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Simulation of PSO-PI Controller of DC Motor in Micro-EDM System for Biomedical Application

Nor Liyana Safura Hashim*, Azli Yahya, Trias Andromeda, Mohammed Rafiq Abdul Kadir, Nazriah Mahmud, Syahrullail Samion

Faculty of Health Science and Biomedical Engineering, Universiti Teknologi Malaysia, UTM Johor, 81310 Skudai, Johor, Malaysia

Abstract

An Electrical Discharge Machining is one of the non-traditional machining processes. It is now been used widely in many applications due to its ability to machine materials with good surface finish. This paper presented a new Micro-Electrical Discharge Machining controller model using Particle Swarm Optimization algorithm for efficient search and optimization of Proportional-Integral controller parameters in order to achieve a better positioning system especially in biomedical application. This control method was simulated using MATLAB/SIMULINK to control DC motor. From the simulation, it was found that the proposed method gives better performance with improved step response for precise positioning system in micro-EDM as the settling time and overshoot are reduced.

Keywords: Electrical Discharge Machining, Particle Swarm Optimization, Proportional-Integral controller

1. Introduction

Electrical discharge machining (EDM) is a non-traditional machining process that machines an advanced difficult-to-machined material such as metal with high precision and complex shapes in terms of thermal and spark energy which becomes more significant especially in mold and die manufacturing industries. It is a non-contact process which could reduce vibration, mechanical stress and force towards the workpiece and produce higher quality than conventional machining. Recently, developments of EDM machining have broaden the need for industrial applications such as in aerospace [1], automotive [2] and medical devices manufacturing [3].

Since EDM is widely used nowadays, it has been modified in many ways so that it is able to meet the specific requirements for the specific applications concerning on improving the machining performance in terms of its surface quality, machining time, tool wear, and material removal rate [4]. Furthermore, in modern mechanical systems such in machine tools, a robust, high speed and high accuracy positioning of motion controller is very necessary. In addition, for biomedical application, micro-EDM machining is important manufacturing methods such as in manufacturing surgery or implant devices. It is very important to ensure that the machining is precise and accurate especially when it involves micro-

* Corresponding author. Tel:+6012-7064855
Email address: nlsafura88@gmail.com

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machining process. However, so far there has too little attention has been focused on precise positioning system in micro-EDM specific for biomedical application.

In EDM, DC motor is commonly used for those purposes for its servomechanism to control the gap between the electrode and workpiece. The DC motor is chosen instead of using AC motor because of its speed control capability which the speed, torque, and direction can be changed at any time to meet new conditions. Furthermore, smaller DC motor (eg. 12V operation condition) makes them easier to interface with control electronics [5]. Due to the advantages offered by the DC motor, a closed loop control system is utilized for precise workpiece positioning in micro-EDM. Therefore, the mechanical servo system using multiple DC motor such as represented in Fig.1 is considered for the development of workpiece positioning system in micro-EDM. However, for this paper, only a single DC motor is used for the simulation while further research involving simulation of multiple DC motors will be reported in a future paper.

In order to control the DC motor, controller such as PI and PID are used in EDM [6-7] because of its robustness. Gain such as K_P, K_I and K_D are determined by the controllers. However, the three adjustable controller parameters should be tuned appropriately. With the existence of various artificial intelligence techniques such as Ziegler- Nichols (ZN), Genetic Algorithm (GA), Artificial Neural Network (ANN), Ant Colony Optimization (ACO) and Differential Evolutions (DE) as they could help to tune, determine the optimize parameters value of the controller and get a better response of the system. Some of them [8-11] were successfully implemented in EDM machining.

More recent, a newly optimization technique, Particle Swarm Optimization (PSO) has been introduced. A comparative study between PSO and GA has been carried out by [12] and it was found that PSO gives better performance as it has good global searching ability and easier to be implemented than GA. It also has been used in applications such as in [13-14] and also in drilling process [15]. However, as PSO is a newly evolutionary computation technique, there are not many research have been done yet in implementing PSO technique in micro-EDM. Hence, this paper will be focusing on designing a controller model that can be used in micro-EDM system to get a better performance for the system response to tune PI controller and PSO algorithm using MATLAB/SIMULINK. Section 2 discusses on the model of the plant used in the simulation. Then, an explanation of PSO and its implementation will be included in section 3 and 4, respectively while section 5 includes the results, comparative studies between different controller design and its discussions.

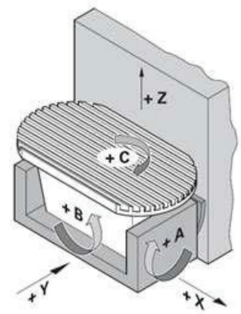


Fig. 1. Mechanical Structure of Workpiece Positioning Involving Multiple DC Motor [16]

2. DC Motor Model for EDM

In order to perform the simulation for the system, an appropriate DC motor model needs to be established. The schematic diagram of the DC motor is shown in the Fig.2 below and equation 1 describing the transfer function for the dynamic behavior of the DC motor.

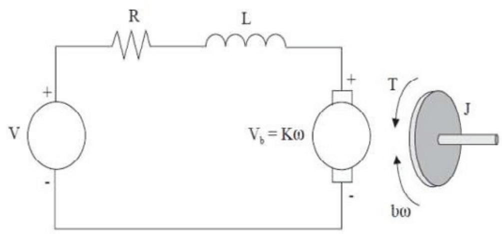


Fig. 2. Schematic Diagram of DC Motor

$$\frac{\theta(s)}{V(s)} = \frac{K}{s[(R+Ls)(Js+b)+K^2]} \quad (1)$$

The transfer function then was presented in the linear DC motor model. The linear DC motor model then was simulated. The result of armature current, motor torque and angular velocity of the DC motor without PI controller are taken and compared with the value in the data sheet. It is necessary to make sure that there are no obvious differences between the value obtained in the simulation and in the data sheet. Note that DC motor that used in this simulation is Quantum NEM17. A unit of step input was used to determine angular position and motor torque in this simulation. Parameters used in this simulation are such as in Table 1. The simulation was proceeded to control DC motor performance conventionally using PI controller. The basic of linear motor control model without PSO in the micro-EDM system is shown in Fig.3 below.

Table 1. DC motor parameters

Motor parameter	Symbol	Units	Value used in simulation
Armature resistance	Ra	Ω	1.51
Armature inductance	La	H	0.55e-3
Inertia of motor	Jm	Kgm2	1.10e-6
Torque constant	Kt	Nm	0.027
Back emf constant	Ke	V/rad/s	0.027
Friction viscous gain	Kf	Nm/rad/s	5.06e-6

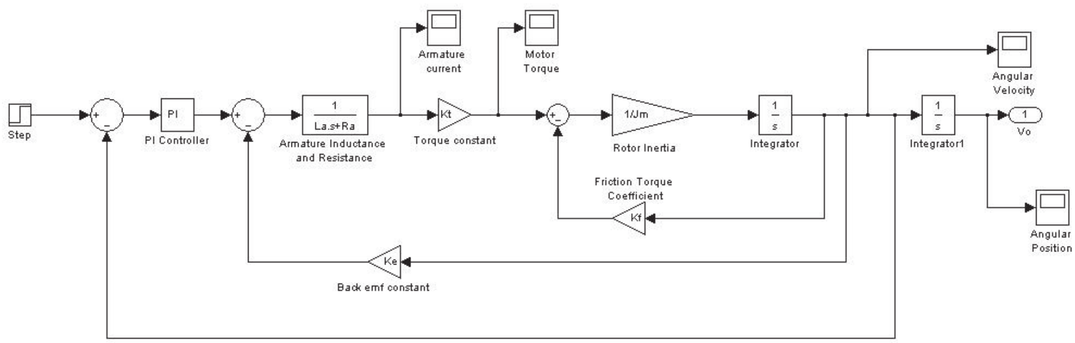


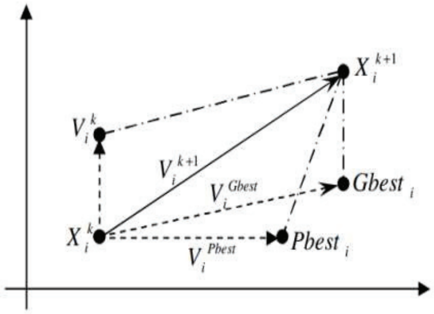
Fig. 3. Feedback Loop PI Controller of DC Motor

3. Tuning of PI Controller using Particle Swarm Optimization Approach

3.1 Particle Swarm Optimization, PSO Overview

PSO in one of optimization technique used to optimally tune the gain parameter in controller to get better performance. It was developed by Dr. Eberhart and Dr. Kennedy in 1995, inspired by social behavior of bird flocking or fish schooling. This type of technique is initialized with a population of random solutions and searches for optima by updating generations, using a population of particles, corresponding to individuals. It has many similarities with evolutionary computation techniques such as Genetic Algorithm (GA), but there are no operators inspired by the human DNA procedures are applied such as crossover and mutation [17]. Some of research have found that PSO technique could provides an excellent performance yet easy to be implemented. It is also robust in solving non-linear such as in [18] and high dimensionality problems through an adaptation. Compared to GA, PSO has a flexible and well-balanced mechanism to enhance the global and local exploration abilities and the convergence speed is quick without too many parameters [12, 19].

In PSO system, particles change their positions by flying around in a multidimensional search space until computational limitations are exceeded. Each particle represents a candidate solution to the optimization problem. For each particle, at the current step, a record of their position, velocity and the best position found in the search space so far is kept. Initially, each particle, X_i is assigned with a randomized velocity in a random position. The best previous position recorded by each particle is recorded from its own experience and represented as $Pbest_i$. Then, the index of the best particle among all the particles in the group is represented as Gbest [17]. Fig.4 below illustrates the concept of modification of a searching point by PSO. This type of optimization technique has been successfully implemented previously by [17, 20] for DC motor which it can perform an efficient search for the optimal values of controller parameters.



X^k: current position,
X^{k+1} : modified position,
V^k: current velocity,
V^{k+1}: modified velocity,
V^{Pbest}: velocity based on Pbest,
V^{Gbest}: velocity based on Gbest.

Fig. 4. Modification of a Searching Point by PSO[17]

3.2 Implementation of PSO into PI Controller for EDM System

The optimal of parameters in PI controller (K_p and K_i) is obtained using PSO. This is to ensure the controller is in a stable closed loop system. Fig. 5 below is the block diagram of the controller system while table 2 shows the selection parameters of PSO used in this simulation. The general equation of PI controller is such in Eq.2 below,

$$U(t) = Kp \times e(t) + \frac{1}{Ti} \int e(t)dt \quad (2)$$

where K_p is a proportional gain, T_i is an integral time and e(t) is a tracking error between the desired input value and actual output.

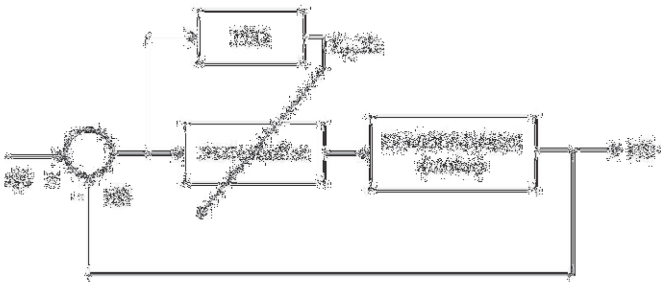


Fig. 5. Block Diagram of Proposed Controller

Table 2. Selection Parameters of PSO

Population Size	3
Number of Iterations	50
Velocity Constant, c1	1.2
Velocity constant, c2	0.12
Inertia weight, w	0.35

The performance of each particle in PSO system is measured according to a pre-defined fitness function that is related to the problem being solved [15]. Quantification of system performance is achieved through a performance index. The performance index that was used in this simulation is Integral of Time Multiplied by Absolute Error (ITAE) in order to calculate the fitness functions of the system. This is because system designed using ITAE criterion has small overshoots and well damped oscillation compared to other criterions such as ISE, IAE and ITSE [21]. The equation for ITAE criterion is such as in Eq.3.

$$ITAE = \int_0^\infty t|(e)t|dt \quad (3)$$

The PI controller is proposed with the optimal parameters derived from the PSO algorithm such that the value of ITAE is minimized. The flowchart of PSO algorithm that was implemented in this system is depicted such as in Fig.6.

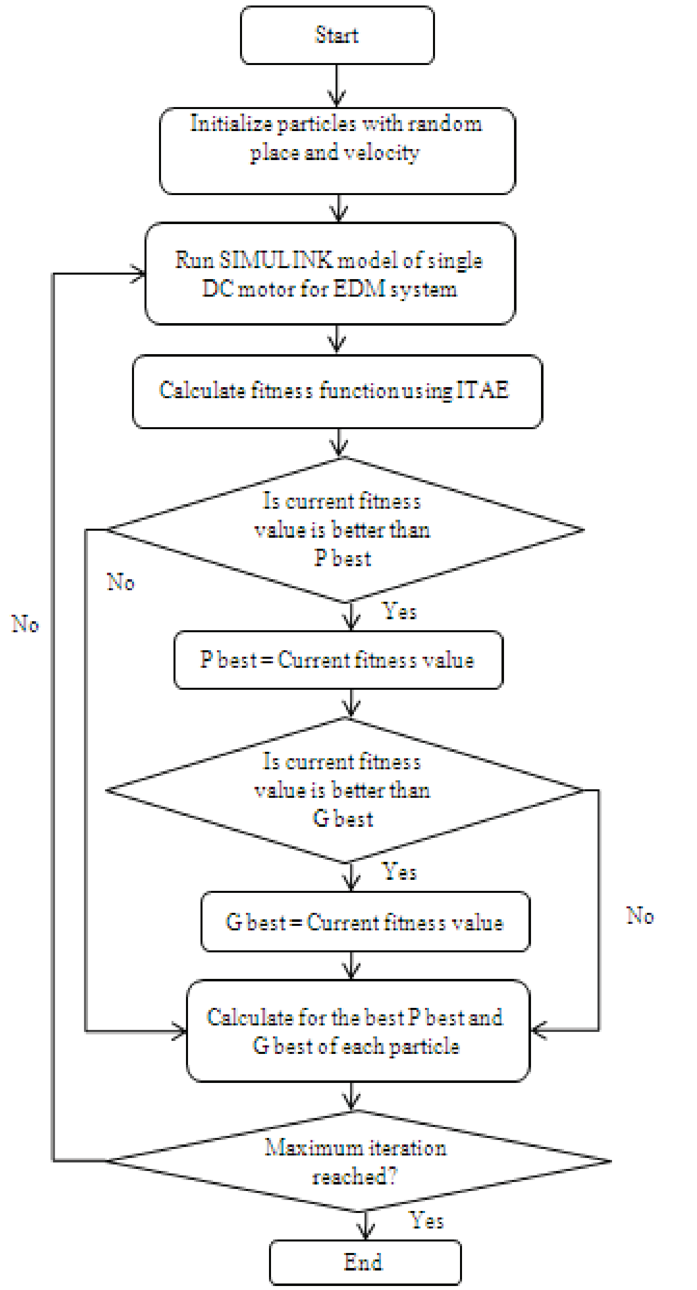


Fig. 6. Flowchart of PSO Implementation for micro-EDM System

4. Results and Comparisons

The results are taken from angular position and motor torque. Analysis of angular position is important to make sure the precision of DC motor output and movement while motor torque is important as it will determines force to produce rotation of DC motor. The output from angular position of the system without PSO and with PSO is shown in Fig.7 (a) and Fig.7 (b) respectively. The figures show that there has slightly different for rise time between PI with PSO and PI without PSO but the overshoot was obviously can be reduced from 1.14 to 1.04 by implementing PSO. Table 3 is summarizes of output from angular position system performance with and without implementing PSO.

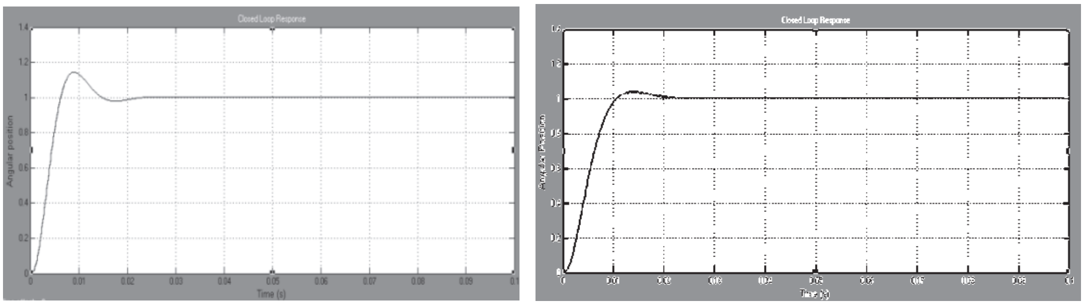


Fig. 7. (a) Step Response of Angular Position without PSO; (b) Step Response of Angular Position with PSO

The same goes to motor torque which the settling time also was reduced to 0.028s rather than 0.043s and maximum overshoot can be reduced from 0.1317 Nm to 0.0795 Nm. When the system is having minimal overshoot, it means that the system is more stable. Therefore, the speed of the output motor shaft also can be increased as motor torque is inversely proportional to the speed of the output shaft. This can be shown in Fig.8 (a) and Fig.8 (b) below.

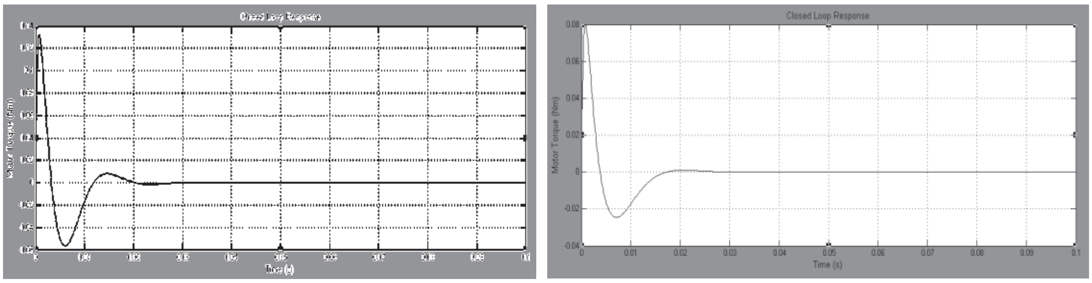


Fig. 8. (a) Step Response of Motor Torque without PSO; (b) Step Response of Motor Torque with PSO

Table 3. Performance Criteria of Micro-EDM System

	PI Controller without PSO	PI Controller with PSO
Kp	9.5256	5.7756
Ki	3.9876	1.9347
Rise time (sec)	0.0091	0.0140
Settling time (sec)	0.0485	0.0380
Steady state error	0.0015	0.0015
Peak	1.1446	1.0412

5. Conclusion

This paper presented a new design of controller for EDM servomechanism using PSO method to optimize PI parameters. The comparison between PI controller without and with PSO implemented has been made. From the result, it can be shown that PSO method can be used to optimize PI controller is more efficient and gives better performance for positioning system in micro-EDM application with reduced settling time and overshoot of the system. Future research is intended to be focused in the application of the proposed method for designing controller to control multiple DC motors especially in biomedical application.

Acknowledgments

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