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Optimal Design of Controller for Antenna Control Using ACO Approach

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ABSTRACT

In this paper the application of Ant Colony Optimization Algorithm (ACO) to the design of a PID controller for position control of parabolic dish antenna system is presented. Parabolic dish antennas are used for line-of-sight communications, and are sometimes actuated by servomotors. Such arrangements minimize human errors and energy, are quick and easier for repositioning to another direction or original position of the antenna when displaced by disturbances such as wind, gust, bearing and aerodynamic frictions. A PID controller was designed for the system, using the Ziegler-Nichols method (ZN Controller); the controller was then redesigned using Ant Colony Optimization (ACO) Algorithm (ACO Controller). The closed loop system without controller, with ZN Controller and ACO Controller were simulated using SIMULINK/MATLAB 2010a software. The simulation results revealed that with the ZN controller the rise time of system was improved by 210%, the peak time by 179%. And with the ACO controller, the rise time was improved by 243%, the peak time by 663% and the settling time by 41%. The rise time, peak time and settling times were best with the ACO controller; therefore all control schemes performed well but the ACO Controller outperformed the rest.

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INTRODUCTION

Parabolic dish antennas have high gain and directivity at very high frequencies, these properties made such systems suitable for use in satellite communications, radar systems, radio telescopes and so on (Natalia, 2010) .They operate in point-to-point mode, therefore the transmitting and receiving antenna have to be aligned or be facing each other. Servomotors can be used to position the parabolic dish antennas, such that if the system is perturbed by disturbances most especially wind and gust it can be repositioned with relative ease. It can be made automatic most especially in critical sectors such as banks, mass media, airports etc.

The PID controller has three parameters; the proportional gain K_p, the integral gain K_i and the derivative gain K_d. The performance of the controller depends on the relative magnitudes of these three parameters. Determination of the magnitudes of the parameters is called tuning of the PID controller. The Ziegler-Nichols tuning rule is one of the techniques used for tuning the PID controllers (Stanislaw, 2008).

In the work of Atef (2009) a Proportional Integral and Derivative PID Controller for a brushless DC motor using Ziegler-Nichols tuning rules was designed. The result of his research showed that the system had a faster response with small overshoot and zero steady state error. Neenu and Poongodi (2009), in their paper designed a position controller for a DC motor by selection of a PID parameters using genetic algorithm. The model of the DC motor was considered as a third order system. The paper compares two methods of tuning the parameters of a PID controller. One of the controllers was designed by the genetic algorithm; the second was designed by the Ziegler-Nichols method. It was found that the proposed PID parameters adjustment by the genetic algorithm was better than the Ziegler–Nichols method. They also concluded that the proposed method could be applied to the higher order system also.

Boumediène *et al.*, (2009) proposed an intelligent controller of DC Motor drive was designed using particle swarm optimization (PSO)

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method for formative optimal proportional-integral-derivative (PID) controller tuning parameters. The proposed approach have superior feature, including easy implementation, stable convergence characteristics and very good computational performances efficiency. The DC Motor Scheduling PID-PSO controller was modeled in MATLAB environment. It was observed that comparing with fuzzy logic controller using PSO intelligent algorithms, the planned method was more proficient in improving the speed loop response stability, the steady state error was reduced, the rising time was perfected and the disturbances do not affect the performances of driving motor with no overtaking.

Problem Formulation:

The design of the PID controller using ACO can be considered as optimization problem of the cost function J (w) stated as follows:

$$MinJ(w) \quad w \in W \tag{1}$$

$$J(w) = \frac{1}{N}\sum_{k=1}^{N}\left(\theta_i(k) - \theta_0(k)\right)^2 \tag{2}$$

Where; w = $\left[K_p, K_{i,}, K_d\right]^T$ is the PID controller parameter vector and W is the entire search space.

The aim is to minimize the cost function J (w) by adjusting w. The cost function can be expressed as the time-averaged cost function defined in equation (2);

Where $\theta_i(k)$ and $\theta_0(k)$ are the input or desired and output or actual responses of the system respectively, and N is the number of samples used for the calculation of the cost function.

Concept of Ant Colony Optimization (ACO):

The ACO is one of the most successful general purpose optimization technique among the methods developed through ant behaviors and it takes inspiration from the foraging behavior of some species of ant. The ACO is a swarm intelligence approach to solving problems. Swarm intelligence techniques are usually inspired base on the behavior of insects or other animals. Ants deposit pheromone on the ground in order to mark some favourable path to guide other members of the colony; this was proved through experiments by Deneubourg *et al* in 1990 (Marco, 2006). The ACO has the advantage of keeping the best result after iteration (Maniezzo *et al*.,2002).

As mentioned previously literature revealed that there are variants of ACO algorithm. The Ant System (AS) was utilized in this research was which the first ACO algorithm ever proposed (Marco, 2006). The pheromone values are updated by all ants that have built a solution in the iteration associated with nodes m and n.

The pheromone $\tau_{m,n}$ is then updated as;

$$\tau_{m,n} = (1-\rho)\tau_{m,n} + \Delta\tau_{m,n} \quad \ldots(3)$$

Where;

$\tau_{m,n}$ is the amount of pheromone on a given edge *m,n*

ρ is the rate of pheromone evaporation

and $\Delta\tau_{m,n}$ is the amount of pheromone deposited, typically given by

$$\Delta\tau^{g}{}_{m,n} = [\ \frac{1}{d_g}\ \text{if ant g travels on edge m,n, and 0 otherwise }] \quad \ldots(4)$$

Where d_g is the cost of the gth ant's tour (typically length or distance).

For the edge selection; an ant will move from node *m* to node *n* with probability $P_{m,n}$;

$$P_{m,n} = \frac{\left(\tau^{\alpha}{}_{m,n}\right)\left(\eta^{\beta}{}_{m,n}\right)}{\sum\left(\tau^{\alpha}{}_{m,n}\right)\left(\eta^{\beta}{}_{m,n}\right)} \tag{5}$$

Where;

$\tau_{m,n}$ is the amount of pheromone on edge *m,n*

α is a parameter to control the influence of $\tau_{m,n}$

$\eta_{m,n}$is the desirability of edge *m,n* (a priori knowledge, typically 1 / $d_{m,n}$, where d is the distance between node *m* to node *n*)

β is a parameter to control the influence of $\eta_{m,n.}$

Implementation of the ACO Based Position Controller:

The PID controller was designed for the system using the Ziegler -Nichols method (ZN controller) which is a classical method of tuning a PID controller. The controller was then redesigned using Ant Colony Optimisation (ACO) Algorithm; ACO based controller (ACO controller). The ACO controller was tuned using a program written in MATLAB codes. The responses of the system without any controller, with NZ controller and ACO controller were simulated using SIMULINK/MATLAB 2010a software. The performances of the system without controller, with NZ controller and with ACO controller were then compared.

Fig. 1 is a unity feedback system with Proportional, Integral and Derivative (PID) controller. The input to the closed loop system is θ_i and θ_0 is the output, which the position of the parabolic dish antenna system which is the plant. The parabolic dish antenna system model used by Ahmed *et al*. (2012) was adopted which is given by:

$$\frac{136.8}{s^3 + 15s^2 + 50s} \tag{6}$$

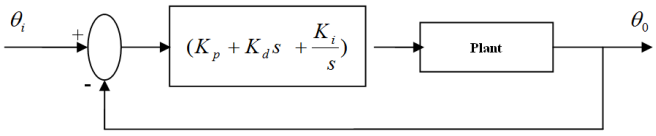

Fig. 1: A Unity Feedback System with PID Controller .

Consider the input-output relationship of the system with the PID controller as shown in Fig. 1, the system transfer function becomes;

$$\frac{\theta_0}{\theta_i} = \frac{136.8K_d s^2 + 136.8K_p s + 136.8K_i}{s^4 + 15s^3 + (50 + 136.8K_d)s^2 + 136.8K_p s + 136.8K_i} \quad (7)$$

Simulation Results and Discussion:

The results were simulated using SIMULINK/MATLAB 2010a. The parameters of the PID controllers were as shown in table 1. Figure 1 shows the unit step responses of the system without controller, with ZN Controller and with ACO Controller. From the graphs without the controller; the rise time was 0.7900 seconds, the peak time was 1.1450 seconds, the maximum overshoot was 14.77% and the settling time was 2.4900 seconds. For the system with ZN controller, the rise time was 0.2550 seconds, the peak time was 0.4100 seconds, the maximum overshoot was 18.88% and settling time was 1.9300. And with the ACO controller; the rise time was 0.2300 seconds, the peak time was 0.1500 seconds, the maximum overshoot was 23.70% and the settling time was 1.7600. The results showed that the response had improved drastically with the ACO controllers. And they portray that the ACO controller gives the best response.

Fig. 2 shows the responses of system without the controller, with ZN Controller and with ACO Controller to a tracking signal. The signal in this case was the rectangular signal. The tracking response represents the ability of the system to track the input supplied to it, it is simply a scenario whereby the position or direction of the antenna is changed, so it shows the ability of the system to respond to the command given to it. Here also the response of the system with the ACO controller was most superior because its response follows the input signal more closely.

Figs. 3, 4 and 5 are graphs of the system without controller, with ZN Controller and with the ACO Controller respectively, for different positions of the antenna in 60^0, 40^0 and 20^0 steps. Therefore this portrays a situation whereby the antenna is position at those positions. It can be seen that from the plots that irrespective of the position the system it returns to steady state.

Figs. 6 and 7 are plots of the system when perturbed. The perturbation represents a situation whereby the antenna system is hit by disturbances which are mainly gust and wind. The system is perturbed in Fig. 6 when it is in transient state while the latter when it is at steady state. For all the controllers and both case perturbations the system reaches steady state, as it can been seen from the graphs the ACO Controller was the fastest to reach steady state, followed the ZN Controller and then without the controller. These show that all the controllers are robust.

Table 1: Optimal Controllers Parameter Settings.

PID Parameter	ZN Controller	ACO Controller
Proportional gain K_p	3.5156	3.9712
Integral gain K_i	3.1649	3.0014
Derivative gain K_d	0.7812	5.2543

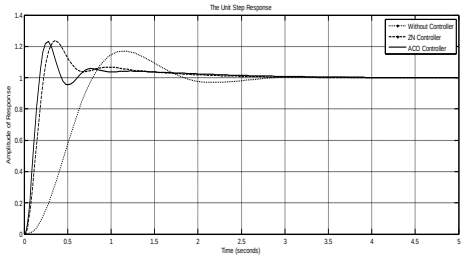

Fig. 2: Unit Step Response of the System.

Summary and Conclusion:

In this paper, a PID controller was successfully designed for the system based on the Ant Colony Optimization (ACO) Algorithm. The system was also successfully simulated and tested without controller, with ZN controller and with ACO controller using SIMULINK/MATLAB 2010a. The system performance with the ZN controller were improved in terms of the rise time by 210%, the peak time by 179% and the settling time 22%, while the maximum overshoot was worsen by 22%. And with the ACO controller, the rise time was improved by 243%, the

peak time by 663% and the settling time by 41%, while the maximum overshoot was worsen by 38%. It was observed that the ACO controller has better performance in terms of the rise time, peak time, maximum overshoot and settling times are superior with the controllers, with that of the ACO controller being the best with an acceptable overshoot (Katsuhiko, 2010). It performed best in signal tracking test, the system reaches steady state when positioned at different positions and all the controllers pass robustness test. Therefore, all control schemes performed well but the ACO Controller outperformed the rest. Therefore, a controller has been designed successfully using the Ant Colony Optimization algorithm for the closed loop operation of the parabolic dish system with better performance than without controller and using the Ziegler-Nichols method.

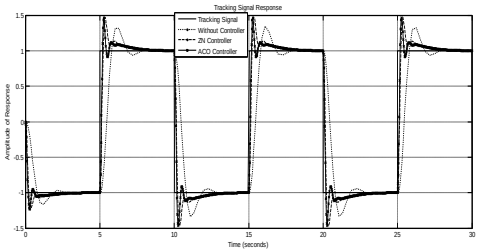

Fig. 3: Tracking Signal Response.

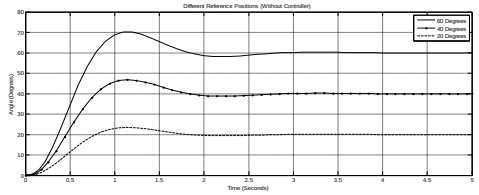

Fig. 4: Unit Step Response for Different Reference Positions without controller.

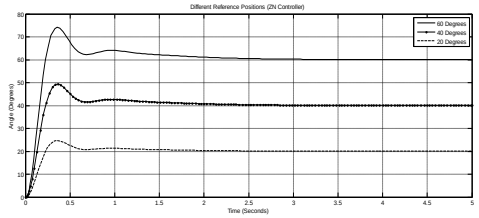

Fig. 5: Unit Step Response for Different Reference Positions with ZN Controller.

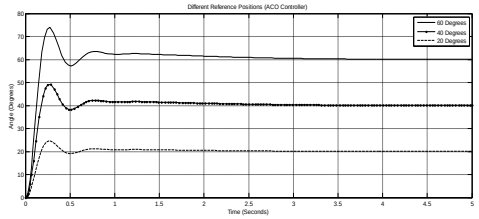

Fig. 6: Unit Step Response for Different Reference Positions with ACO controller.

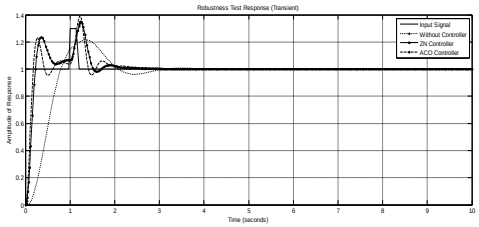

Fig. 7: Response to Perturbation/Robustness Test (Transient State).

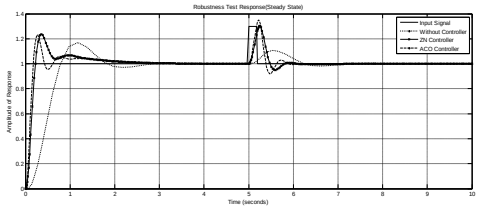

Fig. 8: Response to Perturbation/Robustness Test (Steady State).

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