Satellite Control System Tuned by Particle Swarm Optimization

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Abstract—**This paper aims to control of satellite position using the two-phase Hybrid Stepping Motor. it's used to receive satellite signal and must accurately track the satellite as it moves across the sky. This system applies the traditional Proportional Integral Derivative (PID) control, the fuzzy PID control methods Fuzzy Logic Control (FLC) and Fractional Order PID (FOPID)control. Firstly, the PID controller and FLC was designed by Ziegler-Nichols tuning method to obtain control parameters. secondly, the PID controller and FOPID controller was designed by Particle Swarm Optimization (PSO) tuning method to obtain control parameters. finally, the PID controller and FOPID controller was designed by Crazy PSO tuning method to obtain control parameters. The system was simulated by MATLAB, SIMULINK and compared be control methods.**

I. Introduction

In the satellite communication [1], received systems are mounted on the movable device such as ship, train, car or airplane. In order to receive continuous signals, antenna system must be steered in both the azimuth and elevation angle to track a satellite. Tracking capabilities depend on the beam width of the antennas and the speed of mobile motions. In the fact that, antennas should track the satellite only in the azimuth directions because the elevation angles to the satellite are almost constant. Here getting better response of antenna position for satellite using malt controller without overshoot or steady state error and less rise time, setting time and peak time.

The paper is covering the following: Section II presents system analysis and transfer function. Section III displays the control techniques used. Section IV review the optimization techniques. Section V illustrates simulation results. Section VI, conclude the whole work. Finally, updated list of reference is given.

II. System Analysis and Transfer Function

In this paper, control of antenna tracking position used to receive satellite signal and must accurately track the satellite as it moves across the sky. antenna system must be steered in both the azimuth angle to track a satellite [2], [3], [4], pressing azimuth up and down keys, to drive a motor system. Tracking capabilities depend on the beam width of the antennas and the speed of motor move, in control terminology getting better response of antenna controller without overshoot or steady state error and less rise time, setting time and peak time.

There are two types of satellite searching methods: Mechanical and electrical. In the mechanical method [5], both elevation and azimuth angles of transmitter are controlled drive a motor system. For electronic method, searching system is done automatically by rotating the antenna according was calculated by software program.

From Fig. 1, the transfer function $G(s)$ of the open-loop system of the two-phase Hybrid Stepping Motor is as follows [6], [7].

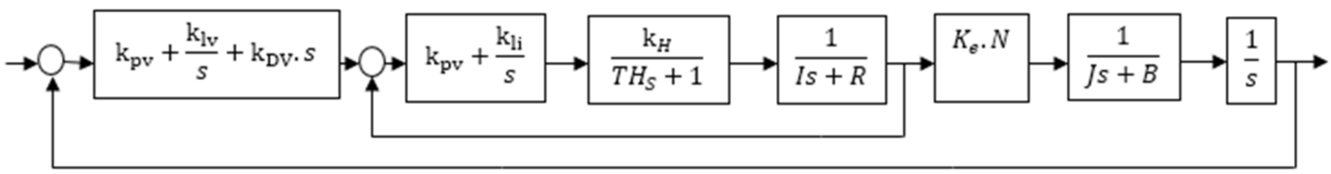

Fig. 1. The Model of the Two-Phase Hybrid Stepping Motor

Finding the transfer function of overall system after PID control:

In order to calculate the control parameters K_P, K_I, K_D These parameters affect the setting time, overshoot, steady-state error of the system. We have to determine transfer function of the control object. Parameters of the DC motor are shown in Table I.

TABLE I. PARAMETERS OF THE DC MOTOR USED WITH SATELLITE

Parameter	Description	Value
R	Armature Resistant	2.96 Ω
L	Armature Inductance	150 mH
J	Moment of Inertia	42.3e-6 Kg.m^2
B	Viscous- Friction Coefficient	48.6e-6 Nms
Ke	Torque Constant	13.5e-3 N.m/A
K_b	Back EMV Constant	13.5e-3 V-sec/rad
N	Number of Teeth	180
β	Beta Gain	1
K_H		15
K_{PV}	Voltage Gain	500
K_{IV}	Voltage Integrator Parameter	0
K_{DV}	Voltage Deferential Parameter	100
K_{Ii}	Current Integrator Parameter	500
K_{Pi}	Current Gain	5

The open-loop transfer function $G(S)$ of two-phase Hybrid Stepping Motor is as follows:

$$G(S) = \frac{A(S)}{B1(S) + B2(S)} \tag{1}$$

Where

$$A(S) = \left(K_{PV} + \frac{K_{IV}}{S} + K_{DV}\, S\right)(K_{Pi}\, S + \ K_{Ii})\, K_e\, N\, K_H$$

$$B1(s) = \ JLS^4 + (JR + \beta L + JK_{Pi}\, K_H)S^3$$

$$B2(s) = \ \beta\, K_{Pi}\, K_H\, S + \ (J\, K_{Pi}\, K_H \ + \ \beta R + \beta\, K_{Pi}\, K_H)\, S^2$$

Transfer function of the control object are calculated by the following formula:

$$G\,(S) \ = \frac{13500}{6.345\, S^2 + 132.498\, S + 326.106} \tag{2}$$

III. CONTROL TECHNIQUES

This system Proportional, Integral, and Derivative (PID), Fuzzy and Fractional Order PID (FOPID) controllers applies on multiple controller methods.

A. Proportional, Integral, and Derivative (PID) Controllers

PID were widely used in industrial control because simple structure, simple design, and low-cost, implementation have made the classical PID controller still the most popular industrial controller [8], [9]. it is the sum of three components: proportional, integral and derivative. PID parameter are K_P, K_I, K_D. Transfer function of the PID controller as illustrated in [10]:

$$G_{PID}\,(s) \ = \frac{U(s)}{E(s)} = K_P \ + K_I\,\left(\frac{1}{s}\right) + K_D\, s \tag{3}$$

They are many methods to tuning parameter of PID controller like hand tune, Ziegler-Nichols tuning, Particle Swarm Optimization (PSO) tune, Artificial Neural Networks (ANN) tune and fuzzy logic, the most popular method is the Ziegler – Nichols (Z-N). In this work PID tuned by Z-N, PSO, and Crazy PSO.

B. Fuzzy Logic Controller (FLC)

FLC is used in many applications such as camera, microwave, and medical industrial. fuzzy control always employs a set of rules than complex mathematical expressions those rules designed by Mamdani throughout the plant mathematical model. the used method is IF_ Then type. Inputs of fuzzy logic are error (e) and derivative of error (Δe) the outputs are controller parameters K_P, K_I, K_D the structure of fuzzy PID is two inputs and three outputs. To getting better response of antenna position interface in malt controller by anther controller.

Fuzzy PID Controller FLC will perform optimizing control parameters of PID To design FLC using 'Mamdani' model with two inputs(error and derivative of error) and three outputs (K_P, K_I, K_D) The member ship of function input and output used triangular shapes, the rule base of parameters using the MAX MIN (AND OR) inference in operations [11-14].

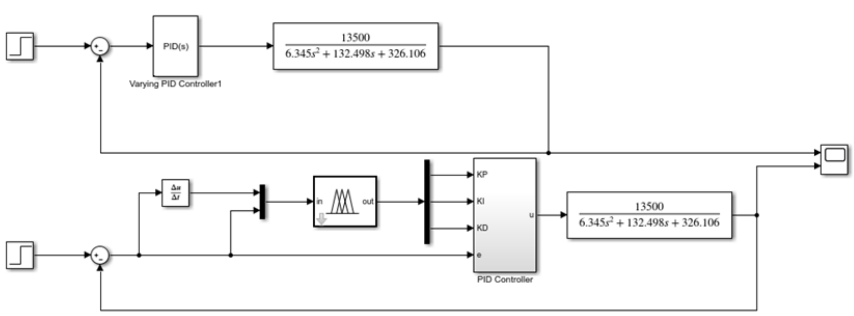

Fig. 2. Simulink diagram for Fuzzy PID controller

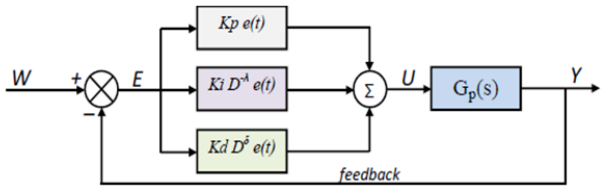

Fig. 3. Generic closed loop control system with the FOPID

C. Fractional Order PID (FOPID)

The intelligent optimization method. FOPID is expansion of convention PID controller based on fractional calculus [15]. The FOPID controller at first time was proposed by Podlubny in 1999 [16]. In FOPID controller beside the proportional, integral and derivative parameters K_P, K_I, K_D it has two additional parameters the order of fractional integration λ and the order of fractional derivative μ. FOPID Equation [17], [18] is shown as follows:

$$G_{FOPID}\ (s) = K_P\ + K_I\ s^{-\lambda} +\ K_D\ s^{\mu} \qquad (4)$$

The λ and μ are rang terms between (0-2) with excluding [0, 1, 2].

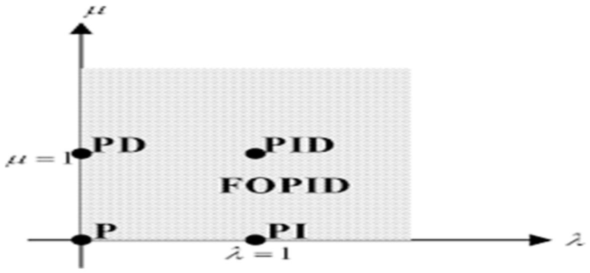

Fig. 4. Generalization of FOPID controller

IV. OPTIMIZATION TECHNIQUES

To getting better response of antenna position interface in malt controller by anther controller.

A. Particle Swarm Optimization (PSO)

PSO is an optimization method based on stochastic technique that is developed by Dr. Eberhart and Dr. Kennedy in 1995 [19-22]. In PSO the particle is same as bird in swarm; it has position, velocity, and distance from optimal solution. The condition of each particle is changing according to three principles:

a) To keep inertia of particles.
b) To change the condition according to most, optimize position of particle [$Pbest$].
c) To change the condition according to most, optimize position of swarm [g$best$].

The first two steps are fairly trivial. Fitness evaluation is conducted by supplying the candidate solution to the objective function. Individual and global best fitness and positions are updated by comparing the newly evaluated fitness against the previous individual and global best fitness and replacing the best fitness and positions as necessary. The fitness function is evaluated as shown in equation (5).

$$f(S) = \sum (\omega_1 \times E) + (\omega_2 \times \%OS + \omega_3 \times T_S) \qquad (5)$$

Where

- E: Steady state error
- OS: Overshoot percentage
- T_S: Settling time
- $\omega_1 = 0.3$, $\omega_2 = 0.5$, and $\omega_3 = 0.2$
- $0.1 < \omega_1, \omega_2, \omega_3 \leq 0.5$

The control equation [13]:

$$V_{id}^{k+1} = M.V_{id}^{k} + C1.rand_1[Pbest_{id} - xid_k] + C2.rand_2[gbest_{id} - X_{id}^{k}] \qquad (6)$$

$$X_{id}^{k+1} = X_{id}^{k} + V_{id}^{k+1} \qquad (7)$$

Where $i = 1,2,3,\ldots,N$ where N is a number of particles in swarm, $d = 1,2,3,\ldots.,D$; where D is a number of dimensions of the particle (number of variables that optimize the fitness function), V and X are the velocity and position of particle respectively, rand is random number in range (0-1), $C1$ and $C2$ are regulating constants random number rang $(0-2)$, M is inertia weight constant.

This paper deals with optimization and design of an PID and FOPID controller tuned PSO.

Usually tuned of PID by Ziegler-Nichols but in this work [23], we tuned parameter of PID by PSO, PSO firstly produces initial swarm of particles in search space represented by matrix. Each particle represents a candidate solution for PID parameters where their values are set in the range of 0 to 100. For this 3-dimentional problem, position and velocity are represented by matrices with dimension of 3xSwarm size as $X = [K_P, K_I, K_D]$.

Since each FOPID controller has 5 parameters optimized with PSO. PSO algorithm searches all of the controller parameters in 5 dimensional spaces. The particle includes 5 elements assigning real values. The order of a particle is shown as follows $X = [K_P, K_I, K_D, \mu, \lambda]$.

B. Crazy Particle Swarm Optimization (CPSO)

CPSO the idea was randomizing the velocities of some of the particle referred to as crazy particles select by applying a certain probability. the probability of craziness ρ_{cr} is defined as a function of inertia weight [24]:

$$\rho cr = \omega_{min} - exp(-\frac{\omega^t}{\omega_{max}}) \qquad (8)$$

A large inertia weight factor is used during initial exploration and its value is gradually reduced as the search proceeds the concept of time-varying inertial weight is given by:

$$\omega = (\omega_{max} - \omega_{min}) \times \frac{(iter_{max} - iter)}{iter_{max}} + \omega_{min} \qquad (9)$$

Where

$\omega_{max} = 0.9$, $\omega_{min} = 0.4$

where $iter_{max}$ is the maximum number of iterations, to improve the convergence of PSO algorithm [25], a constriction factor is introduced. Then velocities of particles are randomized as per the following logic:

$$V_i(\mathrm{t}) = \begin{cases} rand(0;\ V\max) & \text{if } \rho cr \geq rand(0;\ 1) \\ \mathrm{Vi(t)} & \text{otherwise} \end{cases} \qquad (10)$$

Crazy PSO such as PSO technique to tuned PID and FOPID parameters but extension randomized velocities of particles.

V. Simulation Results

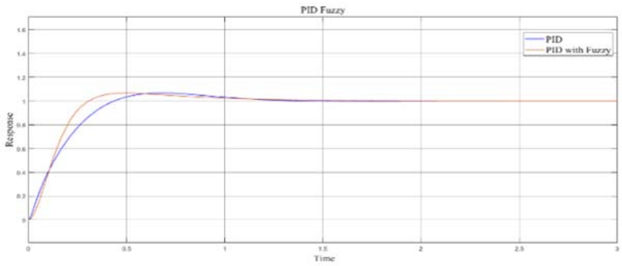

Fig. 5. The step response of the PID controller and the fuzzy PID controller

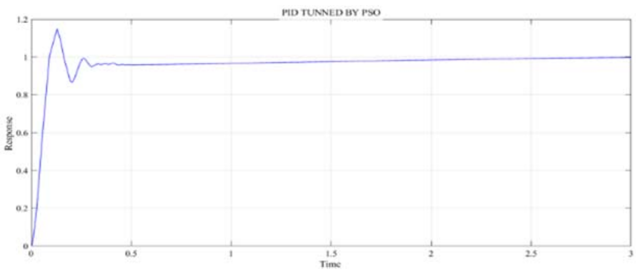

Fig. 6. The step response of the PID controller tuned by PSO

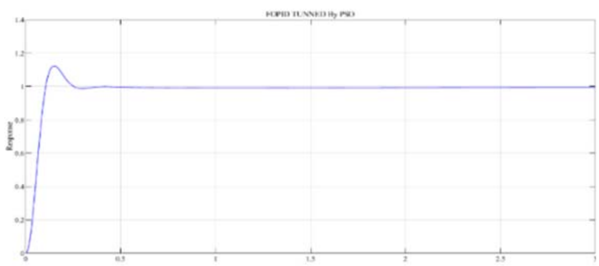

Fig. 7. The step response of the FOPID controller tuned by PSO

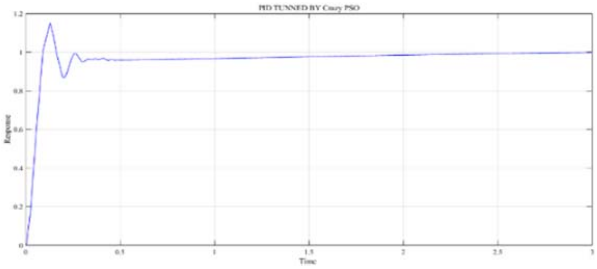

Fig. 8. The step response of the PID controller tuned by Crazy PSO

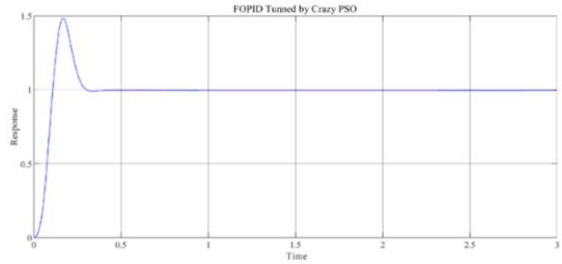

Fig. 9. The step response of the FOPID controller tuned by Crazy PSO

The simulated results of PID controller and fuzzy controller are shown in Fig. 5. From Fig. 5, the result shows that the response of PID controller is oscillatory and long setting time, which can damage the system. But the response of fuzzy PID controller is better than PID controller.

The simulation results for all controllers are listed in Table II.

TABLE II. The Result of All Controllers

Controller	Peak Time (Sec)	Settling Time (Sec)	Overshoot (%)
PID	0.52	2.0	9
PID FLC	0.39	1.82	7
PID Tuned by PSO	0.17	2.4	18
FOPID Tuned by PSO	0.14	0.51	15
PID Tuned by Crazy PSO	0.13	2.5	17
FOPID Tuned by Crazy PSO	0.15	0.36	50

VI. Conclusion

This paper presented the study, optimization, and performance evaluation of the satellite position. From response we can find that fuzzy PID method has better response in Overshoot characteristics of satellite position and Fractional order controllers are more flexible because they provide more parameters and perform in a better way than the integer order controllers. In this work an armature-controlled dc motor is considered. The transfer function of DC motor is being calculated for controlling its speed. There are PID types of tuning such as, PSO and Crazy PSO and more other type to improve the position of satellite response in this work we fund

PID controller tuned by PSO that batter than Ziegler-Nichols tuning.

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