Implementation of Evolutionary Optimization Techniques in Tuning PID Parameters for Tremor Patient Active Assistive Writing Device

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Abstract— Genetic Algorithm (GA) and Particle Swarm Optimization (PSO) are methods of the Evolutionary Optimization techniques and autonomously tuning method used in this study to tune the parameters of the Proportional-integral-derivative (PID) controller. PID controllers need to be tuned appropriately to establish the good performance of the Active Assistive Writing Device (AAWD). This AAWD device is used to help patients who face difficulties due to hand trembling while writing. The actual hand tremor data while writing was measured by attaching an accelerometer to the device. Based on the simulation results, it has been found that applying PID controller and GA optimization techniques to the assistive device has an enormous potential in helping tremor patients improve their quality of handwriting.

Keywords—Active Assistive Writing Device, Evolutionary Optimization, Genetic Algorithm, Particle Swarm Optimization.

I. Introduction

TREMOR is an involuntary or rhythmic uncontrollable movement that may occur to one or more body parts and can affect the hands, arms, eyes, face, head, vocal folds, trunk, and legs. For normal people this symptom called physiological tremor and this involuntary movement is very small and only clearly visible when their emotions get disturbed, such as being anxious, furious or scared, as well as due to a cold environment. The chattering of teeth occurs because of cold temperature induced in the body. A neurological disorder is another symptom of tremor that is suffered by patients, also known as, Parkinson's disease (PD). Several cause of tremor has been found out for instance stress, smoking, alcohol, use of certain drugs and others [16]-[17]. The patients who suffer from PD face the difficulty of controlling some of their body parts from shaking or oscillating, and it is commonly visible in the hands [14]. Tremor patients will face difficulties especially when performing daily tasks such as holding and eating [15]. Handwriting capabilities become worse when the tremor is severe. The oscillation of hand during writing may affect the quality of handwriting. Therefore, this research has been conducted by presenting biomechanical loading approach without surgical interventions or ingestion of drugs. Recently, the application of biomechanical loading has shown to be a technique that is able to suppress the uncontrollable movement caused by tremor on the human body. Micron like intelligent active hand-held microsurgical instrument has become a great interest in the field of microsurgery, helping a surgeon perform better ophthalmological microsurgery procedure due to physiological tremor occurring during operations [7]. The device will sense the undesired motion and counter it with an equal but opposite deflection of the instrument's tip. MARo2 [8] is a meal-assist robot developed by E.Ohara *et al.*(2009) where the human-machine interface makes it possible for the person with a tremor to manipulate the supporting robot without causing operability to deteriorate and without hazards due to improper operation. This non-invasive method will measure the unwanted movement due to the tremor using appropriate sensor and suppress the movement with smart actuator.

This study is intended to develop such a device in suppressing hand tremor during writing, and to study the performance of the implementation of Proportional-Integral-Derivative (PID) controller to the currently developed AAWD for tremor patients. The PID controller was selected due to extensive use in the industry field [1]. The heuristic method, GA and PSO are employed to tune the parameter in the PID controller. The overall results are compared based on the performance. The GA and PSO optimization techniques are able to generate a high-quality solution in search of optimal solutions, and the results will show the convergence characteristic by implementing these techniques.

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II. Methodology

A. Descriptions of AAWD

The AAWD is physically designed to be suited by a patient hand similarly like gripping a normal pen. There are two main parts; static part and moving part. The static part, named as outer shell where the patient applied hand grip for performing handwriting. The latter is moving parts, named as center core where it placed inside outer shell. The center core with a physical dimension of 100mm in length and 6 mm in diameter, a cylindrical hole with 4 mm in diameter along center core purposely to be filled with a pen tip. This center core will be moving in a single axis known as a dominant direction when the AAWD detect the unwanted movement or tremor motion characteristic from patient's handwriting. The outer core with inner diameter of 20 mm is the boundary limits for the center core to move. The clearance movement of center core can be reached is 14 mm and 7 mm for each side from its center position.

In normal writing condition, center core is in the center position inside the outer shell and when the accelerometer sensor detecting the unfamiliar signal (tremor) within the frequency range of 2-12 Hz from the patient's handwriting, then center core will move in the opposite direction from the detected signal direction. This idea is to ensure the pen tip moving to the actual position of tremor hand should be. This center core movement is controlled by a very responsive actuator, DC servo motor is used in this research. The DC servo motor is mounted at the back end of outer shell and the moving shaft of the DC servo motor linked to the center core with using the rudder. In promising a good movement of center core, two linear bearings are installed to the AAWD. This two linear bearing then joined to the outer shell to hold the center core.

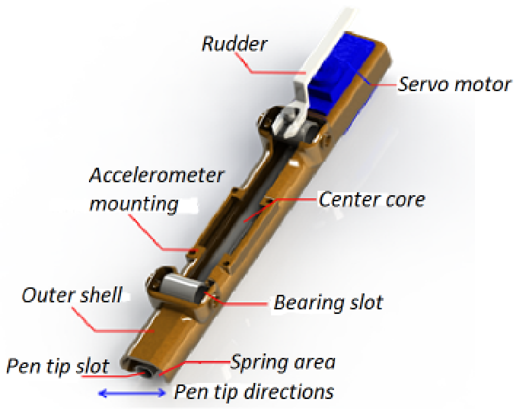

Fig. 1 The overview of AAWD system.

B. System Modelling

In this research works, there are two mathematical model need to be determined to represent the dynamics model of the AAWD system. In closed-loop system, this two mathematical model shows crucial parts in searching these three parameters of the proposed PID controller. Firstly, the mathematical model to represent actuator for the AAWD system need to be obtained. In these works, the actuator is DC servo motor. Fig. 2 depicts the block diagram of the DC servo motor that had been used where the input is the voltage act as the input command for the actuator and the angle represent the output of the actuator systems.

The parameters *Jm, Kb, Kt, Ra,* and *Dm* denote as motor inertia, back-emf constant, motor torque constant, armature resistance and equivalent viscous density of motor respectively. The open loop transfer function of second order DC servo motor system is as follows;

$$\frac{\theta(s)}{E_a(s)} = \frac{\left(\frac{K_t}{R_a J_m}\right)}{s^2 + s\frac{1}{J_m}\left(D_m + \frac{K_t K_b}{R_a}\right)} \quad (1)$$

Currently, the DC servo motor model Futaba s148 was used and the linear transfer function of DC servo motor system is given below [2];

$$\frac{\theta(s)}{E_a(s)} = \frac{950}{s^2 + 40s + 950} \quad (2)$$

The latter is to obtain the mathematical modeled to represent a plant for the closed-loop systems. For AAWD system, one-degree-of-freedom system consists of mass, springs and damper is selected to represent a plant system.

$$m\ddot{x} + c\dot{x} + k_t x = F \quad (3)$$

Where m, c, and k_t denotes as the overall mass of AAWD, damping, and stiffness, respectively. While the F denote as hand tremor force. The force of hand tremor can be obtained from acceleration while writing by multiplying the estimated mass of patient hand palm. Assuming $c = 0$ and rearrange the equation (3) becomes;

$$m\ddot{x} + k_t x = F \quad (4)$$

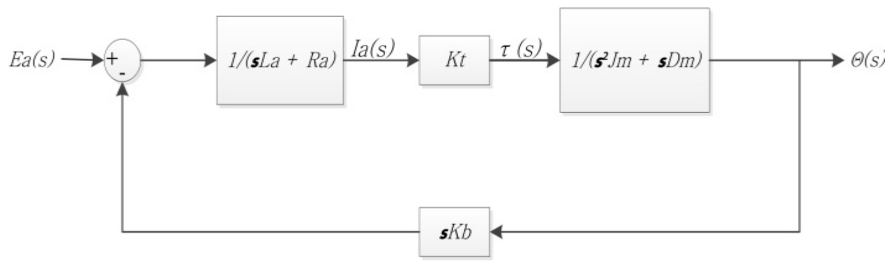

Fig. 2 Model of DC servo motor.

C. Data Measurement

The actual data of the tremor patients while performing handwriting task need to be measured and recorded. In this research, the performance of handwriting tasks from an Essential Tremor (ET) patient diagnosed according to the clinical criteria is selected and a patient need to complete the task by having them to track the Archimedes spiral. Tracking Archimedes spiral is the most common way to diagnose Essential Tremor (ET) [12]. The AAWD is used while performing that task without activating the actuator. While writing, acceleration of a patient's hand is measured by using a miniature accelerometer ADXL 330. This accelerometer is mounted to an AAWD and the signal output from this sensor then linked to the microcontroller before transmitting the data to the computer for recording purposes. The sampling rate of 1000 data per seconds is set by a microcontroller while doing the measurement. This set of recorded data then applied to the simulation analysis acts as a disturbance for the systems in MATLAB environment to validate the AAWD performances.

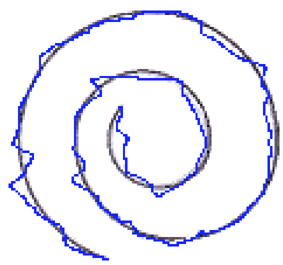

Fig. 3 The sample of tracking an Archimedes spiral completed by a patient.

III. Proposed Controller and Optimization Techniques

Fig. 6 depicts the entire system block diagram of AAWD. The input of the system is the desire acceleration where the system need to be achieved and the acceleration of this system is set near to zero point, which means the system need to minimize the acceleration of a patient hand caused by the tremor as closed to this set point.

A. PID Controller

A Proportional-Integral-Derivative controller (PID) or also known as "three-term" controller [15] is a generic control close loop feedback extensively used in industrial control system. In this simulation study, the PID controller is used to control the response of DC servo motor movement in order to produce better performance in cancelling unwanted movements from patients' hands. Generally, in the PID controller, there are three-term control structure consisting of proportional action, integral action and derivative action. By tuning the three parameters in the PID controller algorithm, the controller can provide controlled action designed for specific process requirements. The proportional gain (Kp), Integral gain (Ki), and Derivative gain (Kd) terms are summed to calculate the output of PID controller.

This three parameters need to be tuned precisely to obtain a good performance for the entire system. There are several methods of tuning a PID control loop. Manual tuning method (heuristic) is relatively inefficient, particularly if the loop systems have longer processes. Since this heuristic method is not appropriate for this case study, the meta-heuristic methods will be used by providing a consistent PID loop tuning. The equation (5) and (6) shows the PID algorithm. Where $K_c(t)$ is the controller output, K_p is proportional gain, K_i the integral gain, K_d the derivative gain, *SP* the ideal value of output and *SV* the measured value

$$K_c(t) = K_p.e(t) + K_i.\int_0^t e(t) + K_d.\frac{d}{d(t)}.e(t) \qquad (5)$$

$$e = SP - PV \qquad (6)$$

B. Genetic Algorithm

Genetic Algorithm is a stochastic global search method that mimics the process of natural evolution [3]-[5]. GA optimization technique was invented by John Holland in the United States in 1970 at the University of Michigan. This optimization technique is inspired by two biological principles known as "natural selection" and "natural genetics" [6]. The term chromosomes are created when there is a potential solution in the population, where each fitness of chromosomes (objective function) will be compared to one another and the fittest will indicate the best solution at the end of the optimization process. At the beginning, the number of individuals needs to be assigned, and typically between 20 to 100 individuals are chosen [6].There are three crucial stages in this optimization technique known as *'reproduction', 'crossover',* and *'mutation'*. Before performing these three stages, the number of the population needs to be decided to get promising results. Based on previous studies, the suggested size of the population is from 30 to 100. During the reproduction process, there are four selection methods and it depends on the user to select one when performing every GA optimization process. In this studying, the 'Tournament selection' is preferred. Fig. 4 shows the GA optimization procedure.

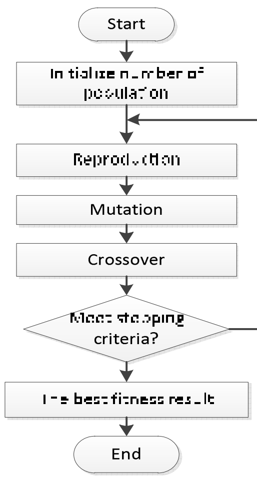

Fig. 4 The GA optimization technique procedure.

C. Particle Swarm Optimization

Particle Swarm Optimization is an evolutionary method that optimizes an objective function by iteratively trying to modify velocities and the position of each candidate in a two-dimension space known as particle. The combination of particles will form a population and for each particle its known their best position previously. If a particle current position is better than its previous best position then it will update and known as P_{best}. Furthermore, each particle keeps interact with its neighbor and keep updated the P_{best} among them. The best value among its group will update the value of g_{best}. If the value of P_{best} and g_{best} is obtained then each particle will update its new positions and velocities. By referring (7) and (8) are the equations to update the new particle velocities and position, respectively [13]. Where V_i^t is the velocity of particle i at iteration t, ω is the inertia weight actor, ℓ_1 and ℓ_2 are cognitive and social parameters, U_1^t and U_2^t are the random numbers between 0 and 1, and X_i^t is the current position of particle i at iteration t.

$$V_i^{t+1} = \omega V_i^t + \ell_1 U_1^t (P_{best}{}^t - x_i^t) + \ell_2 U_2^t (g_{best}^t - x_i^t) \quad (7)$$

$$X_i^{t+1} = X_i^t + V_i^{t+1} \quad (8)$$

This process continues to occur until stopping criteria are satisfied. The Fig. 5 shows the general flowchart of PSO works.

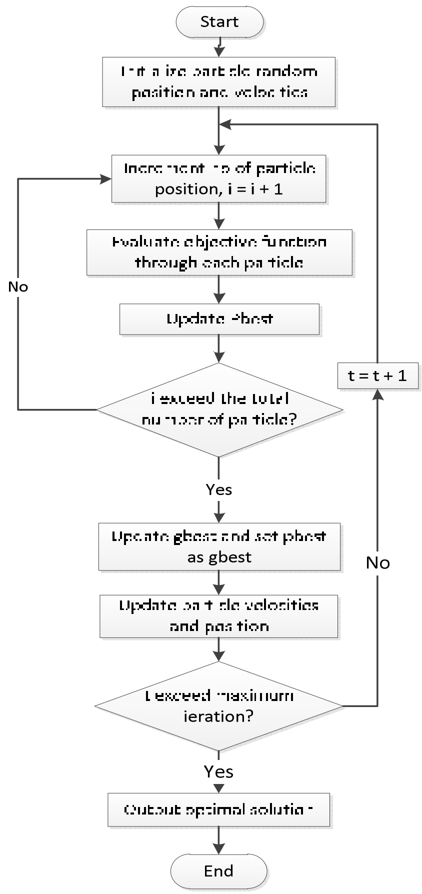

Fig. 5 The PSO optimization procedure.

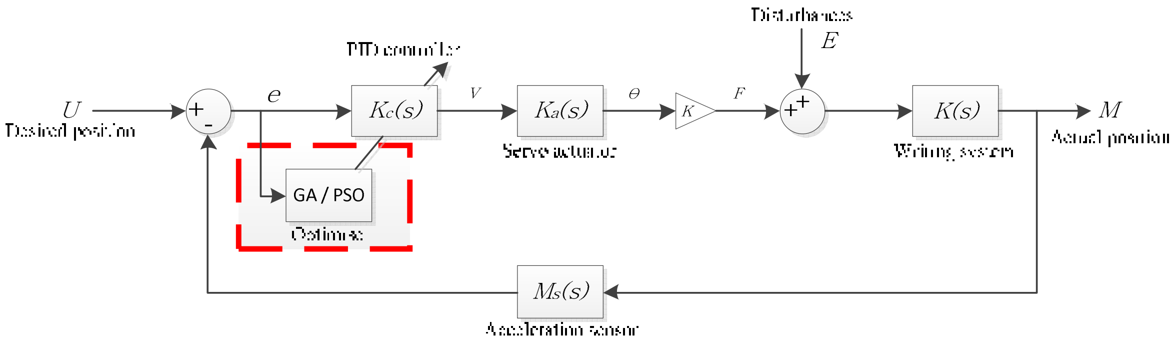

Fig. 6 Block diagram of the AAWD system by using MATLAB Simulink environment

IV. Results and Discussions

This topic presents the results from the simulation analysis using MATLAB environment. The results show the performance based on acceleration in the time domain and frequency domain analysis. From clinical examination of the tremor patients, the frequency and amplitude vary to the degree that the tremor may be hardly noticeable or severely disabling. Frequency of tremor can be separately categorized into three stages, slow (3 – 5 Hz), intermediate (5 – 8 Hz) and rapid (9 – 12 Hz) [11]. From the frequency analysis, the dominant amplitude should be decreased from its current value to ensure the implementation of PID with the heuristic method; GA and PSO optimization will help in improving the quality of handwriting among tremor patient. In this topic, the results were separated into two parts. The first part is the results obtained by implementing GA optimization techniques and the second part is the result obtained by implementing PSO optimization technique. For both parts, the results are compared with the result obtained from heuristic method. The result from heuristic method acts as a reference for both optimization techniques and if the response is closed to zero axis for time domain analysis means the selected optimization technique applied are more better. Fig. 7 represents the acceleration result of a tremor patient while performing handwriting tasks with average of acceleration lies within ±0. 1 m/s². Fig. 8 shows the frequency domain analysis, also done by a same patient and from the results show that the dominant amplitude of 43.72 occurred at frequency 8.3Hz. .

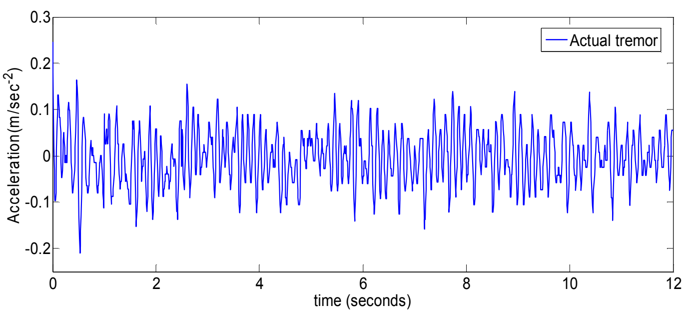

Fig. 7 Acceleration for actual tremor

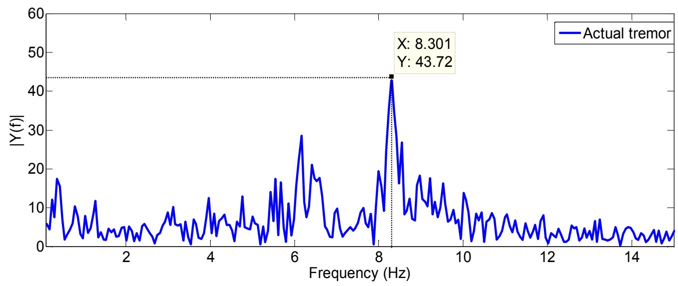

Fig. 8 Frequency of actual hand tremor

A. Genetic Algorithm results

First, the parameters of GA need to be determined. Table 1 shows the parameters of GA optimization set before tuning parameters of PID.

Table. 1 GA tuning parameters

Parameter	Value
Lower bound [Kp Ki Kd]	[0 0 0]
Upper bound [Kp Ki Kd]	[250 200 250]
Stopping criteria(Generation)	70
Population size	60
Crossover fraction	0.8
Mutation Fraction	0.01

Fig. 9 shows the results of the objective function convergence by setting the parameters as stated in Table 1. From the graph, the initial error of the IAE is 0.1637, and after 2nd generation, the IAE starts to decrease significantly to 0.1546. After 2nd generation, the error begins to reduce gradually until 70 generations and the final IAE value is 0.1525.

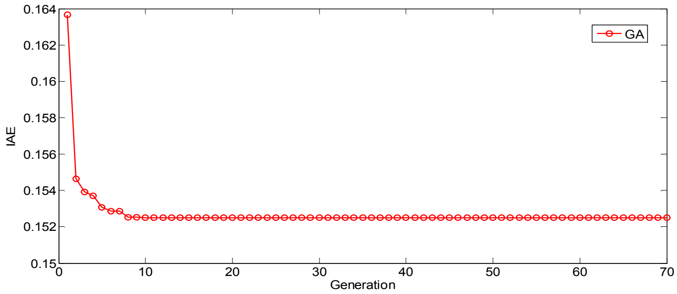

Fig. 9 The convergences of objective function in tune PID controller.

Fig. 10 illustrates the results for parameters Kp, Ki, and Kd tuned by GA optimization technique after 70 generations. From the graph, the first 8 generations show that the value of PID parameters is unstable. At this point, the GA optimization is searching the best, optimal fit and after 18 generations, all PID parameters respond positively, where the final values of Kp, Ki, and Kd are 250, 200 and 23.59 respectively.

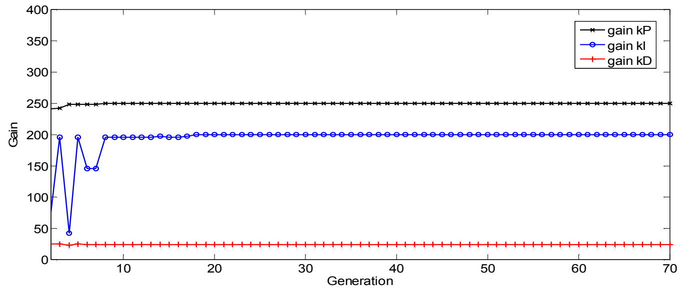

Fig. 10 The performance of the GA algorithm through 70 generations in tune parameters KP, Ki and Kd of PID controller.

The Fig. 11 and Fig. 12 show the frequency response and time response using a PID controller with GA optimization technique compare with heuristic methods. The result is in Fig. 8 obtained after implementing the PID controller using heuristic tuning method (manual tuning) by presenting dominant amplitude about 0.2558 showed an improvement of 99.41% and the parameters of Kp, Ki and Kd are tuned to 100, 66.56 and 2.636 respectively. Meanwhile, by implementing the GA optimization technique, the results are better and represent an increment of 99.6% to be final dominant amplitude of 0.07771.

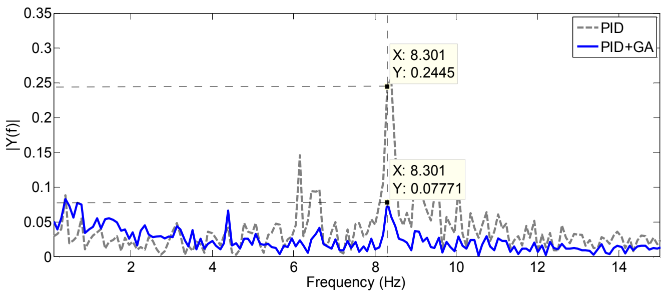

Fig. 11 Frequency response for PID with heuristic method and GA optimization

Fig. 12 shows the average boundary of acceleration amplitude within -0.001m/s² to 0.001m/s² with using the heuristic tuning method. Furthermore, by applying the GA optimization technique, the results are more promising, with an average boundary of acceleration amplitude lying within -0.00025 m/s² to 0.00025 m/s².

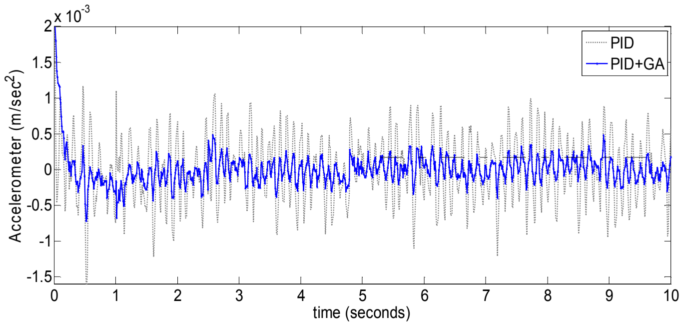

Fig. 12 Acceleration response for PID with heuristic and GA optimization

B. Particle Swarm Optimization results

The parameters of PSO need to be determined and as shows in Table 2 are the parameters of PSO optimization that was set while tuning PID control parameters. At the initial stage, the number of generations was decided in 30. Since the result was not promising, the number of generations was increment to 40, 50, 60 and finally it was observed that at 100 generation shows the better performances.

Table. 2 PSO tuning parameters

Parameter	Value
Lower bound [Kp Ki Kd]	[0 0 0]
Upper bound [Kp Ki Kd]	[250 200 250]
Stopping criteria (Generation)	100
Population size	60
Maximum velocity factor	0.2
Inertial weight factor [min max]	[0.4 0.9]
Acceleration constant [C1 C2]	[2 2]

The Fig. 13 shows the results where the objective function convergence by setting the parameters as in Table 1. From the graph the initial error of IAE is 0.168 and after 2nd generation the IAE start to decrease significantly to be 0.164 when 4th generation. After 4th generation the error start to reduce gradually until 100 generations and the final IAE value is 0.1632.

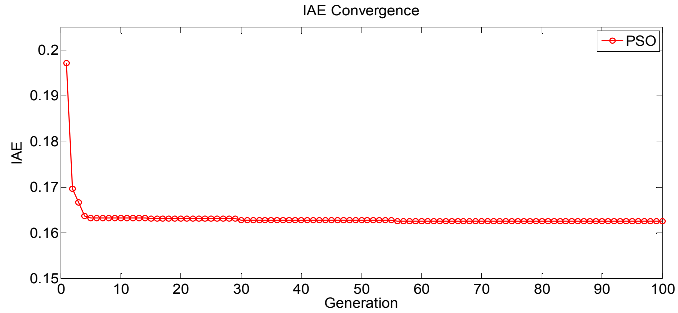

Fig. 13 The convergences of objective function in tune PID controller.

The Fig. 14 illustrated the results for parameters Kp, Ki, and Kd tuned by PSO optimization technique for 100 generations. From the graph, the first 55 generations show the value of PID parameters is unstable and significantly for gain Ki. At this point, the PSO optimization is searching the best optimal fit and after 55 generations all PID parameters show good response where the final values of KP, Ki, and Kd is 199.22, 47.77 and 22.13 respectively.

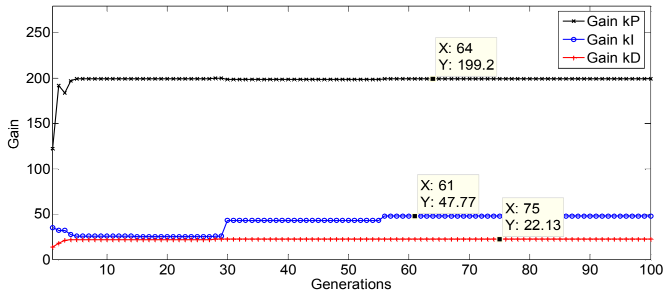

Fig. 14 The performance of PSO algorithm through 100 generations in tune parameter KP, Ki and Kd of PID controller.

The Fig. 16 shows the response time by using a PID controller with PSO optimization technique. By implementing PSO optimization technique the results as in Fig. 15 is obtained by presenting improvement of 99.81% to be final dominant amplitude of 0.08033.

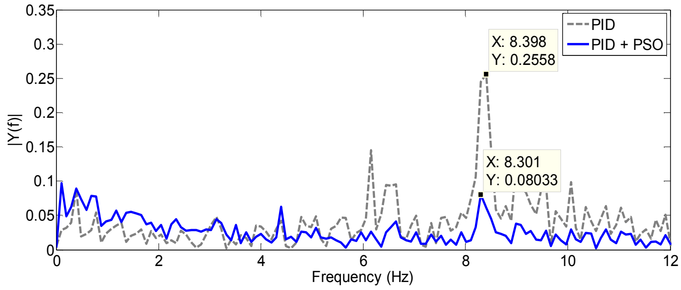

Fig. 15 Frequency response for PID with heuristic method and PSO optimization

The Fig. 14 shows the improvement by applying PSO optimization technique and the results are more promising by presenting the average boundary of acceleration amplitude lying within -0.00026m/s² to 0.00026 m/s² which lies near to zero axis.

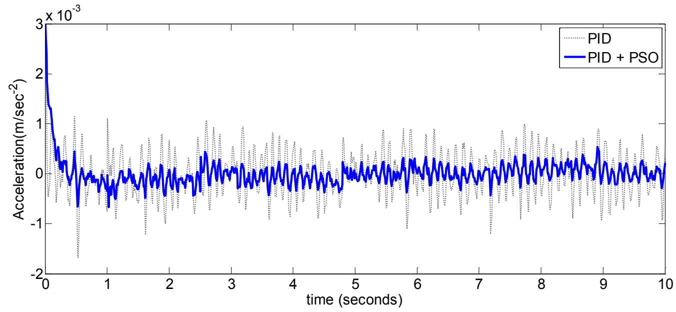

Fig. 16 Acceleration response for PID with heuristic and PSO optimization

Table 3 shows the summarize for all simulation results obtained by implementing the heuristic method, GA and PSO optimization techniques. As shown from Table 3, the PID control with GA optimization represent best results compare with two others technique. The validation of performances is based on the analysis from reduction of dominant magnitude from frequency response. The results between GA and PSO optimization techniques seem not to much differ from each other by representing a gap of percentage improvement about 0.013%.

Table. 3 The tuning parameters and results of PID+heuristic, PID+GA and PID+PSO

Parameter	PID+heuristic	PID + GA	PID + PSO
[Kp Ki Kd]	[100 66.56 2.636]	[250 200 23.59]	[199.22 47.77 22.13]
IAE convergence	-	0.1525	0.1632
Dominant magnitude in freq. analysis	0.2558	0.07771	0.08033
Dominant magnitude improvement (%)	99.46	99.823	99.810
Acceleration boundary (m/s²)	±0.001	±0.00025	±0.00026

V. Conclusion

This study provides an investigation of the performance of non-invasive method of suppressing human hand tremor while writing. The research was conducted by implementing the PID controller with an appropriate optimization technique, which is GA optimization and PSO optimization. At the initial stage, the PID controller was tuned by a heuristic method, where the parameters of gain K_P, K_i and K_d were tuned manually until the best result is obtained based on its frequency and acceleration analysis.

Afterwards, the GA a PSO optimization technique is implemented in the system where the parameters were self-trained. From the results, it shows that by implementing the GA and PSO optimization techniques, the results have improved as compared to the PID parameters that were tuned manually. From this simulation analysis, the result shows the AAWD that's currently being developed may have a great potential in helping people who are suffering from hand tremor, especially for patients who face difficulties in performing their daily task of writing.

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