International Journal of Engineering and Technology Research
Published by Cambridge Research and Publications
Vol. 19 No.5
September, 2020.

TRACKING OF QUADROTOR UAV USING PID CONTROLLER AND FUZZY LOGIC CONTROLLER

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ABSTRACT
One of the most important applications of is in the field of real life surveillance made possible by a camera payload. However, the images sent by the Quadrotor UAV are unstable and jittery because of the inherent vibration of the drone; these vibrations result from the movement of quadrotor UAV motors and air turbulence. This work aims at obtaining a more stable and clearer image by stabilizing the position of the camera. This is achieved by mounting the camera on the UAV via a servo motor which act as the actuator. The actuator will make it possible to set the reference camera positions. To minimize the layer of deviation, a PID controller will be designed to compensate for the error and keep the camera in relatively stable position. Thus, the output of the system is the camera position while the disturbance in the system is the inherent vibration from the UAV. The overall system will be modeled and simulated in MATLAB/SIMULINK environment. The response of the system to various kinds of inputs (reference positions) in the faces of different kinds of vibrations, with and without the controller would be analyzed. In addition, noise would be added to ascertain the robustness of the system. The developed system is expected to achieve a comparable result at lower cost with lower computational overhead than the software image processing methods or the gimbal system.

Keywords: *Tracking, Quadrotor, Using, PID Controller, Fuzzy Logic Controller.*

INTRODUCTION
Background Information
UAV also known as drones, are aircraft that have no pilot. In recent years, unmanned aerial vehicles have found extensive use in commercial applications such as urban surveillance, disaster management, aerial photography, delivery services, inspection of pipelines etc (Elkholy, 2014). Engineers in the United States started experimenting with smaller, slower, cheaper UAVs that mimicked large model airplanes. Progress

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in this field was achieved over the years as these vehicles became larger and more capable, leading to a successful, wide deployment in the mid-90s, and due to their reconnaissance and tactical capabilities, UAVs are now a major component of the global war on terrorism. (Gupta et al., 2013).

The quadrotor UAV's today are equipped with a variety of payloads for autonomous navigation, data acquisition, real time surveillance for which the UAV has a streaming camera on board. The main drawbacks of videos taken by UAV are the undesired shaking motion caused by atmospheric turbulence and jittery flight control of the platform. (Eisenbeiss, 2004) The shaky motion in the video proves to mitigate the fundamental aim of using UAV for vision-based tasks. In particular, the unstable motion also inhibits higher level vision tasks, such as detecting and tracking of objects in the video. Thus the need for the images/videos to be stabilized

In Plate 1, a picture of a UAV is shown with different parts outlined, while Plate 2 shows a camera on a gimbal system mounted on a UAV

Plate 1: Picture of a UAV

Plate 2: Camera Mounted on an UAV

Plate 1

Plate II

Aim

To Track quadrotor UAV using PID Controller and Fuzzy Logic Controller

Objectives

1. To develop the conceptual and mathematical models for the effect of vibration of the camera mount
2. To design a PID controller in MATLAB/SIMULINK that will stabilize the camera position.
3. To discuss, analyze and validate the results with Fuzzy Logic Controller at various frequencies and amplitudes of vibration

IJETR ISSN-2329-7309 (Print)

Statement of Problem

UAVs are equipped with cameras to capture scenes in real time, however these images jitters as a result of vibration and wind resistance which produces undesirable effect on the captured images/video, making them not to be useful for intelligent purpose. This work proposes an image stabilization algorithm which adjusts the camera position so as to obtain a more stable and clearer image.

LITERATURE REVIEW

Introduction

In this section the concept of the Quadrotor UAV is discussed also relevant works carried out by various researchers is presented.

The Quadrotor UAV Concept

The UAV has six degree of freedom, three rotational and three translational, but only four equally spaced rotors placed at the corners, as shown in plate 3 below. These four inputs make it to be severely under-actuated, this makes system to be non-linear in nature and except for air friction, which is negligible, UAV do not have friction to suppress or aid their motion; so, they provide their own damping for stability and movement, (Tiwari, 2017).

Each rotor consists of a propeller fitted to a separately powered DC motor. Propellers 1 and 3 rotate in the same direction while propellers 2 and 4 rotate in an opposite direction leading to balancing the total system torque and cancelling the gyroscopic and aerodynamics torques in stationary flights (Elkholy, 2014)

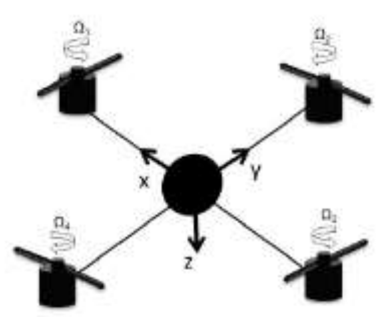

Plate 3: Quadrotor UAV Configuration

Wang et al., (2011) also reported a work on real-time video stabilization for unmanned aerial vehicles. The stabilizations task was achieved in three steps: The key points are located based on FAST corner detection and preliminarily matched. Secondly, the matched key points are then involved for estimation of affine transform to reduce false matching key points and thirdly motion estimation was performed based on affine transform model while the compensation for vibration was conducted based on Spline smoothing

Plasencia et al., (2012), in a paper titled, Modelling and Analysis of Vibrations in a UAV Helicopter with a Vision System, generated a range of vibrations originating in the main rotor and design a control methodology in order to damp these vibrations. The UAV was modelled using VehicleSim, the vibrations that appear on the fuselage were analysed to study their effects on the on-board vision system by using Simmechanics software, after which a control method based on an Adaptive Neuro-Fuzzy Inference System (ANFIS) was implemented to achieve satisfactory damping results over the vision system on board.

Manohar and Ananda (2015), worked on design and simulation of a 2 axes gimbal for micro aerial vehicle (MAV). The gimbal mechanism was employed to keep the camera towards target position by compensating the disturbances and vibrations caused by MAV while tracking target. The demerit of this method however is that additional hardware is required hence high cost

Nicolás et al., (2012) presented a paper on the Modeling and analysis of vibrations in a UAV Helicopter with a Vision System. The UAV was modelled using VehicleSim and a range of vibrations originating in the main rotor was generated, after which a control method based on an Adaptive Neuro-Fuzzy Inference System (ANFIS) was implemented to achieve satisfactory damping results over the vision system on board. However the disadvantage of this method is that it required a very high memory speed and expensive computer.

Windau & Itti (2011), work on a Multilayer real-time video image stabilization, which was a combination of four independent stabilization layers running in parallel this includes vibrations detection via an inertial measurement unit (IMU) using an external motorized gimbal, vibration dampings using mechanical devices. The internal optical image stabilization of the camera represents Layer 3, while Layer 4 filters remaining vibrations using software. This method is Expensive for UAVs and is thus applicable for big aircrafts.

METHODOLOGY

This section presents the system equations, Actuator model, vibration model, UAV model and the PID controller equation and structure.

3.1 System Equations

Error equation

$$\boldsymbol{e(t) = r(t) - y(t)} \quad \text{....1}$$

PID equation

$$\boldsymbol{u(t) = K_p e(t) + K_i \int e(t)dt + K_d \frac{de(t)}{dt}} \quad \text{....2}$$

Actuator Model

$$\frac{\theta(s)}{V_a(s)} = \frac{K_T}{s[(R_a + L_a s)(J_m s + B_m)K_T K_B]} \quad \text{....3}$$

Vibration Model

$$x = Asin(\omega t) \quad \text{...4}$$

UAV model

The dynamics of a UAV with respect to the earth inertial frame (E-frame) and the body-fixed frame of the vehicle (B-frame) as the two coordinate systems are to be considered and this is shown in figure 1. The two co-ordinates are related through three successive rotations such as the:

- Roll: Rotation of φ about the x- body axis
- Pitch: Rotation of θ around the y- body axis
- Yaw: Rotation of ψ around the z- body axis

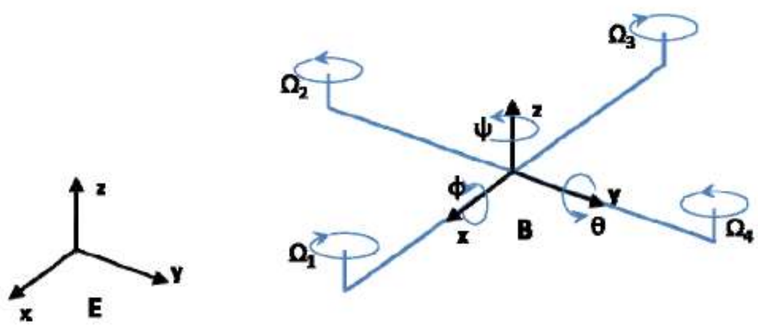

Figure 1: Quadcopter dynamic configuration

The quadrotor dynamic model presented in Pipatpaibul (2011) will be adopted. However, the vibrations from the UAV dynamics will be extracted using the quadrotor UAV motions defined by the equations of motion given in (1).

$m\ddot{X} = -\sin\theta\cos\phi\sum_{i=1}^{4}[b\Omega_i^2]$ …1

$m\ddot{Y} = \sin\phi\sum_{i=1}^{4}[b\Omega_i^2]$ …2

$m\ddot{Z} = -mg + \cos\theta\cos\phi\sum_{i=1}^{4}[b\Omega_i^2]$ …3

$I_{xx}\ddot{\phi} = \dot{\theta}\dot{\psi}(I_{yy} - I_{zz}) - \dot{\theta}\Omega_r J_r + lb(-\Omega_2^2 + \Omega_4^2)$ …4

$I_{yy}\ddot{\theta} = \dot{\theta}\dot{\psi}(I_{zz} - I_{xx}) + \dot{\theta}\Omega_r J_r + lb(-\Omega_1^2 + \Omega_3^2)$ …5

$I_{zz}\psi = \dot{\theta}\dot{\phi}(I_{xx} - I_{yy}) + \dot{\Omega}_r J_r + \sum_{i=1}^{4}[(-1)d\Omega_i^2]$ …6

UAV motion with vibrations

The motion of the UAV is a combination of one of the translations or rotations in a chosen direction as presented below.

Z-direction Translation

To translate in the +Z direction, from hovering, rotor speed is increased equally to each rotor and vice versa in the -Z direction. Changes in rotor angular momentum in each pairs are equal and thus be canceled out. Figure 2 illustrates the concept of a vertical translation.

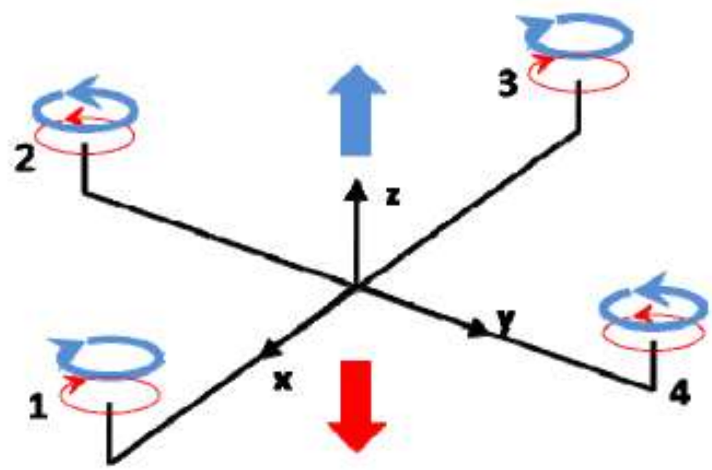

Figure 2: Z-direction translation

X-direction Translation and Pitching Motion

Since quadrotors are highly coupled, rotation in certain angles results in translation in a direction and that is fundamentally how a quadrotor UAV translates. This is also true to the pitching motion. Starting from hover, increasing rotor speed in rotor 3 and decreasing in rotor 1 while maintaining speeds in rotor 2 and 4 results in rotation in the $+\theta$ direction and translation in the +X direction of Earth frame and vice versa. Note that at this point the quadrotor UAV tilts in a small angle and thrust are approximately equal to weight, thus no translation in the Z direction. This is illustrated in Figure 3.

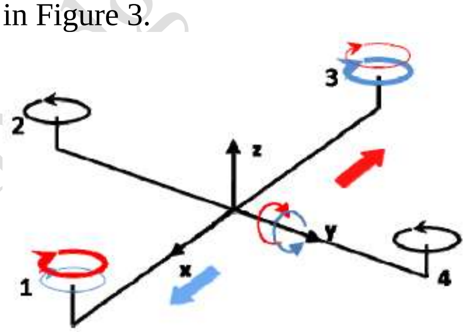

Figure 3: X-direction Translation and Pitching Motion

Y-direction Translation and Rolling Motion

Similar to pitching, rolling is coupled with the Y direction translation. In this case, starting from hover, increasing the rotor speed in rotor 4 and decreasing in rotor 2 while maintaining speeds in rotor 1 and 3 results in rotation in $+\emptyset$ direction and translation in -Y direction of the Earth frame and vice versa. This is also depicted in Figure 4.

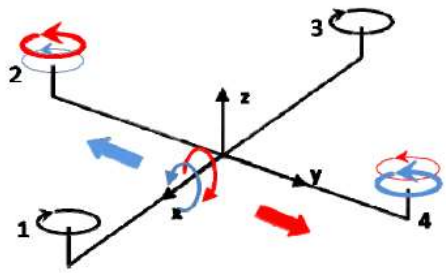

Figure 4: Y-direction Translation and Rolling Motion

Yaw Rotation

Yawing is similar to vertical translation in that the motion is not coupled. Instead of cancelling out rotor angular momentum, thrust is balanced to maintain altitude in this case. To perform a pure yaw motion, starting from hover, increasing the speed in rotor 2 and 4 while decreasing speeds in rotor 1 and 3 results in body rotation in $+\varphi$ direction and vice versa. See Figure 5 for more details.

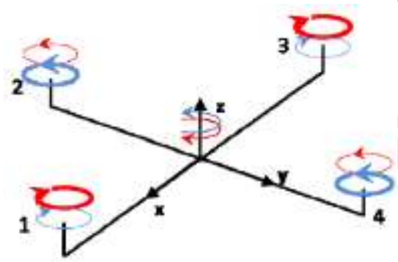

Figure 5: Yaw Rotation

The PID Controller

PID controllers are commonly used in a broad range of controller applications and thus the most widely used controller in industry. The PID controller structure is shown in figure 6. The parameters (K_p, K_i, K_d) will be tuned using SIMULINK PID tune tool.

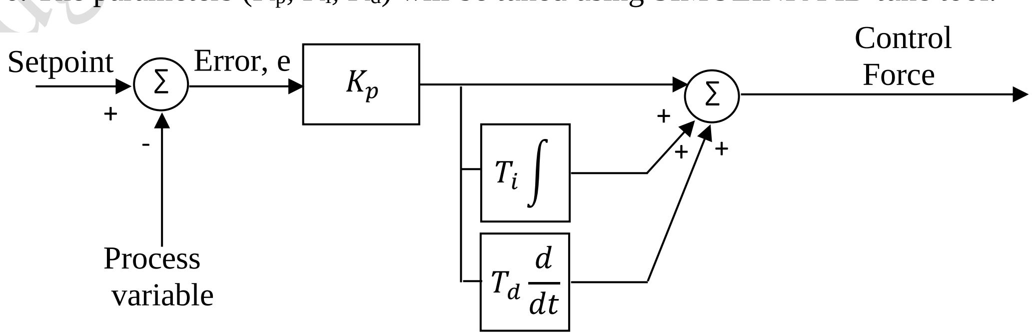

Figure 6: PID control structure

In time domain, the PID control force $u(t) = K_p.e + K_i \int edt + K_d \frac{de}{dt}$

Where e is the error in measurement, K_p is the proportional constant, K_i is the integral constant, K_d is the derivative constant
In frequency domain, by Laplace transform, the transfer function for the controller will be

$$U(s) = \left(K_p + \frac{K_i}{s} + sK_d\right)E(s)$$

$$C(s) = \frac{U(s)}{E(s)} = K_p(1 + \frac{1}{T_i.s} + sT_d)$$

T_i is the integral time constant, T_d is the derivative time constant

RESULTS AND DISCUSSION

System Response at Varying Frequencies

As shown in Figure 7, without controller, the camera jitters, when PID controller was applied the system was fully controlled and vibration was reduced to the minimum. No overshoot was observed. The time response was less than 0.2 seconds. Comparing with fuzzy logic controller, the system was also controlled at amplitude $A = 50$ and frequency $f = 0.5Hz$

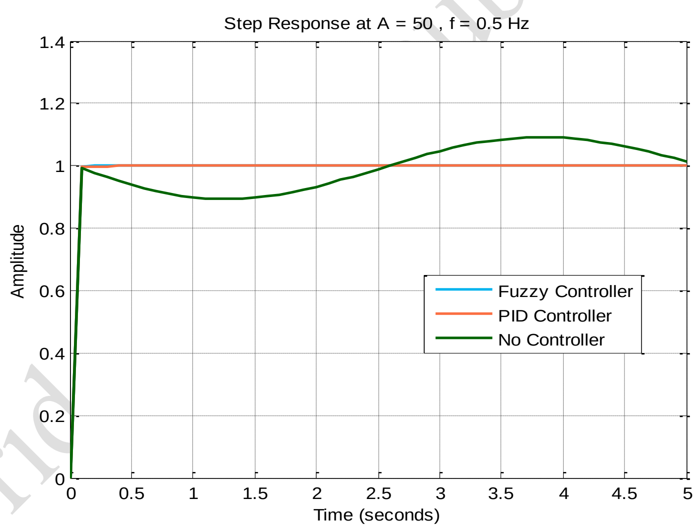

Figure 7: System response at $A = 50, f = 0.5Hz$

With the frequency at 1Hz and amplitude at 50, the camera jittery was increased, while when PID control was applied the system was brought to stability, and gives a better result than when fuzzy logic controller was applied. Although fuzzy logic controlled it, there was still some inherent vibration noticed at the background. In both cases there was no overshoot however, and the response time was still less than 0.2 seconds, as shown in Figure 8

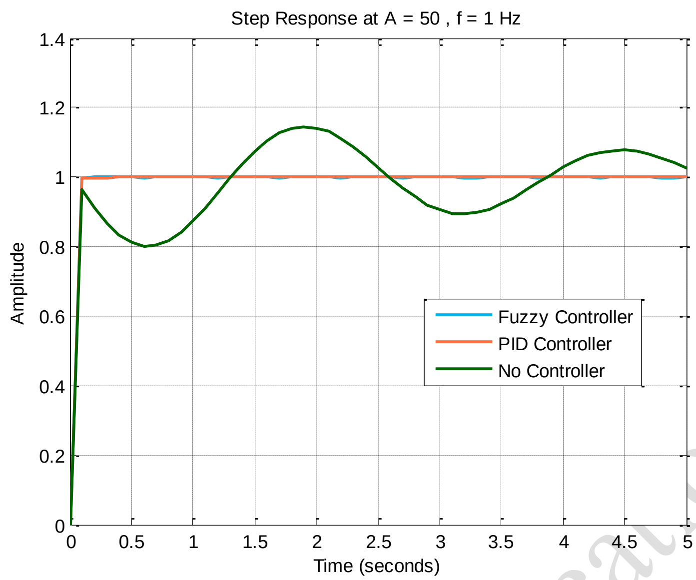

Figure 8: System response at $A = 50, f = 1Hz$

When the frequency was increased to 1.5Hz, it was observed that for the response without controller the jittery tends to die out as time increases. With PID controller the position was controlled while with the fuzzy logic controller, there is still a little vibration at the background. However, no overshoot was noticed with the PID and fuzzy logic controller as presented in Figure 9.

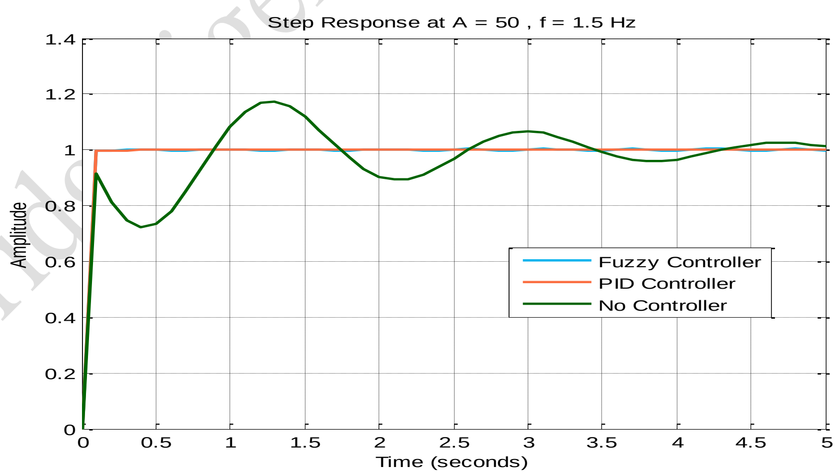

Figure 9: System response at $A = 50, f = 1.5Hz$

It was observed that as frequency increases the amplitude was lowered and vibration died out even faster. While the PID controller still had a better response than when the fuzzy logic was used, however no overshoot was observed in both Figure 10 and 11.

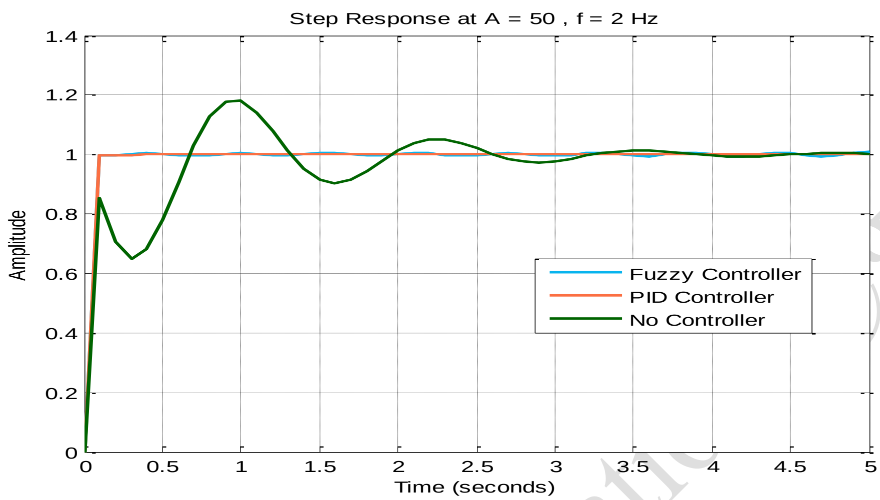

Figure 10: System response at $A = 50, f = 2Hz$

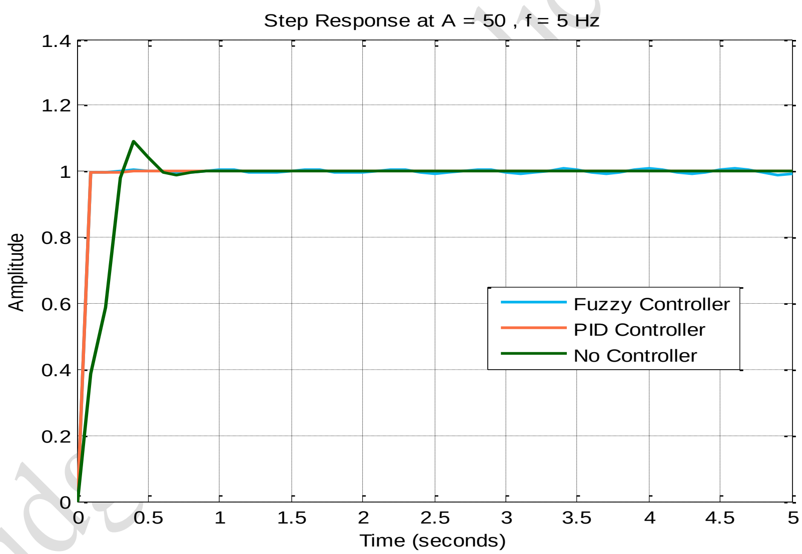

Figure 11: System response at $A = 50, f = 5Hz$

Responses with Varying Amplitude

As shown in Figure 12, without controller, the camera jitters, when PID controller was applied the system was fully controlled and vibration was reduced to the minimum. No overshoot was observed. The time response was less than 0.2 seconds. Comparing with fuzzy logic controller, the system was also controlled at amplitude $A = 100$ and frequency $f = 2Hz$

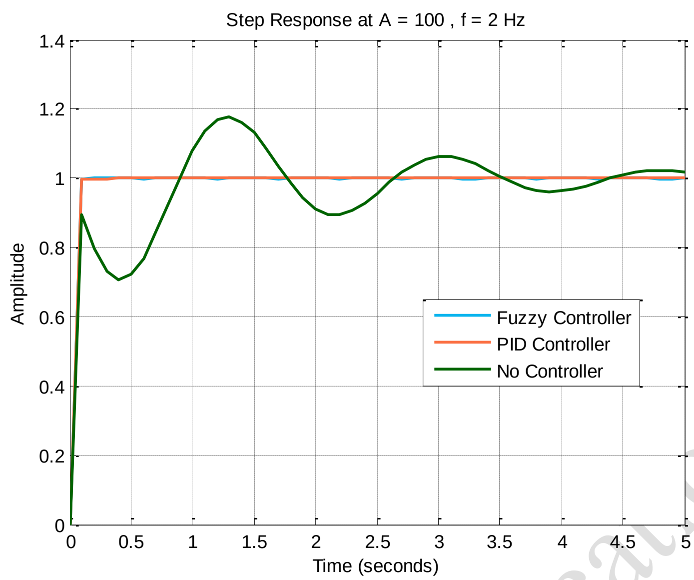

Figure 12: System response at $A = 100, f = 2Hz$

With amplitude at 100 and frequency at 2 Hz, jittery increased when no controller was used, when PID control was applied, the system was brought to stability, and gives a better result than when fuzzy logic controller was applied. It was observed that with the fuzzy logic controller, inherent vibration in the system is noticeably present at the background. In both cases there was no overshoot and the response time was still less than 0.2 seconds, as shown in Figure 13

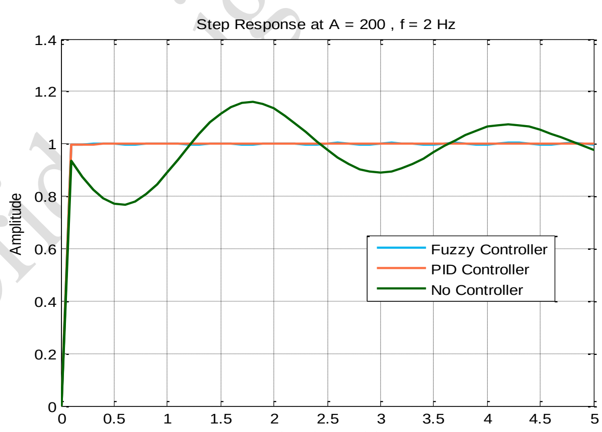

Figure 13: System response at $A = 200, f = 2\ Hz$

When amplitude was increased to 300 and 400 at frequency steadied at 2 Hz, it was observed that the force of vibration was increased for the responses without controller. While with the PID controller the system was brought under control and becomes stable. It was also noticed that with the fuzzy controller, the jittery was observed at the background as shown in Figure 14 and 15.

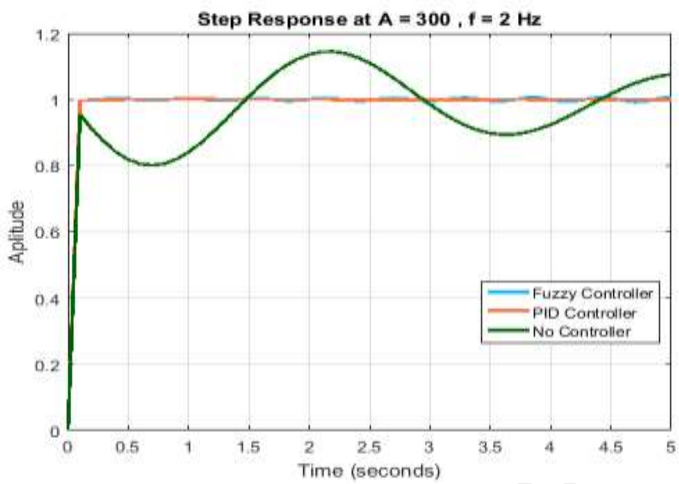

Figure 14: System response at $A = 300, f = 2\ Hz$

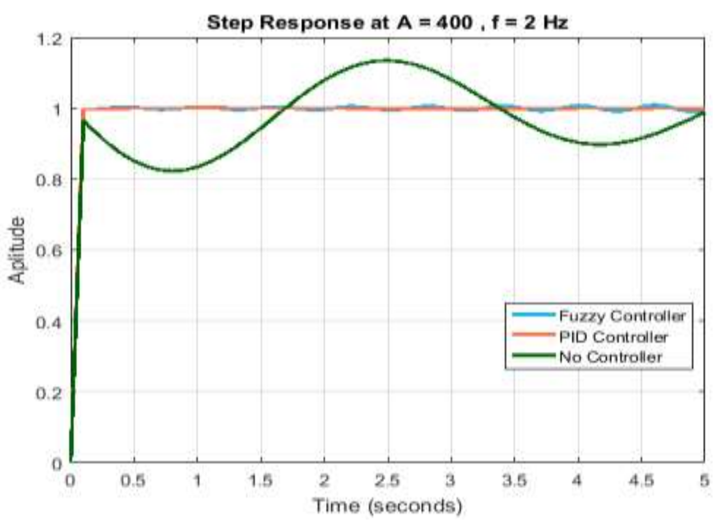

Figure 15: System response at $A = 400, f = 2\ Hz$

System Response with Noise

Figure 16 to Figure 24 shows the response when noise was added to the system model in the presence of vibrations at varying frequencies and varying amplitudes. The effect of noise is more pronounced in the responses without controller. But with PID controller, the effect of noise is drastically reduced. This reduction shows better results than those of fuzzy logic.

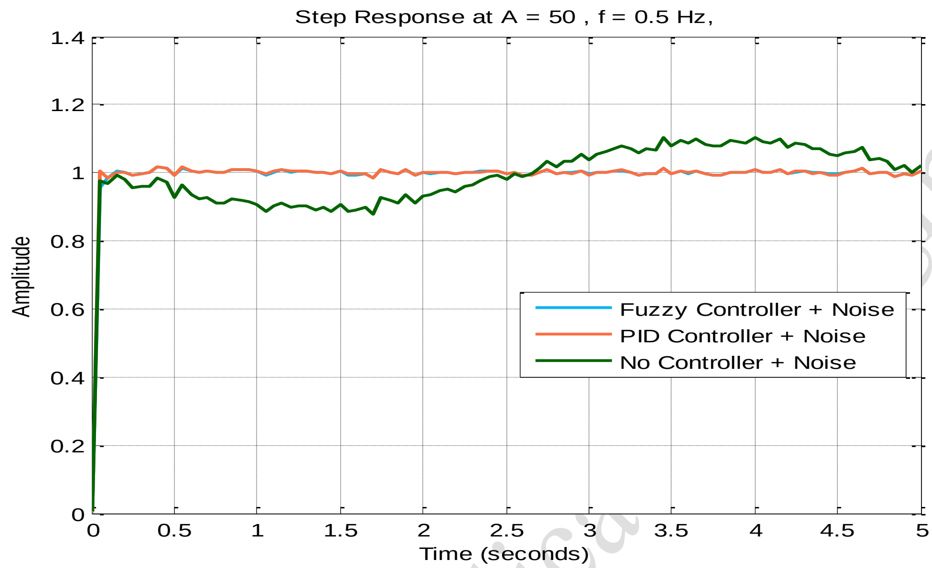

Figure 16: System response at $A = 50, f = 0.5\ Hz$

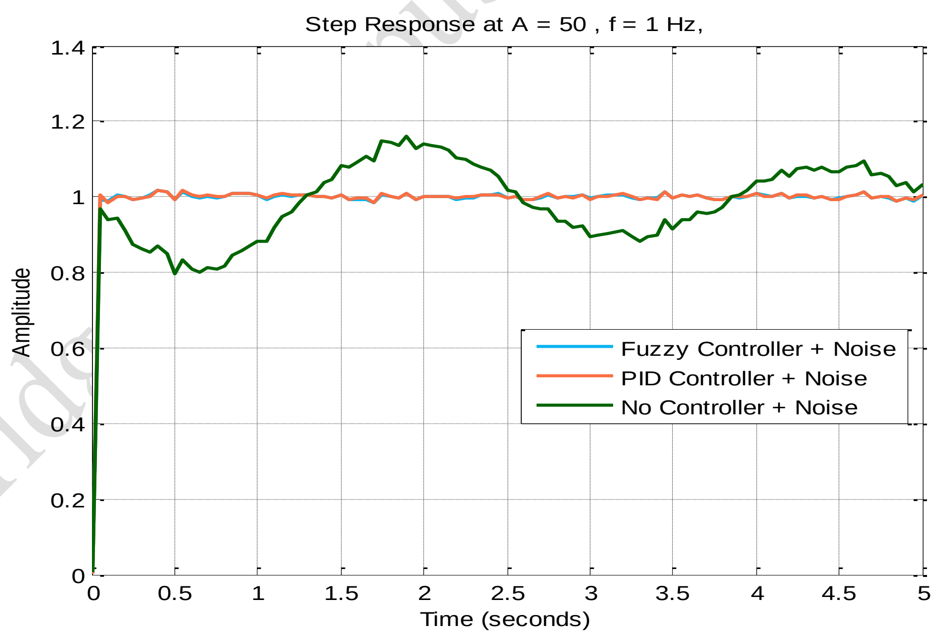

Figure 17: System response at $A = 50, f = 1\ Hz$

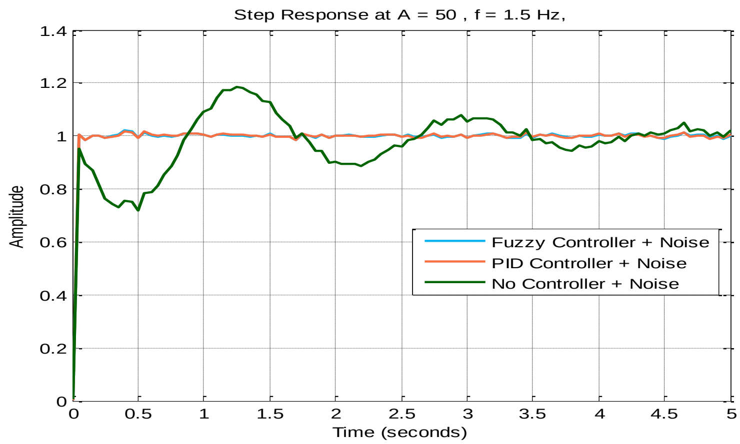

Figure 18: System response at $A = 50, f = 1.5\ Hz$

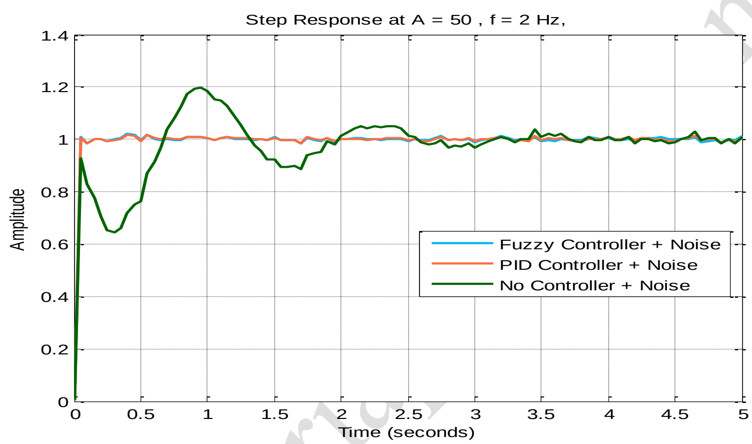

Figure 19: System response at $A = 50, f = 2\ Hz$

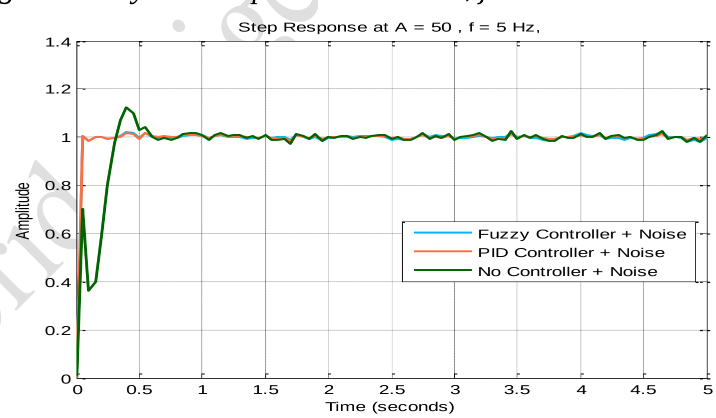

Figure 20: System response at $A = 50, f = 5\ Hz$

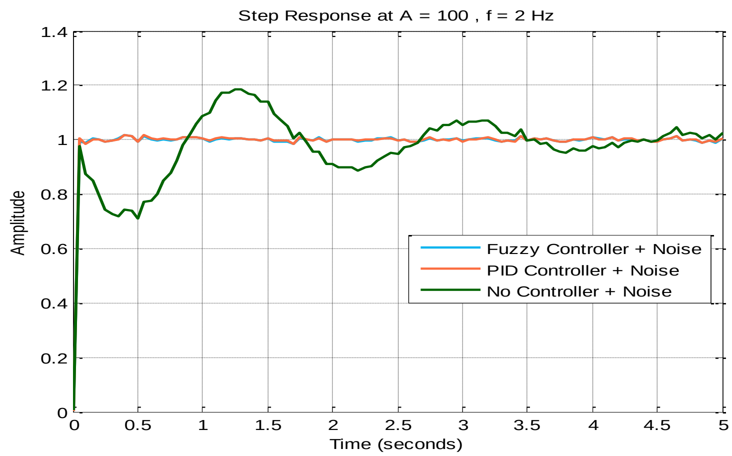

Figure 21: System response at $A = 100, f = 2\ Hz$

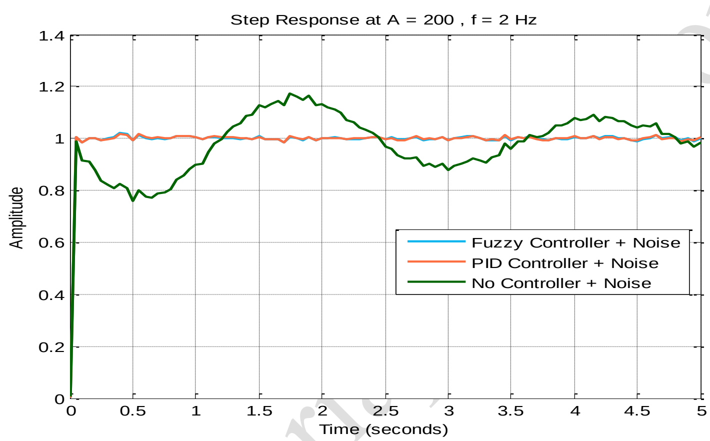

Figure 22: System response at $A = 200, f = 2\ Hz$

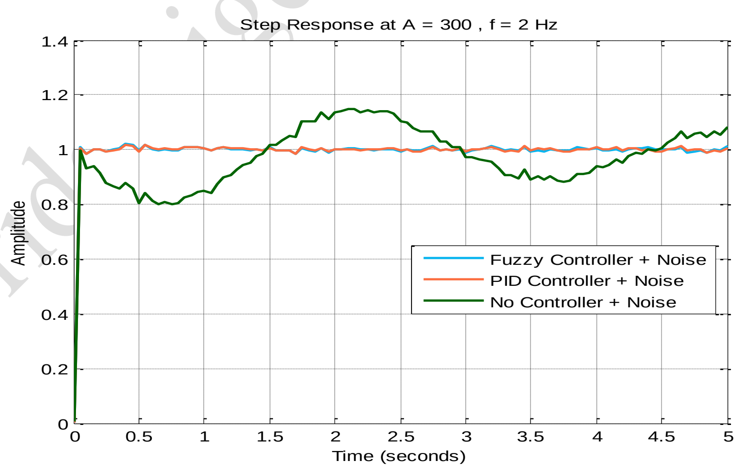

Figure 23: System response at $A = 300, f = 2\ Hz$

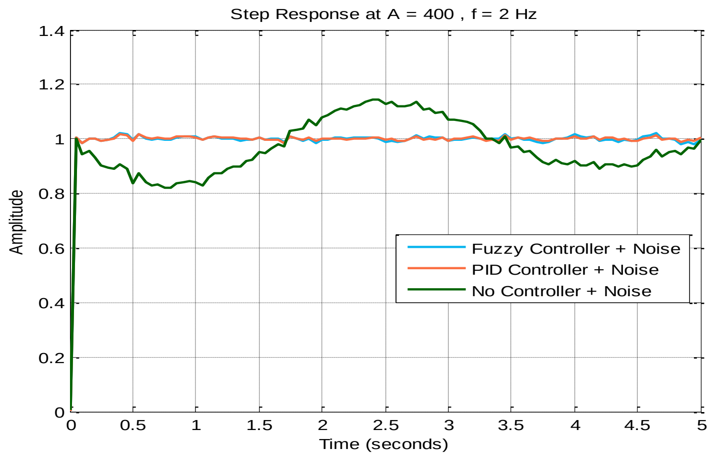

Figure 24: System response at $A = 400, f = 2\ Hz$

Summary

The purpose of the work is to stabilize the position of a camera on a UAV in order to obtain a clearer and more stable image. Four different mathematical models represented the complete structure of the system, which was simulated in MATLAB/SIMULINK environment. Simulations varying the frequencies at constant amplitude and vice versa were carried out. The response of the stabilized and unstabilized system was obtained and it was observed that the stabilized response was clearer, more stable and of better quality than the unstabilized response. Comparison was made between the two stabilized responses, that is the PID controller and fuzzy logic controller and it was also noticed that the PID controller gave a better more stable response than the fuzzy logic controller even in the presence of noise.

Conclusion

Mathematical model for one dimensional image stabilization using ordinary differential equation of the simple harmonic motion as the vibration model was derived and validated. Simulation of the system was performed using PID controller and fuzzy logic controller. And comparison of the system response was made when no controller was used, with PID controller and fuzzy logic controller. It was observed that the response with the PID controller was better than the fuzzy logic controller. It was also noticed that when noise was added to the system, the responses without was effected, that means the response was jittery and unstable but when PID controller and fuzzy logic controllers were used the effect of noise was reduced drastically although the PID had more stable and clearer response.

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