PSO TUNED PID CONTROLLER FOR CONTROLLING CAMERA POSITION IN UAV USING 2-AXIS GIMBAL

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Abstract*— In this paper, camera gimbal control is designed which controls the on board camera position used in UAV for various applications such as target tracking, Surveillance, Aerial photography, autonomous navigation and so on. Traditional tracking systems are heavy and large to mount on small airframes. Gimbal with camera replaces traditional tracking systems and used to capture aerial photography without video noise and vibrations. So, the gimbal trajectory planning and its motion control are necessary. The controlling of camera gimbal is designed using different controlling techniques which respond quickly without excitation of damping flexibility. In order to develop the control, kinematics is derived using different robotics techniques. In this paper PID controller is designed to control camera position using gimbal mechanism. PID control is the popular controller used in industries for its effectiveness, simplicity of design and its feasibility. PID consists of three tuning parameters which can be tuned using different techniques. Manual tuning is not preferred since it is time consuming, tedious and leads to poor performance. Here, traditional tuning methods and evolutionary algorithms/bio-inspired algorithms are used to tune PID parameters. PSO is the evolutionary algorithm used because of its stable convergence, dynamic and static performance, good computational efficiency due to which system performance with minimum errors can be achieved. In this paper, performance of system with conventional PID and PSO tuned PID are compared and optimum solution is implemented

Keywords—UAV, Gimbal, PID controller,Particle Swarm Optimization(PSO), Ziegler Nichols, Cohen Coon, Kinematics

I. INTRODUCTION

Unmanned Aerial Vehicle (UAV) is a type of aerial vehicle which carries payload such as cameras and is governed by onboard flight control system. It uses servo motors, sensors, and transducers, communication equipments and so on to control the movement of aircraft and its payload [1]. UAVs have a wide range of applications in military, agriculture, surveillance, aerial photography and so on. They are used to perform missions such as surveillance, rescue operations during floods, earthquake disaster management etc. Many of these applications require live video recording, video transmission, tracking of moving objects and, surveillance for which image or video processing algorithms are necessary. The primary requirement for such missions is that the video be well stabilized and noise free. This can be achieved only when the camera control is compensated for the vibrations, vehicle attitude rate transients and gust. Controlling the camera position is realized using gimbal mechanism having different control algorithms.

Gimbal is a mechanical device which consists of two or more rings mounted on axes at right angles to each other. Objects in unstable environments are kept in stable position using gimbal device. They have wide range of applications in shipboard, aircraft environments and so on. Gimbals used in aerospace applications consider Euler angles to orient the payload on it. In the application of aerial photography the camera vibrates and shakes due to which image and video is not clearly captured. So, the camera position is controlled in order to make the camera movement is corrected and compensated to avoid video noise due to vibration. The control which keeps the camera position corrected for stabilized video is called Gimbal control [2]. The camera gimbal can be controlled manually by a camera operator or it can be automated using control algorithms. In manual control independent camera operator and a pilot to navigate UAV are required. Here camera operator compensates the camera gimbal for UAV body motion and communication between pilot and camera operator is compulsory. In this type of control, multiple skilled technicians are necessary and controlling becomes complicated. Whereas in automated systems tracking software can be used along with different control algorithms to control camera position without human in loop [3].

The goal of this paper is to design control algorithm for controlling the camera position used in UAV using 2-axis gimbal mechanism. The gimbal consists of servo motor, position encoder and inertial measurement unit (IMU). In this application camera is mounted on gimbal and gimbal is mounted under the aircraft frame at the front end [4]. This camera control device is used for monitoring, object tracking, to capture motion pictures, surveillance and so on, which uses different control algorithms such as adaptive control, PID control, Fuzzy logic control etc., as compensators. If the camera is left uncompensated, it loses the target path or object and fails to meet the objective. To control the camera position,

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gimbal actuators need to be controlled. The gimbal CAD model for which the controller is designed is shown in figure 1. [9]

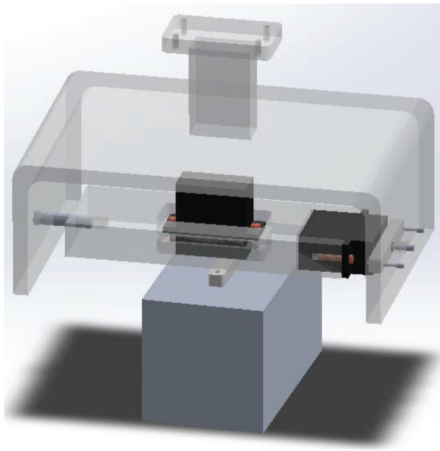

Fig 1: CAD model of 2-axis Gimbal with camera as payload

In this application pitch-yaw axis movement gimbal mechanism is used [5]. The movement of each axis is limited to +/- 90 deg.

II. MATHEMATICAL MODELLING

The mathematical modelling of gimbal is necessary for designing different control stratergies. In this application PID controller is designed [6].

A. *Gimbal Modelling*

The 2-axis gimbal consists of two joints which rotate by angles θ_1 and θ_2 along y-axis (pitch) and z-axis (yaw) respectively. The gimbal shown in figure 1 consists of 3 body frames (body (0) to body (2)). The link transformation diagram is shown in figure 2. Here, in figure 2 $X_0Y_0Z_0$, $X_1Y_1Z_1$ and $X_2Y_2Z_2$ represent as frames of body (0), body (1) and body (2) respectively.

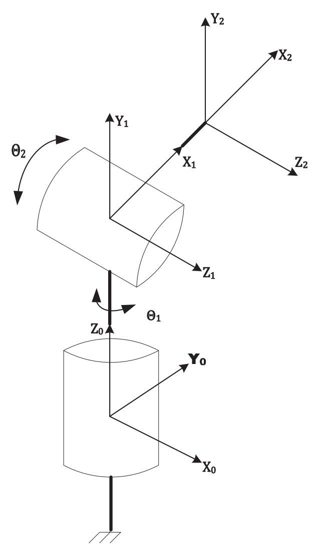

Fig 2. Link frame assignment of gimbal

The forward kinematics of gimbal is derived using Denavit-Hartenberg convention. The gimbal transformations between the bodies are as follows.

The rotation matrix between the frame of body (0) and the frame of body (1) is

$$^{0}R_1 = \begin{pmatrix} \cos\theta_1 & 0 & \sin\theta_1 \\ 0 & 1 & 0 \\ -\sin\theta_1 & 0 & \cos\theta_1 \end{pmatrix} \quad (1)$$

The rotation matrix between the frame of body (1) and the frame of body (2) is

$$^{1}R_2 = \begin{pmatrix} \cos\theta_2 & -\sin\theta_2 & 0 \\ \sin\theta_2 & \cos\theta_2 & 0 \\ 0 & 0 & 1 \end{pmatrix} \quad (2)$$

The total rotation matrix between the base frame (0) and frame of body (2) is

$$^{0}R_2 = \begin{pmatrix} \cos\theta_1\cos\theta_2 & -\cos\theta_1\sin\theta_2 & \sin\theta_1 \\ \sin\theta_2 & \cos\theta_2 & 0 \\ -\sin\theta_1\cos\theta_2 & \sin\theta_1\sin\theta_2 & \cos\theta_1 \end{pmatrix} \quad (3)$$

The gimbal model consists of IMU sensor attached to camera frame (body (2)) and position encoders attached to servo motors. The angular position of body (2) with respect to ground is derived from the gyros and accelerometers of IMU attached to the body (2). α_1 and α_2 are the angles of pitch and yaw axis of body (2) derived from the IMU. $\alpha_{1desired}$ and $\alpha_{2desired}$ represent the desired position of camera frame with respect to ground frame. ε_1 and ε_2 be the errors of pitch and yaw of camera's reference frame. Here, body (2) represents camera frame.

$$\varepsilon_1 = \alpha_{1desired} - \alpha_1 \quad (4)$$

$$\varepsilon_2 = \alpha_{2desired} - \alpha_2 \quad (5)$$

The rotation matrix of camera's error reference frame is

$$^{2}R_e = \begin{pmatrix} \cos\varepsilon_1\cos\varepsilon_2 & -\cos\varepsilon_1\sin\varepsilon_2 & \sin\varepsilon_1 \\ \sin\varepsilon_2 & \cos\varepsilon_2 & 0 \\ -\sin\varepsilon_1\cos\varepsilon_2 & \sin\varepsilon_1\sin\varepsilon_2 & \cos\varepsilon_1 \end{pmatrix} (6)$$

By the use of inverse kinematics the new joint angles are derived. The total rotation matrix between frame of body (0) and error frame ε of camera's reference frame is

$$^{0}R_e(\theta,\varepsilon) = {}^{0}R_2(\theta)\,{}^{2}R_e(\varepsilon) \quad (7)$$

Where, current joint angles are θ_1 and θ_2.

$$^{0}R_2(\theta_{new}) = {}^{0}R_{\varepsilon}(\theta,\varepsilon) \qquad (8)$$

The equation (8) represents that the frame of body (2) is same as error frame ε with desired joint angles. From equation (7) and (8) we can deduce equation (9).

$$^{0}R_2(\theta_{new}) = {}^{0}R_2(\theta)\,{}^{2}R_{\varepsilon}(\varepsilon) \qquad (9)$$

The right hand side of equation (9) is expressed as

$$^{0}R_2(\theta)\,{}^{2}R_{\varepsilon}(\varepsilon)=\begin{pmatrix} r_{11} & r_{12} & r_{13} \\ r_{21} & r_{22} & r_{23} \\ r_{31} & r_{32} & r_{33} \end{pmatrix} \qquad (10)$$

r_{ij} represents the components of matrix $^{0}R_2(\theta)\,{}^{2}R_{\varepsilon}(\varepsilon)$.The new joint parameters are calculated using the equations (11) and (12).

$$\theta_{1new} = \tan^{-1}\left(\frac{-r_{31}}{r_{11}}\right) \qquad (11)$$

$$\theta_{2new} = \sin^{-1}(r_{21}) \qquad (12)$$

θ_{1new} and θ_{2new} are the new desired joint angles.

B. *Motor Modelling*

The dc motor transfer function equation to find position is shown in equation (13).

$$\frac{\theta(s)}{V(s)} = \frac{K}{s[(Ls+R)(Js+B)+K^2]} \qquad (13)$$

Where,

- K represents emf in (Nm/A)
- L is inductance in (henry)
- R is resistance in (ohm)
- J is the moment of inertia of rotor in ($kg.m^2/s^2$)
- B is the damping ratio of mechanical system in (N-m/rad)
- Θ(s) is the angular position
- ω(s) is the angular velocity

Also the dc motor block diagram is shown in Figure 3.This motor is the gimbal actuator whose position is controlled in order to control camera position

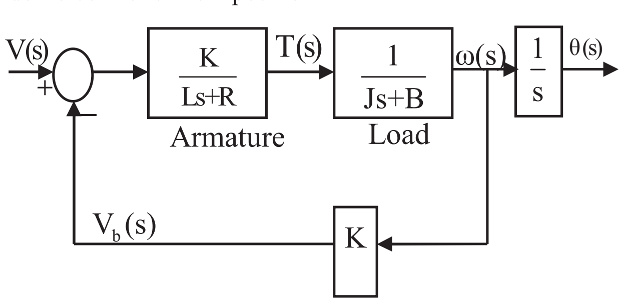

Fig 3. Block diagram of dc motor

C. *PID Controller*

The most commonly used controller in industries is PID controller. It contains parameters such as K_P, K_I and K_D which provides accurate closed loop performance where K_P, K_I, K_D are proportional, integral and derivative gains. The transfer function of PID controller is shown in equation (14).

$$G_{PID} = K_P + \frac{K_I}{s} + K_D s \qquad (14)$$

III. CONTROL BLOCK DIAGRAM

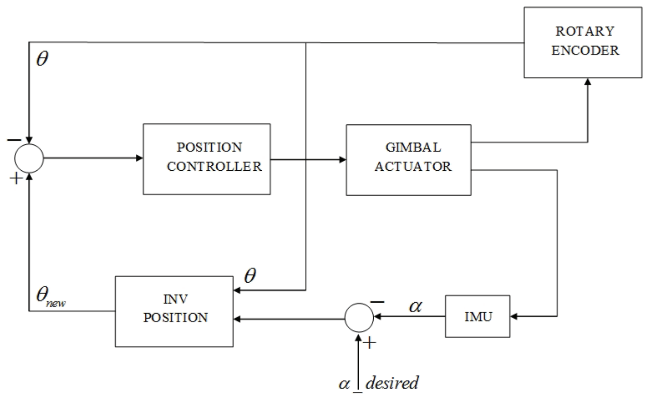

Fig 4. Control block diagram of gimbal

The control block diagram for controlling camera position using gimbal mechanism is shown in figure 4. Inv. position block gives the new joint angle calculated using inverse kinematics of gimbal. PID controller is used as position controller. The tuning of PID values is performed using different tuning methods such as Particle Swarm Optimization (PSO), Ziegler Nichols, and Cohen Coon method and so on.

IV. PSO TUNING METHOD

PSO is a type of evolutionary computation technique and is a population based robust stochastic optimization technique. This method has shown its optima in solving problems considering nonlinearity, non-differentiability and so on. It solves problems based on the movement and intelligence of swarms [7]. PSO works as a searching algorithm which gives optimum position. This algorithm was developed by the inspiration of bird flocking. In this method, the solution is a bird known as particle. The particles fly in the problem space of n dimensions (n is the no. of tuning parameters) by considering current optimum particles. The PSO consists of parameters such as swarm size, position, and maximum number of iterations. Random initialization of its position and velocity is performed. For every iteration, particle is updated with two best values. One best value is the best solution achieved by individual particle so far known as P_{best} and the other best value is the optimum best solution obtained by a particle in the entire population of particles called G_{best} [8]. After obtaining the two best solutions the position and velocity of all the particles is updated using equations (15) and (16).

$$v_{i,m}^{t+1} = w.v_{i,m}^{t} + c_1 * rand() * (P_{best(i,m)} - x_{i,m}^{t}) + c_2 * rand() * (G_{best(m)} - x_{i,m}^{t}) \quad (15)$$

$$x_{i,m}^{t+1} = x_{i,m}^{t} + v_{i,m}^{t+1} \quad (16)$$

Where,

i	- 1, 2, 3…….n
m	- 1, 2, 3.....d
n	- Number of particle population in a group
d	- Dimension of space (no. of tuning parameters)
t	- Current iteration value
$v_{i,m}$	- velocity of a particle I at iteration t
w	- Inertia weight factor
c_1, c_2	- learning factors
rand ( )	- random no. between 0 and 1
$X_{i,d}$	- current position of particle i at t iteration
$P_{best\ (i)}$	- best particle position of i_{th} particle
G_{best}	- best particle position among all the particles in the population

The flow chart of PSO algorithm implementation is as shown in Figure 5 [8].

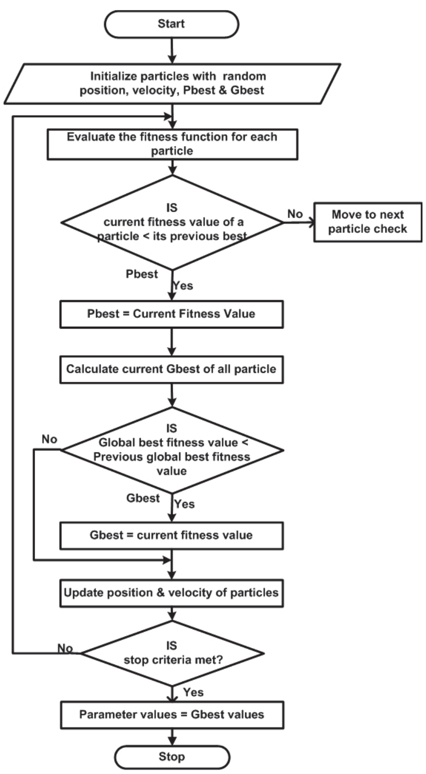

Fig 5. Flow chart of PSO algorithm

V. SIMULATION RESULTS

The simulink model of camera gimbal control is shown in figure 6. Here the IMU reading is taken as step input generated using stair generator block in simulink.

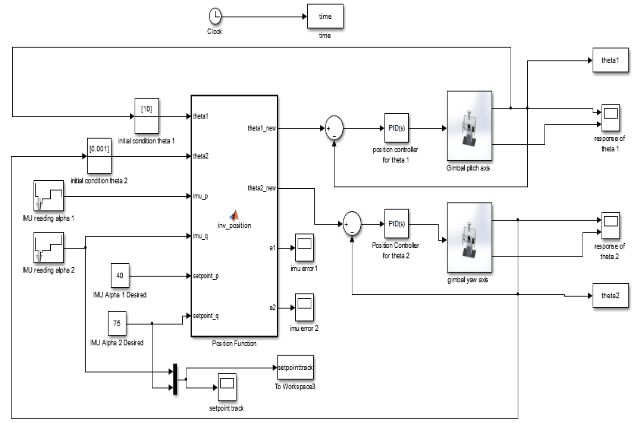

Fig 6. The simulink model of camera gimbal

In this gimbal control model the IMU desired angles are the set point to be achieved in order to make camera stable and point to desired object. The error given to PID controller is the difference between the joint angle calculated by inverse kinematics of gimbal and the joint angle obtained by position encoder. The responses in figures 8, 9, 10 and 11show the joint angles obtained for achieving the set point.

A. *Implementation of PID controller using Conventional Tuning methods*

The PID tuned values using Ziegler Nichols method and Cohen Coon method is shown in Table 1. These tuning methods are the conventional tuning methods.

Table 1: PID parameter values obtained using Conventional methods

Tuning method	Proportional Gain (Kp)	Integral Gain (Ki)	Differential Gain (Kd)
Ziegler Nichols	5.376	0.49085	0.1227
Cohen Coon	17.78	0.7375	0.1090

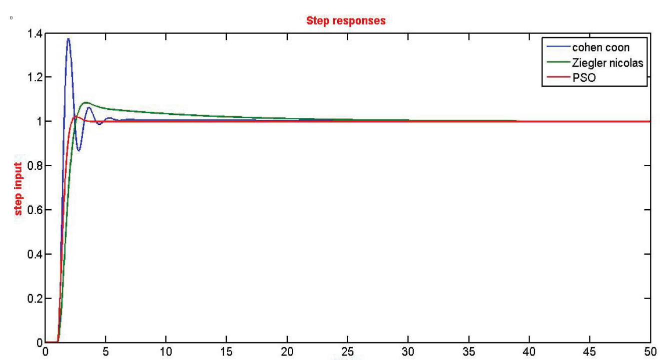

Fig7:.Step responses of system for different tuning methods

The responses of 2-axis camera gimbal of pitch axis and yaw axis is shown in figure 8 and figure 9

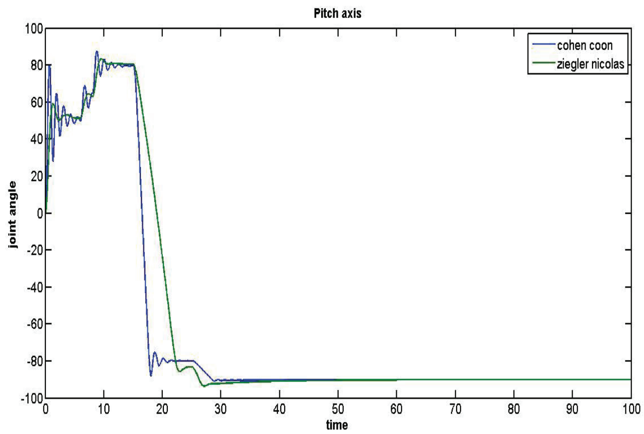

Fig 8. Pitch axis response using conventional method

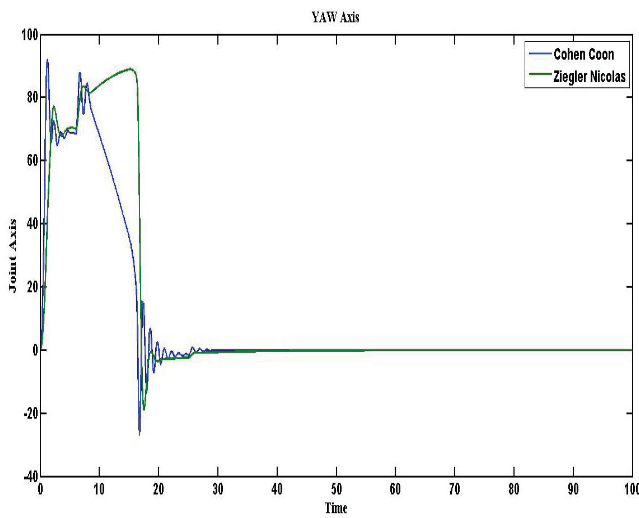

Fig 9. Yaw Axis response of gimbal using conventional method

B. *Implementation of PID controller using EvolutionaryTuning methods*

There are many evolutionary tuning methods such as ACO (Ant Colony Optimization), PSO (Particle Swarm Optimization), and GA (Genetic Algorithm) and so on. In this paper PSO algorithm is used. The implementation of PSO-PID is done according to the flow chart as shown in figure 5.The PSO parameters used are shown in Table 2.

Table 2. The PSO algorithm parameters

Parameter Name	Variable	Value
Cognitive component	c_1	1.5
Social component	c_2	1.5
No. of particles (Population)	n	100
No. of iterations	N	1000
Minimum inertia weight	W_{min}	0.4
Maximum Inertia weight	W_{max}	0.9
Dimension (No. of parameters)	dim	3

The fitness function used in PSO algorithm is as shown in equation (17). Selection of fitness function is crucial to get better tuning values due to which system responses are optimum. Here β value is taken as 1.

$$F = (1- \exp(-\beta))*(Mp+Ess) + \exp(-\beta)*(Ts -Tr) \quad (17)$$

Where, F is the fitness value, β is the weighing factor, Ess is the steady state error, Mp is the overshoot, Ts is the settling time and Tr is the rise time.

The responses of PSO tuned PID controller for camera gimbal control used in UAV are shown in Figure 10 and figure 11. Pitch and Yaw axis responses are shown which represent the final joint angles obtained by position encoder.

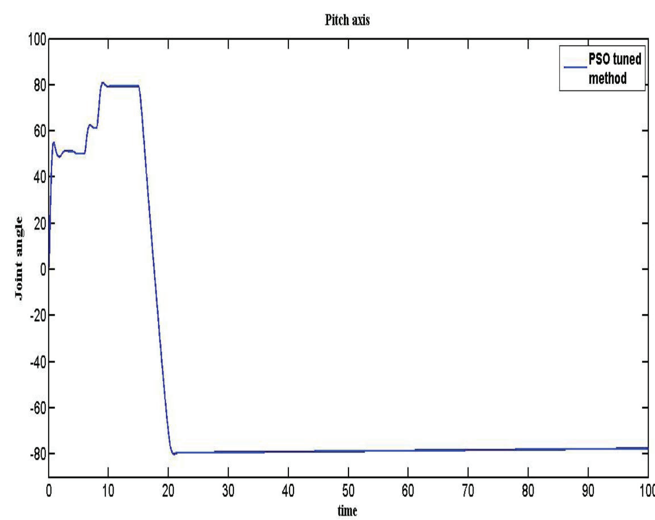

Fig 10. Pitch axis representation of gimbal using PSO tuning method

The responses clearly indicate the performance variation of the system for different tuning methods used to tune the PID controller parameters. PSO tuned PID controller gives the better performance of the system. The system performance depends on controller and its tuning parameter values.

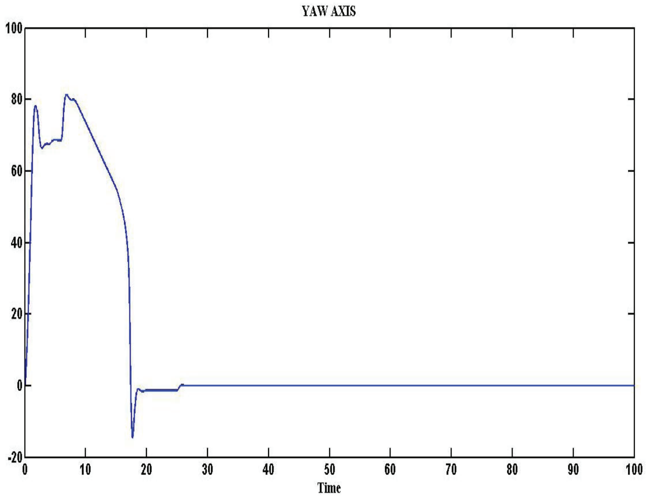

Fig 11. Yaw Axis response of Gimbal using PSO tuning method

VI. CONCLUSION

The position control of camera in UAV is very important for different applications as discussed. The PID controller designed keeps the camera stable as shown by the responses. Tuning methods used to tune PID parameters show different variations in performance in the system as seen in simulation results. PSO tuned PID controller gives accurate and stable convergence. So, PSO tuned PID controller is preferred to control camera position using gimbal mechanism.

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