Modern Optimization-Based Controller Design for Speed Control in Flyback Converter-Driven DC Servomotor Drive

S. Subiramoniyan and S. Joseph Jawhar

Abstract Implementation of proportional-integral (PI) controller for speed control of direct current (DC) servomotor drive is an emerging trend in recent years. PI controller is a simple effective method and it needs tuning of the control parameters to improve the performance of the converters. The local treatment of the parameter tuning is no longer possible and it is thus essential to design a suitable topology for flyback converters that has to reduce the overshoot and settling time. Here an advanced PI control algorithm has been framed that optimize the PI controller parameters using ant colony optimization and cuckoo search algorithm. The PI control algorithm is implemented in FPGA to drive the DC servomotor drive. Framing the conventional system with optimized PI control algorithm shows significant reduction of overshoot and settling time and works effectively for DC servomotor drive.

Keywords ACO · Cuckoo search · ISE · Objective function · Overshoot time · Settling time

1 Introduction

Nowadays, DC servomotor is widely used in industries due to its wide range of speed control even if its maintenance cost is higher than the other motors like induction motor, etc. [1]. The speed control of DC motor is very interesting from research point of view and hence several methods are proposed in this field [2].

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Flyback converters [3] have been widely used in DC servomotor because of their relative simplicity and their excellent performance for multi-output applications [4]. They can save cost and volume compared with the other converters, especially in low power applications.

One of the most important factors in the power efficiency of flyback converters is the isolation transformer (coupled inductor) [5, 6]. Even though power losses in the main switch and diode are worth considering, that of the transformer is one of the dominant factors in terms of efficiency for flyback converters [7]. This can be controlled by an optimized controller that has to replace manual tuning of parameters. Adaptive control techniques have been proposed by researchers assuming linearized system models. These controllers have the ability to cope with small changes in system parameters such as valve flow coefficients, the fluid bulk modulus, and variable loading [8].

The proportional-integral (PI) controllers are very stable and have fast control due to the enhanced properties of the current-mode circuits used in the design [9, 10]. Regarding the simplicity and the nature of the PI controller, they are highly suitable for the immense use in a variety of different control systems [11].

Considering that the PI controller parameters have great impact on the responses of the complete system, tuning of the parameters is a significant task [12, 13].

Many random search methods, such as genetic algorithm (GA) have recently received much interest for achieving high efficiency and searching global optimal solution in space [14, 15]. Tuning of PID parameters is yet difficult because of variable system parameters. PSO is an efficient technique, drawn for optimization of PI parameters in recent years [16].

Syed and Ying [17] developed a fuzzy control approach with minimal rules to intelligently control engine power and speed behavior in a power option toward achieving these goals.

Abidin et al. [18] developed a decentralized PI tuning method using PSO algorithm. Utomo [19] proposed voltage tracking of a dc–dc flyback converter using neural network control. Bagis [20] proposed determination of the PID controller parameters by modified genetic algorithm.

Awouda and Mamat [21] carried a work on optimizing PID tuning parameters using gray prediction algorithm. Mahdi [22] proposed an optimization of PID controller parameters based on genetic algorithm for nonlinear electromechanical actuator.

The existing system designed with fuzzy technique requires large constraints and variables. The PSO optimization technique struck in selection of a single solution. The limitations of genetic algorithm are its slow convergence and lagging in rank-based fitness function. Also no such methods are available to effectively reduce the overshoot and settling time by optimizing the K_p and K_i values.

To overcome the above drawbacks here a new PI control algorithm has been introduced that makes use of the fine-tuned values of K_p and K_i optimized by ant colony optimization (ACO) and cuckoo search in maintaining low overshoot as well as settling time with improved performance.

1.1 Traditional PI Controller

Proportional-integral (PI) controllers have been used for industrial purpose due to their simplicity, easy designing method, low cost, and effectiveness. Due to presence of nonlinearity in the system, conventional PI controller is not very efficient.

For effective working of DC servomotor drive, the PI controller parameters namely K_p and K_i have to be tuned to achieve reduction in overshoot and settling time. The flyback converter has to be modulated with the PI controller that has to use an optimization algorithm for optimizing the values for K_p and K_i.

1.2 Modeling the Transformer Equivalent Circuit

The basic design of transformer equivalent circuit to be implemented for flyback converter is shown in Fig. 1.

1.3 Tuning of PI Controller Parameters

It is desired to select optimized values for K_p and K_i that reduce the overshoot and settling time. The objective function can be framed as minimization of ISE to eliminate small errors and the transfer function can be formulated as

$$F_1(x) = \int_0^{\infty} |e(t)|^2 \mathrm{d}t \tag{1}$$

with respect to the constraints $0 <= K_p <= 5, 0 <= K_i <= 5$ and the fitness function can be evaluated as

$$Ft_i = \frac{1}{Fi(x)} \tag{2}$$

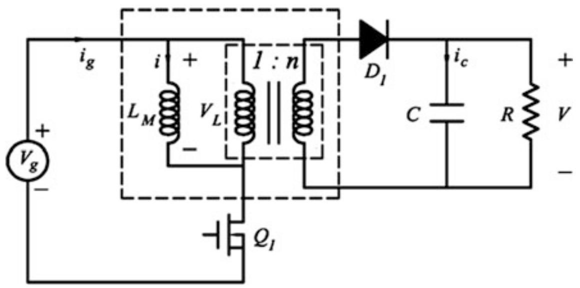

Fig. 1 Design of transformer equivalent circuit

2 Ant Colony Optimization

The algorithm is formulated for PI controller tuning by setting the objective functions as minimization of ISE. From the initial solution set, ACO searches for the optimized one in each step and stops once it grabs the optimized solution. This is clearly explained in the following Algorithm 1.

Algorithm 1 Ant colony optimization for PI parameters

♦*Initialization:*

a. Set initial parameters that are system: function

b. Set initial pheromone trails value CT.

c. Each ant is individually placed on initial state with empty memory.

♦*While termination conditions not meet do*

a. Construct Ant Solution ST(x):

Each ant constructs a path by successively applying the transition function the probability of moving from state to state depend on: as the attractiveness of the move, and the trail level of the move.

b. Apply Local Search

c. Best Tour check:

If there is an improvement, update it in ST(x).

d. Update CT:

- Evaporate bad solution from ST(x).

- For each ant perform the "ant-cycle" pheromone update.

- Reinforce the best tour with a set number of "elitist ants" performing the "ant-cycle"

d. Create a new population based on (2)

End While

3 Cuckoo Search

Algorithm 2 presents the working procedure of cuckoo search for PI controller.

Algorithm 2 Pseudo code of the cuckoo search (CS)

begin
Objective function f(x), x = (x1, ..., xd)T
Generate initial population of n host nests x_i *(i = 1, 2, ..., n)*
while (t <MaxGeneration) or (stop criterion)
Get a cuckoo randomly by L´evy flights evaluate its
quality/fitness Fi
Choose a nest among n (say, j) randomly
if (Fi > Fj),
replace j by the new solution;
end
A fraction (pa) of worse nests
are abandoned and new ones are built;
Keep the best solutions
(or nests with quality solutions);
Rank the solutions and find the current best
end while
Postprocess results and visualization
end

4 Simulation Model

Figure 2 shows the simulation diagram of the system using MATLAB SIMULINK.

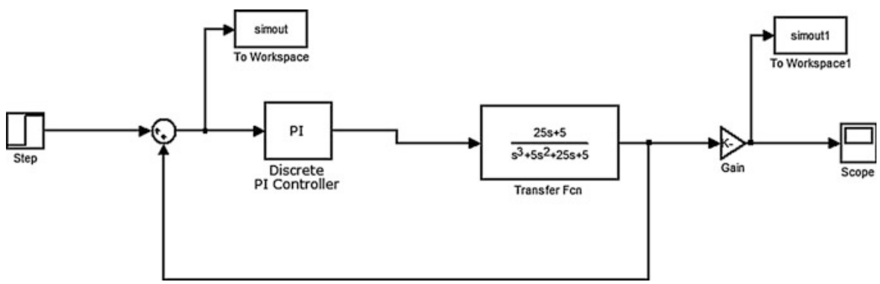

Fig. 2 Software implementation of the system

4.1 Simulation Results

4.1.1 Flyback Converter Subjected to an Input Voltage Variation

The optimized algorithm is implemented in MATLAB with K_p = 1.29 and K_i = 9.63. The input voltage is varied from 12 to 25 volts both in an increasing and decreasing manner. The set point of the output voltage is 12 V. The effectiveness of the controller with respect to overshoot and settling time is studied.

Figures 3 and 4 show the output voltage plotted against time. It is found that the controller acts very effectively and it maintains the constant output voltage irrespective of the input voltage variation.

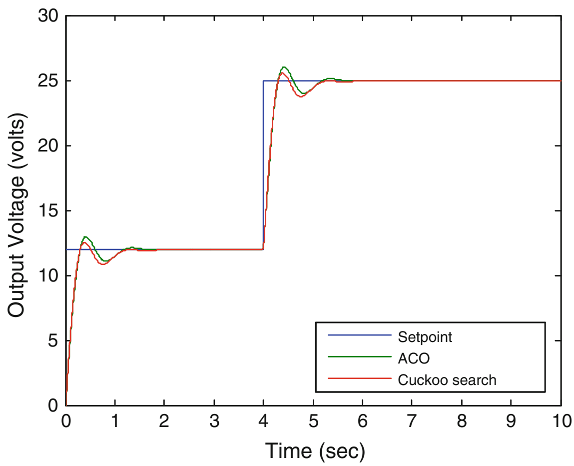

Fig. 3 Performance evaluation of ACO and cuckoo search in case of increased input voltage variation

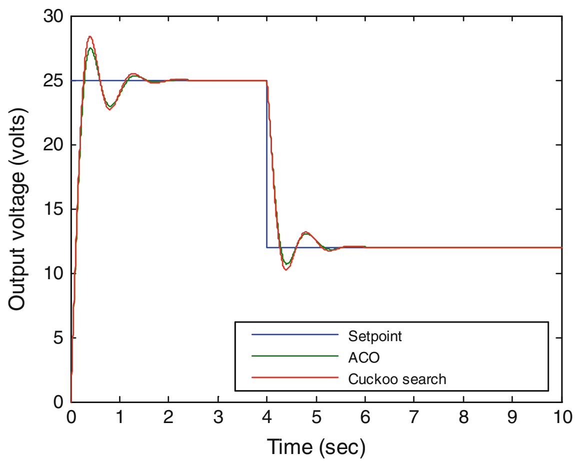

Fig. 4 Performance evaluation of ACO and cuckoo search in case of decreased input voltage variation

4.1.2 Flyback Converter Subjected to Load Variations

The flyback converter is subjected to a variation of load from 3 to 6 Ω both in an increasing and decreasing manner. The effectiveness of the controller with respect to the overshoot and settling time at the time of load variations is studied.

Figures 5 and 6 show the output voltage plotted against time. It is found that the controller acts very effectively and it maintains the constant output voltage irrespective of a variation of load from 3 to 6 Ω.

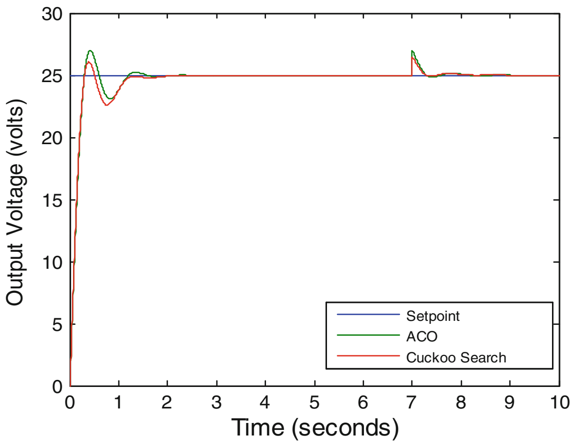

Fig. 5 Performance evaluation of ACO and cuckoo search in case of increased load variation

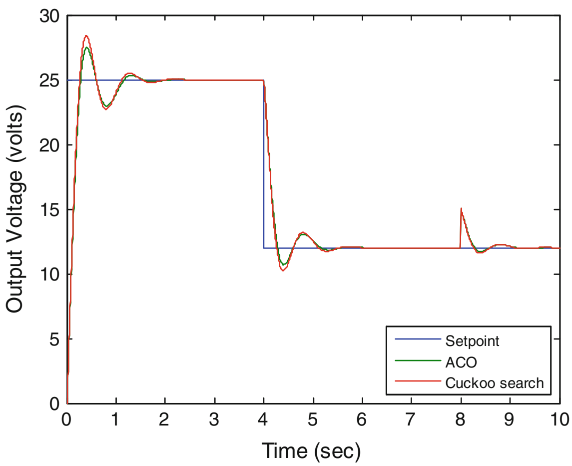

Fig. 6 Performance evaluation of ACO and cuckoo search in case of decreased load variation

4.1.3 Performance Comparison

Comparison has been made between the performance of ACO and cuckoo search and is presented in Table 1.

From Table 1, it can be inferred that the performance of cuckoo search is better than ACO in terms of overshoot and settling time.

5 Hardware Implementation

The components as well as the circuits used in the design of FPGA-based PI controller to drive DC servomotor drive is shown in Fig. 7.

5.1 Hardware Result Analysis

Experimental investigations have been performed for the various input voltages and load conditions to the flyback converter with PI control algorithm implemented using FPGA.

Table 1 Comparison of ACO and cuckoo search

Parameter	ACO		Cuckoo search	
	Input voltage variation	Load variation	Input voltage variation	Load variation
Overshoot (V)	1	0.9	0.5	0.4
Settling time (s)	1	3	0.8	2.8

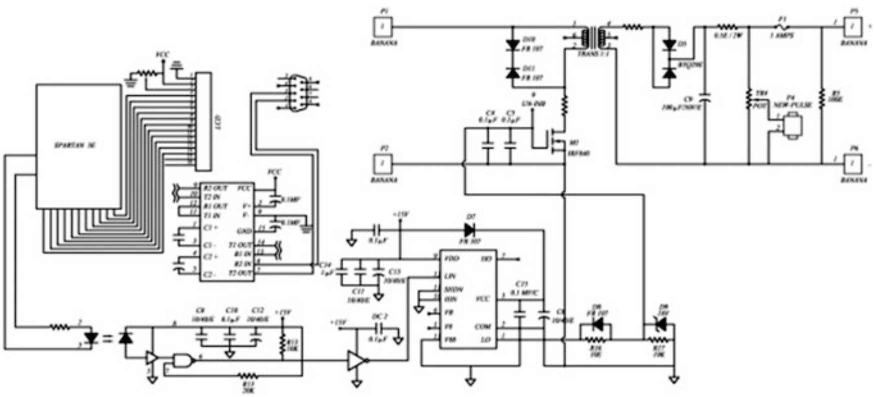

Fig. 7 Hardware implementation of the system

5.2 Flyback Converter Subjected to an Input Voltage Variation

The PI control algorithm is implemented in FPGA-based PI controller to drive the actual circuit of the flyback converter with the tuned values of K_p and K_i obtained by ACO and cuckoo search. The input voltage is varied from 1 to 4 V. The set point of the output voltage is 6 V. The effectiveness of the controller with respect to overshoot and settling time is studied.

Figure 8 shows the output voltage plotted with respect to time. It is found that the controller acts very effectively and maintains the constant output voltage of 6 V irrespective of the input voltage variation. The peak overshoot voltage at the time of input voltage variation is 60 % and the settling time is 90 ms.

Figure 9 shows the variation of output voltage versus time. It is found that the controller acts very effectively and it maintains the constant output voltage of 6 V, irrespective of a variation of input voltage from 2 to 4.2 V. The peak overshoot voltage at the time of input voltage variation is 10 % and the settling time is 75 ms.

5.3 Flyback Converter Subjected to Load Variations

The flyback converter is subjected to a variation of load from 3 to 6 Ω both in an increasing and decreasing manner. The effectiveness of the controller with respect to the overshoot and settling time at the time of load variations is studied.

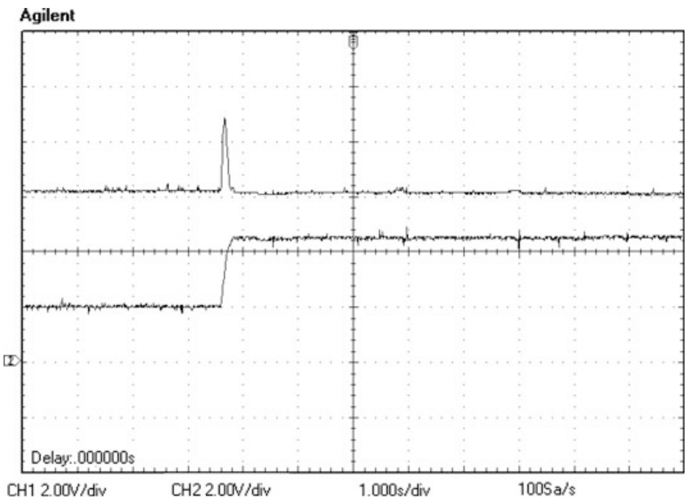

Fig. 8 Input voltage variation with K_p and K_i obtained from ACO

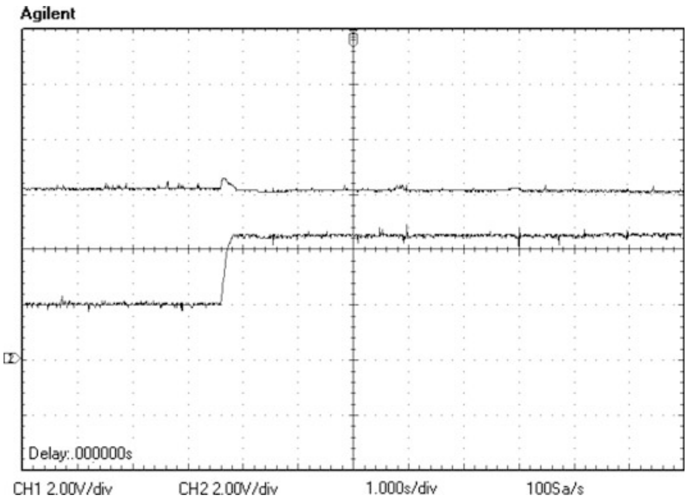

Fig. 9 Input voltage variation with K_p and K_i values obtained from cuckoo search

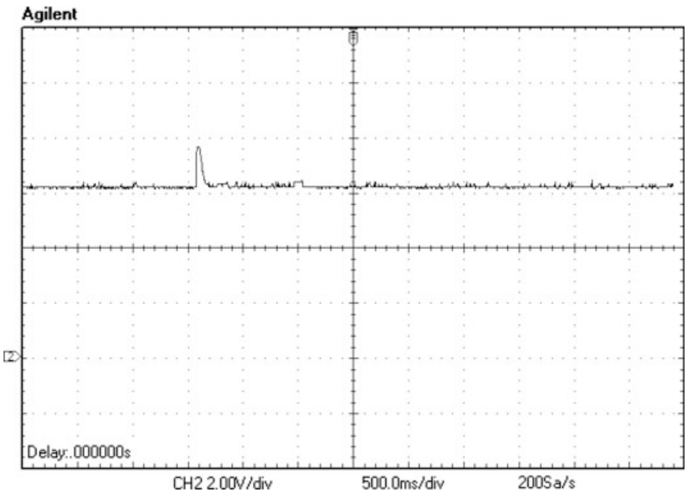

Fig. 10 Input load variation with K_p and K_i obtained from ACO

Figure 10 shows the variation of output voltage versus time. It is found that the controller acts very effectively and it maintains the constant output voltage of 6 V, irrespective of variation of the load from 3 to 6 Ω. The peak overshoot at the time of load variation is 20 % and the settling time is 150 ms.

Figure 11 shows the output voltage versus time. It is found that the controller acts very effectively and it maintains the constant output voltage of 6 V irrespective

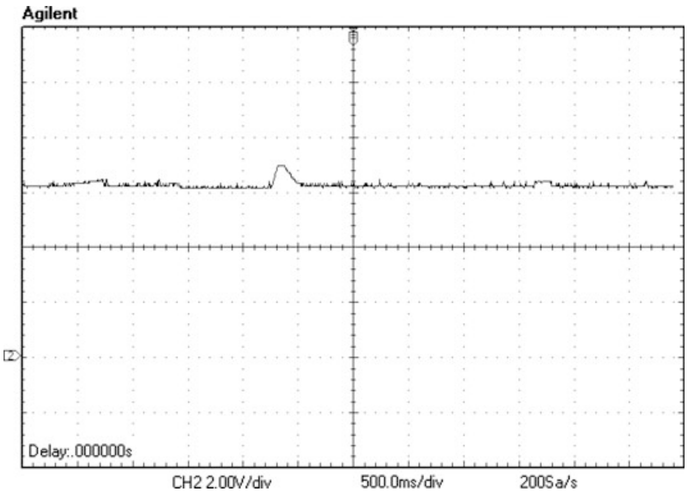

Fig. 11 Input load variation with K_p and K_i obtained from cuckoo search

of the variation of load from 3 to 6 Ω. The peak over shoot at the time of load variation is 40 % and the settling time is 100 ms.

5.4 Performance Evaluation

From the hardware result analysis, the performance of PI control algorithm implemented in FPGA for minimization of overshoot and settling time with different optimized PI controller parameter values obtained from ACO and cuckoo search are discussed in Table 2.

By implementing the above topology the performance of flyback converter increased and it works effectively in electrical equipments.

Table 2 Performance evaluation of PI control algorithm

Set point = 6 V				
Parameter	**ACO**		Cuckoo search	
	Input voltage variation	Input load variation	Input voltage variation	Input load variation
Overshoot (V)	60 %	20 %	10 %	40 %
Settling time (ms)	90	150	40	100

6 Conclusion

In this paper, an advanced PI control algorithm implemented in FPGA-based PI controller for tuning of PI controller parameter using ACO and cuckoo search has been presented. The optimized K_p and K_i values obtained by these techniques are fed as input to the PI control algorithm that works well in minimizing the overshoot as well as the settling time in the output response. The experimental results showed that when compared to the traditional PI controller, implementing the system using PI control algorithm works effectively in reduction of overshoot and settling time. The hardware result also shows that cuckoo search yields better than ACO in overshoot and settling time reduction.

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