A Modified Particle Swarm Optimization with Nonlinear Decreasing Inertia Weight Based PID Controller for Ultrasonic Motor

Alrijadjis Djoewahir, Tanaka Kanya, and Mu Shenglin

***Abstract*—Ultrasonic motor (USM) exhibits non-linearity that relates the input and output. It also causes serious characteristic changes during operation. PID controller has been widely used as the control scheme for USM. However, it is difficult for the fixed-gain type PID controller to compensate such characteristic changes and non-linearity of USM. The present paper proposes a modified PSO with nonlinear decreasing inertia weight (PSO-NDW) for optimal self tuning of PID controller in positioning control of USM. A modified PSO employs the strategy that nonlinearly decreases the value of inertia weight from a large value to a small value. This strategy is to improve the performance of the standard PSO algorithm in global search and fine-tuning of the solutions. The performance of PSO-NDW based PID controller has been evaluated on the USM servo system. The results demonstrate that the proposed modified PSO can improve the accuracy of USM.**

***Index Terms*—PID controller, PSO, ultrasonic motor, inertia weight**

I. Introduction

The ultrasonic motor (USM) is a new type motor, which is driven by the ultrasonic vibration force of piezoelectric elements. USM has excellent features, such as small-size, light-weight, no-running sound, high torque even at the low speed, high retention torque, and no-emitted electromagnetic noise. Therefore, USMs is capable as an excellent actuator in many applications [1]-[3]. However, it is difficult to control USMs because of no-exact model of USMs. Since the modern controls are hard to be applied on USMs, PID controller has been widely used in USM applications [4]-[6]. However, there are limitations of the control performance using the conventional fixed-gain type PID controller because USM causes serious characteristic changes during operation and contains non-linearity. In that case, it is difficult for the conventional one to compensate such characteristic changes and non-linearity of USM.

To overcome those problems, the research on self tuning of PID controller using an intelligent soft computing, such as Neural Network (NN) and Genetic Algorithm (GA), are proceeding. Nevertheless, there are still possibilities for PID gains easily to get stuck in a local minimum and very slow convergence. Meanwhile, particle swarm optimization (PSO) as an alternative to GA has been actively researched. Moreover, despite the simple algorithm in PSO compare to genetic algorithm, PSO is able to solve the nonlinear optimization problem efficiently [7]-[9]. Although PSO has the characteristics of fast convergence, good robustness, strong commonality, and has been successfully applied in many areas, it has the shortcomings of premature convergence, low searching accuracy and iterative inefficiency, especially the problems involving multiple peak values, and it is likely to fall in local optima. In order to overcome the aforementioned limitations, many researchers have attempted to improve the PSO algorithm [10], [11].

In this work, a modified PSO which employs nonlinear decreasing of inertia weight was applied to optimize the PID parameters for a positioning control of USM. To show the effectiveness of our proposed method, the experiment in real system were compared with that of the previous methods (fixed-gain type PID and PSO with linear decreasing inertia weight based PID).

II. Particle Swarm Optimization

PSO is a stochastic optimization method modelled by the behaviour of birds flock to find food known as one of the potential method. The outline for PSO is marked as follows. Let consider the optimization problem of maximizing the evaluation function $f : M \rightarrow M' \square R$ for variable $x \in M \square R^n$. Let there be N particles (mass point) on M dimensional space, where the position vector and velocity vector of i(= 1,2,3,....,N) th particle for m searching number are x_i^m and v_i^m . The best position for each particle in the evaluation function $f(x)$ of $x_i^1, x_i^2, \ldots x_i^m$ searching point is represented as P_i (*Pbest*), while the best position of $f(x)$ in the searching point for the whole particle is represented as P_g (*Gbest*). The particles are manipulated according to the following recurrence equations:

$$v_i^{m+1} = w.v_i^m + c_1.r_1.\{P_i - x_i^m\} + c_2.r_2.\{P_g - x_i^m\} \tag{1}$$

$$x_i^{m+1} = x_i^m + v_i^{m+1} \tag{2}$$

w represented the inertia weight, c_1 and c_2 are two positive constant, where r_1 , r_2 are uniform random numbers of [0,1].

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III. Proposed Modified PSO

An inertia weight is important parameters to balance the exploration (global search) and exploitation (local search) ability of PSO. This balancing is a key to improve the performances of PSO. In last research, a linear decreasing inertia weight (PSO-LDW) was introduced and was shown to be effective in improving the fine-tuning characteristic of the PSO for determining the gains of PID controller on USM [12]. In this method, the value of *w* is linearly decreased from an initial value (w_{max}) to a final value (w_{min}). However, this strategy is still less able to overcome the nonlinearity of USM.

In this research, we will adopt the nonlinear decreasing of inertia weight method to enhance the ability of PSO to address the nonlinearity of USM and the adjustment of *w* is given as [11]:

$$w = w_{\min} + \left(w_{\max} - w_{\min}\right)\left(\frac{m-n}{m-1}\right)^{x} \tag{3}$$

where *x* is the nonlinear modulation index. The value of *x* will determine the degree of non-linearity function of inertia weight. Based on the result in [11], the used value of *x* for the proposed method is 2. This method is known as PSO with nonlinear decreasing inertia weight (PSO-NDW). The effectiveness of PSO-NDW is used to determine the gains of PID controller for positioning control of USM in real system experiment.

Design of PSO-NDW based PID controller for USM is shown in Fig. 1. In this system, three PID parameters, i.e., the proportional gain *Kp*, integral gain *Ki* and derivative gain *Kd*, will be tuned optimally by PSO-NDW algorithm. The signal *e(k)* will be inputted for PSO-NDW and subsequently evaluated in the fitness function to guide the particles during the optimization process. The fitness function for the proposed method is given as:

$$Fitness = \frac{1}{1+\sum_{i=Ts}^{T/2} e(i)^2} \tag{4}$$

where, $T/2$ is half cycle of the object input, and *Ts* is start-time of the evaluation. Fitness shows the following-up of evaluation function for the object input. The purpose is to decrease the steady-state error by maximizing the function. The USM control for clockwise (CW) rotation and the counter clockwise (CCW) rotation use the different PSO in tracking the object input. Since the characteristics of USM is different depends on the rotation direction, we evaluate both rotations separately.

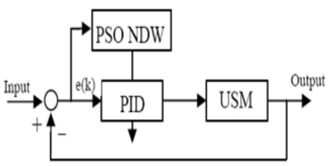


Fig. 1. PSO-NDW based PID controller.

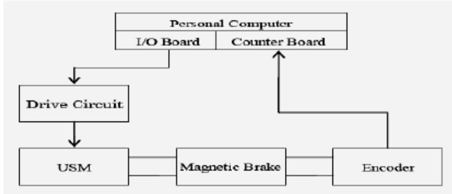


Fig. 2. USM servo system

IV. Experimental Result

The USM servo system constructed in this study is shown in Fig. 2. USM, the electromagnetic brake and the encoder are connected on a same axis. The position information from an encoder is transmitted to the counter board embedded into a Personal Computer (PC). Meanwhile, according to error resulted from the comparison between the output and reference signal, the control input signal which is calculated in PC is transmitted to the driving circuit through the I/O board and oscillator. In each experiment, the load is added or not is discussed to observe the changes of the USM's characteristics. While the voltage of 12 [V] is imported, the force of 0.25 [N.m] could be loaded to the shaft of the USM. Table I shows the specifications of USM including the encoder and the electromagnetic brake.

TABLE I: Specifications of USM, Encoder and Load

USM	Rated rotational speed : 100 [rpm]
	Rated torque : 0.5 [N.m]
	Holding torque : 1.0 [N.m]
Encoder	Resolution : 0.0011 [deg]
Load	0 to 0.5 [N.m]

A. Comparison of the Steady-state Error

We ran our experiments on USM with 10 times of clockwise (CW) rotation and 10 times of counter clockwise (CCW) rotation for no-load condition. After that, we repeat again for with load condition. For the fixed-gain type PID controller, we used gain parameters as follows: $Kp = 0.1815$, $Ki = 10.86$ and $Kd = -0.000069$. The parameters in both PSO LDW and PSO NDW are $c_1 = 1.0$, $c_2 = 1.0$, particle number $n = 5$, $w_{max} = 0.8$, $w_{min} = 0.4$ and $x = 2$ (only in PSO-NDW). Fig. 3 – 8 present steady-state error in histogram for our proposed method and the previous methods. It can be seen that the distribution of steady-state error of our proposed method is narrow and better for frequency of zero steady-state error than the previous methods.

B. Comparison of the Convergence Speed

Fig. 9 - 12 shows the result of convergence characteristic of fitness, gain *KP*, gain *Ki* and gain *Kd* for our proposed method and previous methods. From these results, we can say that at the beginning of iteration, the particles, both in PSO-LDW and PSO-NDW, have a high exploration ability with high-speed to search global solution. Then, according to decreasing of inertia weight, the speed of particles will decrease. At the end iteration, the particles of PSO-NDW have greater local search ability with lower speed than the particles of PSO-LDW and finally homing in onto the best solution area. Thus, the accuracy of PSO-NDW becomes better than PSO-LDW. It is also found that our proposed method have faster convergence and stability better than

PSO-LDW.

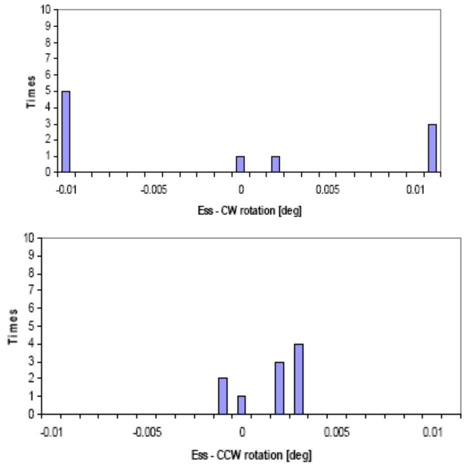


Fig. 3. Positioning error of PID controller (no-load).

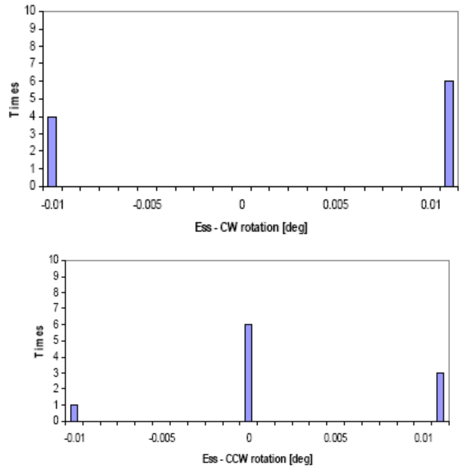


Fig. 4. Positioning error of PID controller (load 0.25 N.m)

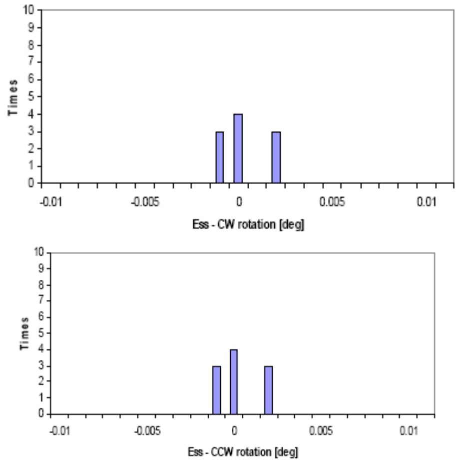
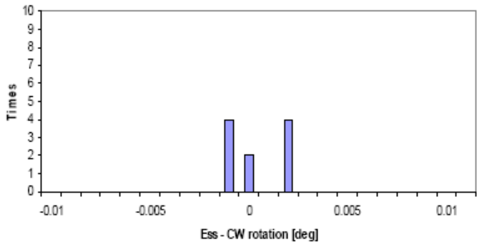


Fig. 5. Positioning error of the PSO-LDW PID controller (no-load)



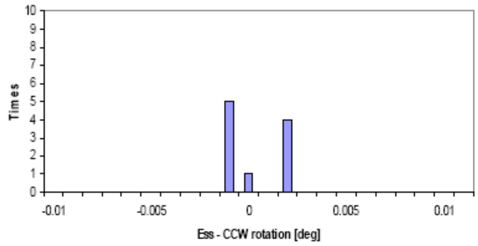


Fig. 6. Positioning error of PSO-LDW PID controller (load 0.25 N.m)

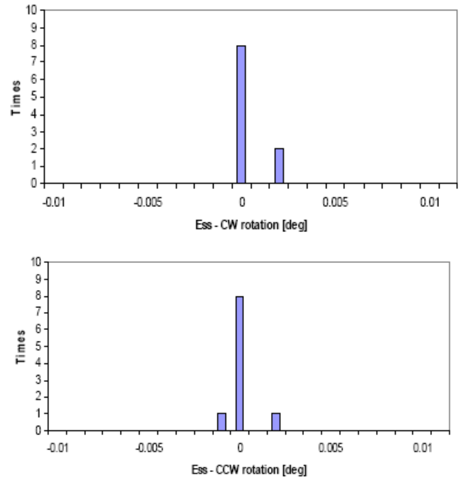


Fig. 7. Positioning error of the PSO-NDW PID controller (no-load)

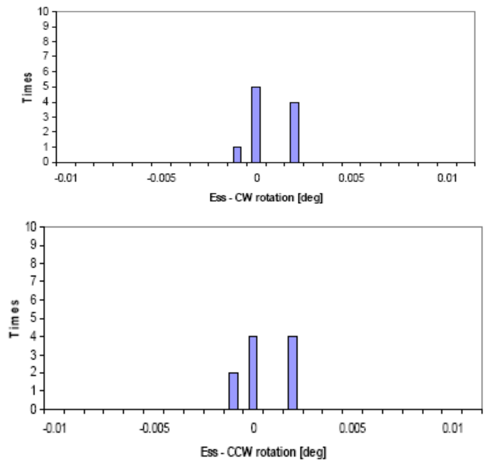


Fig. 8. Positioning of the PSO-NDW PID controller (load 0.25 N.m)

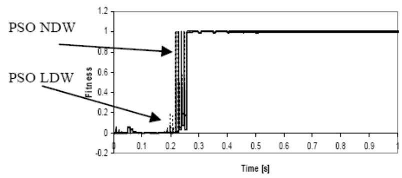


Fig. 9. Convergence of fitness

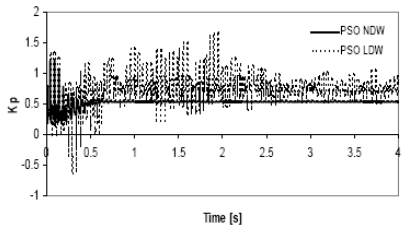


Fig. 10. Convergence of Kp

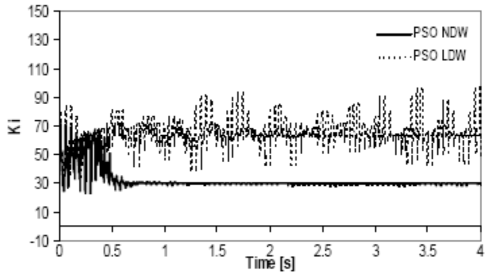


Fig. 11. Convergence of Ki

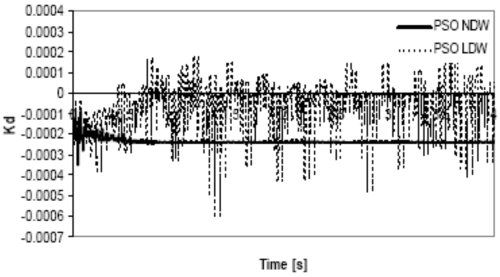


Fig. 12. Convergence of Kd

V. Conclusions

In this paper, a modified PSO with nonlinear decreasing inertia weight for positioning control of USM is proposed. It is shown experimentally and graphically that local search ability of algorithm, convergence speed, stability and accuracy have been significantly improved.

VI. Acknowledgements

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