motor is used in some applications, which has both parallel and series excited windings. When direction of the series field is opposite to that of parallel field, the motor is called step down compound-wound motor. This kind of motor does not have common applications due to its speed instability (weakening of load overflow will reduce speed significantly). Mechanical load would need larger torques whenever the speed is raised. The ascending characteristic of speed-torque in damping compound-wound motors will cause instability once they are attached to such loads. In this case, speed will add to torque and torque will increase speed. On the other hand, if a series excited field contributes to a parallel excited field, the motor will be called step up compound-wound motor. It is evident that the specifications of such a motor are somehow between those of shunt and series motors. When the motor is fed by constant voltage, individual excited and shunt excited specifications of this motor cannot be distinguished. At both conditions, the excitement winding is fed by a voltage independent from the current received by armature. Therefore, one source would be sufficient to be used for both excitement and armature. Permanent magnet DC motor benefits from a permanent magnet to generate powers up to 200 hp for various industries.

One major advantage of permanent magnet DC motors is that they do not need an excitement current. This will lead to energy saving in comparison with equivalent motors having wound poles during typical lifetime of the machine. Pole overflow cannot be controlled in these machines, so their speed and torque are controlled by great currents of the armature. In most cases, application of armature circuit contrail is advantageous over excitement circuit control even in machines with a wound pole. As a result, selection of permanent magnet motors for industrial applications, which need accurate control, does not deteriorate anything else because removing the individual source of excitement current is often known as a great advantage. The effect of constant overflow on operation characteristics of a DC machine is very simple. In fact, the operation of permanent magnet DC motors is very similar to that of shunt machines. Application of permanent magnet to generate excitement in DC motors within specific range of dimensions entails some economic benefits. In small motors (below 70 mm diameters) structure of the electromagnet is unable to compete with permanent magnets in terms of price. However, in large motors (over 150 mm diameters) economic analyses could recommend to use motors with electromagnets [1]. Torque-speed characteristic of permanent magnet DC motor is an almost straight line between two points, namely null load speed on the vertical axis and static torque on the horizontal axis. Permanent magnet motors are potentially more efficient than electromagnet motors since they do not show any field loss. Furthermore, permanent magnet motors provide great efficiency in a large range. Structure of small permanent magnet motors up to several KW is completely different from that of parallel motors. Permanent magnets with directional ferrite grains are devised in these machines. They are magnetized before being placed in the stator. For a given nominal power, armature of such motor must be usually considered a little larger than shunt-wound motor because flux density of the air gap achieved by a ferrite magnet is considerably smaller than that of wound poles. A 30% reduction in weight of the machine can be obtained by replacing excitement coils of the motor with permanent magnets instead of wound poles. Meanwhile, step up compound-wound motor is used where characteristics of a series motor is required but the motor is not inhibited discretely by removing the load such as lathes which experience no load conditions during each working period and then are exposed to full load again. Step down compound-wound motors are used where an almost constant speed is needed, i.e. loads smaller than nominal load. Thus, this type of motors is often used in laboratories to provide constant rotation speed. Various industries mainly use additional compound motor instead of series motor though their designs are very similar. Techniques proposed to control position of DC motors are generally divided into three categories: Classic methods like using PID controllers [3, 4]; modern methods like conforming, optimal and other methods [5, 6]; and intelligent methods like using fuzzy theory and neural network [7, 8]. Some methods are proposed in this paper to intelligently control the position of separately excited DC motor using XCSR, improved XCSR and machine learning systems. The suggested methods are executed on MATLAB software in SIMULINK environment by simulation of a DC motor with its various states being evaluated.

2. METHODS FOR CONTROLLING SPEED OF DC MOTOR

2.1. Controlling Electric Resistance of Armature

It is the oldest method used to control speed which still has some applications in series motors. Terminal voltage, excitement and/or overflow current are constant, with the control being done by altering electric resistance of the armature. When a rheostat is connected to the armature circuit in series, indeed total resistance of the circuit will be increased. Equation above shows that this increased resistance would reduce speed of the stable state except for ideal no load conditions. Electric resistance of the rheostat can be adjusted such that various speeds (from 0 to base speed) are obtained at constant torque (constant current of the armature). Although this speed control system is relatively simple and inexpensive, it suffers from the disadvantages below:

1) Speed is always decreased and it never exceeds the base speed;
2) This method is almost ineffective on no load condition;
3) The motor loses its "constant speed" feature;
4) The maximum power generated is decreased in proportion with speed reduction;
5) A great deal of energy is lost in the rheostat.

Power loss is directly correlated with speed reduction. Current of the armature is not changed under constant torque conditions, while input power of the motors also remains constant. This rheostat method is usually applied in conditions where the motor is continuously turned on and off, or when the low speeds are needed only for a while.

2.2. Controlling Voltage of Armature

The second method to control speed of the motor is changing voltage of the armature. This method is mainly used for separately and serially excited motors. Excitement overflow or current and electric resistance of the armature are kept constant in this speed control system. Current of the armature is kept unchanged at its nominal value in practical applications for a better utilization of the motor whenever speed is altered by changing the base voltage. This technique is actually the same as controlling electric resistance of the armature which enables operation at lower speeds without disadvantages of it. Speed control is usually done at constant current and overflow of the armature. Thereby, the constant torque is met before the base speed. The input power from source to motor is also changed linearly in proportion with the speed. This kind of operation until reaching the base speed is called operation at "constant torque-variable power". Controlling voltage of the armature gently adjusts the speed and alters it such that the speed can be gradually increased from 0 to its base value. Slope of the torque-speed index is not changed and no power is lost in this method.

3. MODELING OF DC MOTOR

Considering the different types of DC motors and numerous methods for controlling them, separately excited DC motor is selected in this contribution. Then, direction of its rotation is set by controlling the source voltage. The governing equations in this regard are given below:

$$V_t = L_a \frac{di_a}{dt} + R_a I_a + E_a \tag{1}$$

$$E_a = K\omega_m \tag{2}$$

$$J\frac{d^2\theta}{dt^2} + B\frac{d\theta}{dt} - T_l = Ki_a \tag{3}$$

$$\omega = \frac{d\theta}{dt} \tag{4}$$

Schematic model of a separately excited DC motor for position control has been depicted in Figure 1.

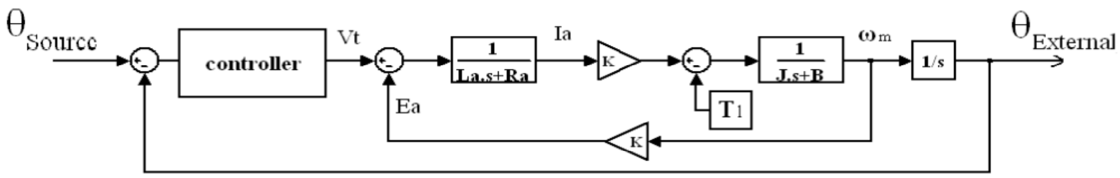

Figure 1. Schematic model of a separately excited motor with controller block

Where, θ_{Source} and $\theta_{External}$represent base and output positions, respectively. Meanwhile, specifications and parameters of the DC motor simulated in this paper are the same for all intelligent controllers as listed below:

electric resistance of armature=1 Ω
inductance of armature=0.46
current of armature=20 A
voltage of armature=110 V
rotational inertia of motor=0.093
friction coefficient at axis of motor=0.008

4. INTELLIGENT XCSR METHOD AND MACHINE LEARNING SYSTEMS

The first Learning Classifier System (LCS) proposed by Holland was designed to work both for individual and continuous problems. This classifier learning system is an example of machine learning which combines time differences and learning supervisions with genetic algorithm and then adopts to solve simple and complicated problems. Based on the supervision introduced by Holland, the LCS system employs a unit property for each of the classifiers which are called power. Power is a divider which indicates impressionability of the divider and is exclusively determined by the percentage of answers related to the expected responses. These criteria are identified with existing principles in supervisory training. After introduction of the LCS, some other types of it have been developed such as XCS. Before 1995 when the extended classification system was not introduced yet, ability of a classifier to get proper answers in the reinforcement system of these classifiers had a key role. Thereby, basic and simple classifier systems were gradually transformed into more accurate decision maker factors. Now, it is well known that the XCS is able to solve even more complicated problems with no need to adjust the parameters. That is why this system is known as the most successful system for learning. XCSR is the same as XCS and works with real numbers. Having introduced the classifier system with continuous variables (XCSR), some intrinsic drawbacks of the binary classifier systems including inability to define specific range of values for their variables were eliminated to a large extent. These systems are now accounted for one of the most successful learning agents. According to the common approach for training XCSR, fitness is only increased for rules which correctly respond the learning data. This means that chance of each rule for not being deleted and taking participation in the process of new rules production, are directly correlated to how they respond to the training data. A realistic determination of this chance requires application of some training data. Two methods are mentioned in this section for learning with teacher (learning rule from training data): “separation and solution” and “decision tree”. One rule is learnt at each phase of the former, then the data covered by that rule are separated and this process is continued on the remaining samples. K-NN algorithm or nearest neighborhood is one of the learning algorithms based on sample which just stores the training samples at learning phase. This algorithm calculates the distance of this sample with other training samples to specify the class of a sample data. The most common criterion for calculation of such distance is Euclidean criterion although some other criteria are also utilized for this purpose including Manhattan-Minkowski. Having measured the distance, a majority voting was held among K training samples nearest to the current test sample. The majority label of this sample is assigned to the test sample then. K is a parameter which is determined the user. Such algorithms are also called lazy learning algorithms since they do nothing during the learning phase and just store the test samples. C4.5 algorithm is one of the most famous algorithms for building the decision tree [2]. This algorithm was proposed in 1993 and is in fact a developed version of ID3 algorithm. Every mid node in the created decision tree represents a test on the values of a property with each branching being indicative of one allowed values of it. The criterion used for selection of an appropriate property for a node is *information gain* which leads to create a bias in favor of the properties of various values. *Gain ratio* criterion is employed to solve this problem. ID3 algorithm just supports distinct properties, whereas C4.5 handles continuous properties in addition to the distinct ones. Moreover, management of the properties with unspecific values is another advantage of C4.5 over ID3. In order to avoid excessive proportion in the classification model formed, techniques of decision tree pruning are used. The excessive proportion phenomenon occurs when accuracy of the developed model is very high on the training data though insufficient on the test data. In other words, the classification model having excessive proportion with the training data has been created and this high proportion does not necessarily lead to greater accuracy of classification on the test data set. There are two major decision tree pruning techniques. In the first technique which is called pre-pruning, growth of the tree is terminated in some paths before completion of the tree. In the second technique entitled post-pruning, the tree is grown completely first and then, some sub-trees are replaced with a leaf node. The obtained tree can be transformed into a set of equal classification rules which is possible to prune its rules by deleting some of the prerequisites. Limited training examples are applied to the generated rules after preparation of the data. Thereby, parameters of the rules will be updated. Genetic mechanism also contributes to make new rules. At the end of the training phase, some acceptable results can be obtained using these trained rules.

5. INTRODUCTION OF THE PROPOSED METHOD

Major drawback of PID controller is difficult adjustment of the parameters to reach the desired answers as well as the required modifications due to the variable operation conditions of the motor which is impossible during operation in practice. Thus, it is suggested to use intelligent controlling methods to solve this problem. A limited set of training data is generally used to modify properties of the rules (i.e. "prediction", "prediction error" and "fitness") in the proposed method. This is done using the following equations:

Updating prediction and prediction error:

If $exp_i < 1/\beta$ then $Pi = Pi + (R-Pi) / exp_i$, $\varepsilon i = \varepsilon i + (|R-Pi| - \varepsilon i) / exp_i$

If $exp_i \geq 1/\beta$ then $Pi = Pi + \beta (R-Pi)$, $\varepsilon i = \varepsilon i + \beta (|R-Pi| - \varepsilon i)$

Updating fitness:

If $\varepsilon i < \varepsilon 0$ then $ki=1$

If $\varepsilon i \geq \varepsilon 0$ then $ki = \beta (\varepsilon i/\varepsilon 0)^{-\gamma}$

$$\mathbf{Fi = fi + \beta\ [(ki/\textstyle\sum kj) - fi]}$$

Where, β, γ and ε denote rate of learning, power of rule accuracy and prediction error, respectively. Meanwhile, exp, P and R represent rule experience, rule prediction and received gain from environment, and k and f are rule accuracy and fitness, respectively. Number of the rule is also demonstrated by the subscript i.

In the next level, "*random selection with remainder*" is used to select numerous pairs as parents among strings available in displayer of data conditions. The new section of data condition is formed using the mid cross over method which is applied on these parent strings. The value of each conditional variable is given by the equation below:

$$\mathbf{a_i = \alpha(a_i^F) + (1-\alpha)(a_i^M)}$$

Where, a_i denotes the value of i^{th} conditional variable in the new data, a_i^F and a_i^M are the values of i^{th} conditional variable in the first and second parents (father and mother), respectively. $\alpha$is participation coefficient of the parents which is determined adaptively. The operation section of the new data is also generated using a nonlinear mapping from the space of the conditional variables to that of existing data. Diversification of the existing data is continued until the termination condition (e.g. percentage of correct answers given for the test data reaches a predefined threshold) is satisfied using the completed data.

The next section deals with introducing some common algorithms for learning with teacher briefly. The results obtained from the proposed method are evaluated for controlling position of DC motor as was previously discussed in section 2.

respectively. $\alpha$is participation coefficient of the parents which is determined adaptively. The operation section of the new data is also generated using a nonlinear mapping from the space of the conditional variables to that of existing data. Diversification of the existing data is continued until the termination condition (e.g. percentage of correct answers given for the test data reaches a predefined threshold) is satisfied using the completed data.

The next section deals with introducing some common algorithms for learning with teacher briefly. The results obtained from the proposed method are evaluated for controlling position of DC motor as was previously discussed in section 2.

6. RESULTS OF RUNNING INTELLIGENT CONTROL METHODS

Main purpose of designing a controller is to increase stability and decrease time to reach the desired state upon application of a disturbance in a process. PID controller was utilized in addition to comparison of answers from the proposed methods in this paper.

Parameter	XCSR	improved XCSR	PID	machine learning
Adaptation time for increased base	2.3	1.5	3.7	3.1
Adaptation time for decreased base	2.3	1.5	3.7	3.1
Overshoot percentage for increased base	0	0	0	0
Undershoot percentage for decreased base	0	0	0	0
Adaptation time for increased base upon 10% change in **J** and B	2.7	1.5	4.5	3.8
Adaptation time for decreased base	2.7	1.5	4.5	3.8
Overshoot percentage for 10% increased base	0	0	2%	0
Undershoot percentage for 10% increased base	0	0	14%	0

7. CONCLUSION

A number of intelligent methods were used in this paper to control the position of separately excited DC motor. It was observed that the PID controller has lost its performance being unable to completely delete the overshoot such that, it was necessary to design and modify its parameters once again. However, the suggested methods were needless of redesign as they were self-correcting. Additionally, time to reach the final answer is significantly shorter in these methods.

REFERENCES

[1] Electric Machines and Direct Current, Ghaem Pub., (In Persian).
[2] Quinlan, J.R. *“C4.5: Programs for Machine Learning”,* Morgan-Kaufmann, San Mateo, CA. 1993.
[3] Ogatha, K. H., “*Control Engineering*”, Translated by: Diani, M., Nass Pub., 4th Edition, 2002, (In Persian).
[4] KworkL. Tang, Robert J. Mulholland, “Comparing Fuzzy Logic With Classical Controller Designs”. *IEEE Trans. SMC*, Vol.17, No. 6.Nov./Dec.1987,pp.1085-1087.
[5] Mokhtari, M., “*Applications of MATLAB and SIMULINK in Engineering*”, Translated by: Samadi, V., Khorasa Pub., 1st Edition, (In Persian).
[6] Menhaj, B., “*Calculational Intelligence, Basics of Neural Networks*”, Hesabi Pub., (In Persian).
[7] R. Rico Martinez, J.S. Anderson and I. G.Kebrekidis, “*Continuous-time nonlinear signal processing: a neural network based approach for griy box identification*”, in Proc. IEEE Workshop on neural network for signal Processing, pp. 596-605, Oct. 1994.
[8] Y.F. La, C.C. Lau, “Development of Fuzzy Algorithms for Servo Systems”. *1988 IEEE International Conference on Robotics and automation*, Philadelphir, PA, April 24-29, PP.65-71.