Error Minimization in Networked DC Motor System using Harmony Search Algorithm

Raji S[1], Mr.Shammy Arun Mathew[2]

[1] PG Student, Department of Electronics, Applied Electronics and Instrumentation, Lourdes Matha College of Science and Technology, Kerala, India

[2] Assistant Professor, Dept. of Electronics and Communication, Lourdes Matha College of Science and Technology, Kerala, India

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Abstract - *Advanced fault detection and accommodation schemes are required for ensuring efficient and reliable operation of modern networked motor system. Here we have applied the Harmony Search Algorithm (HSA) for minimizing the Integral-Square Error cost function. The DC motor is modeled using either armature resistance control or field control method. Then the overall system is controlled by using a PI controller because of its better responsiveness and improvement of steady state response. The Harmony Search Algorithm is used to tune the parameters of controller and it also used to reduce the overall error. The HS algorithm improvises, update and check operators obtain optimal solution for defined objective function. Two important control parameters have been adjusted to obtain better solution. The simulation results demonstrate that the designed harmony search algorithm based controller realize a good dynamic behavior of the DC motor, a perfect speed tracking with less rise and settling time, minimum overshoot, minimum steady state error and give better performance compared to conventional PI controller.*

Key Words: Networked Control System (NCS) Networked DC motor system (NDCMS), Sliding Mode observer (SMO),Harmony Search Algorithm(HSA), Proportional Integral (PI) controller.

1. INTRODUCTION

DC motor is an actuator that converts electrical energy into rotational mechanical energy. This is mainly used for the loads requiring adjustable speed, good speed regulations, braking and reversing. These characteristics are very useful in industrial dc motors such as rolling mills, machine tools, traction, printing presses, textile mills etc [1]. However the variable speed applications are dominated by Dc drives because of lower cost, reliability and simple control of its speed and also the speed/torque characteristics of DC motor is much superior to AC motor. While considering physical system, the mathematical modelling is one of the most important and often the most difficult step towards understanding. But sometimes we use parameter estimation techniques to estimate some parameters, because few parameters of the DC that is complicated to determine using practical measurements. In system identification, building mathematical model of dynamic system from observed input-output data. Which gives interconnection between the real world of applications and mathematical world of control theory to abstract their models? The system identification depend on the character of the models to be estimated either it may be linear, nonlinear, hybrid, or non-parametric model etc.This system identification has four steps to identify the model of the system, data decoding, model set selection, Identification criteria, and model validation.

1.1 Networked Control System (NCS)

The feedback control systems, wherein the control loops are closed through a real time network are called Networked Control system. The main features of a NCS are to exchange the information through these network using control system components such as sensors, actuators, controllers etc [2]. In many practical systems, the physical plant, controller, actuator and sensors are difficult to be placed at the same location, and the signals are required to transfer from one place to another. So the components are always connected through a network. The traditional communication system for control system is point to point connection that means a wire is connected to the main control computer with each sensor or actuator point. But due to the insertion of networking system induces different forms of delay uncertainty between actuators and controllers.

The main problem for designing a NCS include, network induced delays that occurs while exchanging data from one device to another, and packet losses, because of the unreliable network transmission path, where packets not only suffer transmission delays but can be lost during transmission. The main advantages of NCS include simplicity and reliability. They are cheap and easy to use and maintain. To compensate the time delays induces in the NCS, there are various time delay compensation techniques are used, such as adaptive controller, optimal controller, robust control, PID controller, smith predictor, Sliding mode controller, fuzzy controller optimal PI controller etc.

1.2 Networked DC Motor System (NDCMS)

In traditional DC motor control, the system components are located in the same place and are connected using point to point wiring. But in practical system dc motor and controllers are difficult to be transmitted from one place to another, so a communication network induced in the dc motor system, obtaining Networked DC Motor System (NDCMS) (3). The speed control of DC motor is mainly governed by armature control and feed control methods. In armature control of dc motor, it is assumed that demagnetizing effect of armature reaction is neglected, magnetic circuit is assumed to be linear and feed voltage is constant. Figure 1 shows the equivalent model of armature controlled dc motor.

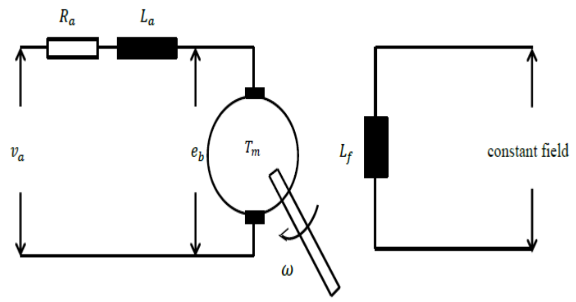

Fig-1: Armature control of dc motor system

The governing equations of a dc motor are given as follows:

$$v_a(t)=R_a(t)\, i_a(t)+L_a\frac{di_a}{dt}+e_b(t)$$

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

$$e_b(t)=K_b\, w(t)$$

$$T_m(t)\text{-}T_L(t)=J_m\frac{d_{w(t)}}{d_t}+B_m\, w(t)$$

On taking Laplace transform, we get:

$$v_a(s)=R_a i_a(s)+sL_a i_a(s)+K_b\, w(s)$$

$$Kt\, Ia(s)=sJ_m\, w(s)+B_m\, w(s)+T_L(s)$$

While considering the state space model, the dynamic equations become:

$$\begin{matrix}\dot{i}_a\\ \dot{w}\end{matrix}=\begin{bmatrix}\frac{-R_a}{L_a} & \frac{-K_t}{L_a}\\ \frac{K_t}{J_m} & \frac{-B_m}{J_m}\end{bmatrix}\begin{matrix}ia\\ w\end{matrix}+\begin{bmatrix}\frac{1}{L_a} & 0\\ 0 & \frac{-1}{J_m}\end{bmatrix}\begin{matrix}v_a\\ T_L\end{matrix}$$

It can also express as:

$$X=A\dot{X}+BU$$

Where:

$$A=\begin{bmatrix}\frac{-R_a}{L_a} & \frac{-K_t}{L_a}\\ \frac{Kt}{J_m} & \frac{-Bm}{J_m}\end{bmatrix} \qquad B=\begin{bmatrix}\frac{1}{L_a} & 0\\ 0 & \frac{-1}{J_m}\end{bmatrix}$$

2. HARMONY SEARCH ALGORITHM (HSA)

The Harmony Search Algorithm is a musical improvisation process in which the musicians in an orchestra try to find a fantastic harmony through musical improvisations. This musical process can be adapted into engineering optimization processes where the main objective is to find the global or near-global solution of a given objective function. In this approach, musical performances seek a best state (fantastic harmony) determined by aesthetic estimation, as the optimization problem seek a musical process can be adapted into engineering optimization processes where the main objective is to find the global or near-global solution of a given objective function. In this approach, musical performances seek a best state (fantastic harmony) determined by aesthetic estimation, as the optimization problem seek an Initialize optimization problem and HSA algorithm parameters.

1. Initialize the Problem and Algorithm parameter

The optimization problem is defined as follows: Minimize$f(x)$ subjected to $x_i \in X_i$, i =1…N. Where$f(x)$the objective function, $x$is the set of each decision variable, that is K_p, K_ivalues (x_i), $X_i$is the set of the possible range of values for each designvariable, that is$X_{iL} \le X_i \le X_{iu}$.Where $X_{iL}$and $X_{iU}$are the lower and upper bounds for eachdecision variables. The Harmony Search Algorithm (HSA) parameters are also specified in this step, they are the harmony memory size (HMS), or the number of solution vectors in the harmony memory, Harmony memory considering rate (HMCR), bandwidth (BW), pitch adjusting rate (PAR), number of improvisations (NI) or stopping criterion and number of decision variables (N).

2. Initialize the Harmony Memory (HM)

The harmony memory is a memory location where all the solution vectors (sets of decision variables) are stored. HM matrix is filled with as many randomly generated solution vectors as the Harmonic memory size.

$$HM=\begin{bmatrix} x_1^{'} & \cdots & x_n^{'} \\ \vdots & \ddots & \vdots \\ x_1^{HMS} & \cdots & x_N^{HMS} \end{bmatrix} = \begin{matrix} f(X^1) \\ \vdots \\ f(X^{HMS}) \end{matrix}$$

3. Improvise a new harmony

A New Harmony vector $x^{'} = (x_1^{'}, x_2^{'}, \ldots\ldots\ldots x_n^{'})$ is generated based on the three rules:

1) memory consideration,
2) pitch adjustment and
3) random selection

Generating a new harmony is called 'improvisation'. The value of the first decision variable $x_1^{'}$ for the new vector can be chosen from any value in the specified HM range. Values of the other design variables $(x_2^{'}, x_3^{'} \ldots x_n^{'})$ are chosen in the same manner. HMCR, which varies between 0 and 1, is the rate of choosing one value from the historical values stored in the HM, while $(1 - HMCR)$ is the rate of randomly selecting onevalue from the possible range of values such as,

$$x_{inew}=L(x_{old})+rand\in(0,1)\times BW$$

Every component of the New Harmony vector $x^{'}=(x_1^{'}, x_2^{'}, \ldots x_n^{'})$ is examined to determine whether it should be pitch-adjusted. This operation uses the PAR parameter (the PAR parameter determines the probability of a candidate member from the HM matrix to be improvised, the value of (1-PAR) sets the rate of doing nothing. If the pitch adjustment decision for $x^{'}$ isYes, $x^{'}$ is replaced as follows:

$$x_{new}=x_{old}+BW(rand-0.5)$$

Where BW is an arbitrary distance bandwidth for the continuous design variable and rand is random number between 0 and 1. In step 3, HM consideration, pitch adjustment or random selection is applied to each variable of the New Harmony vector in turn.

4. Update harmony memory

If the New Harmony vector, $x_i^{'}=(x_1^{'}, x_2^{'}, \ldots x_n^{'})$ is better than the worst harmony in the HM, from the point of view of objective function value, the new harmony is included in the HM and the existing worst harmony are excluded from HM.

5. Check the stopping criteria

If the stopping criterion (i.e.) maximum number of improvisations is satisfied, computations terminated. Otherwise, step 3 and 4 are repeated.

Table -1: Parameter of the dc motor

Parameter	Value
r_a	3.27Ω
l_a	$1.8110^{-3}H$
k_b	$7.7\times 10^{-3}V.s/rad$
k	$168\times 10^{-3}N.m/A$
j	$3.6\times 10^{-4}K_g.m^2$
b	$80\times 10^{-4}N.m.s/$

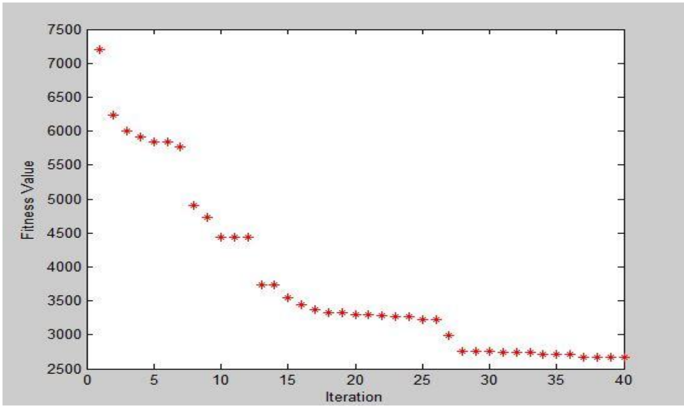

Fig 2-Minimum error value after maximum number of iteration

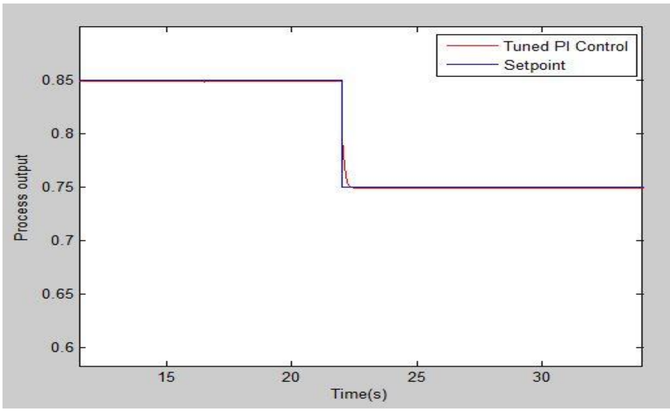

Fig 3-DC motor response for a step input

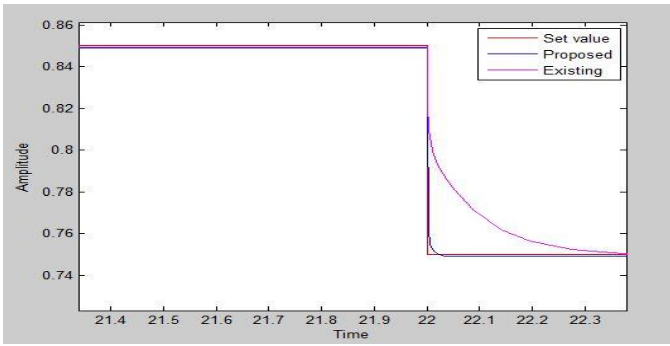

Fig 4- Comparison with the existing and proposed output

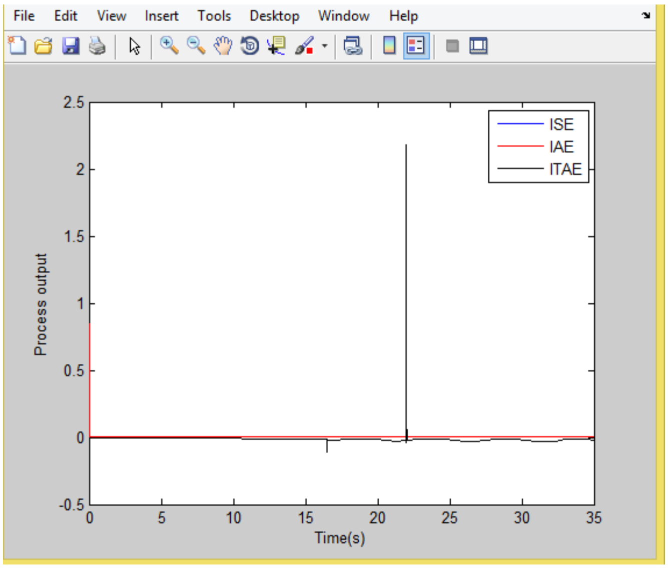

Fig 5-Error plot

3. CONCLUSIONS

A New Harmony Search Algorithm is proposed for minimizing Integral square Error cost function. While considering a Networked DC motor system the PI controller is tuned using this optimal value which derived by the algorithm execution and experimental verifications show that the proposed observer/controllers capable of dumping the adverse effects of unknown and time-varying delays and packet dropouts. It also provide high response time, error rate is low and high step response.

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