Development of a Fuzzy GS-PID Controlled Quadrotor for Payload Drop Missions

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***Abstract*—This study investigates on the use of a new Fuzzy GS-PID controller in reducing the overshoot of a quadrotor during payload drop missions. The new controller design involves a synergy of fuzzy logic reasoning and GS-PID control theory to improve performance of the quadrotor. The payload mass was made as the input to the controller while utilizing fuzzy logic reasoning to obtain the proper gains for the GS-PID controller. The control algorithm was tested on a locally developed quadrotor system with a payload drop test rig to verify its effectiveness during actual implementation. Results show that the Fuzzy GS-PID controller was able to reduce the overshoot of the system as compared to the PID and the GS-PID controllers.**

***Index Terms*—Fuzzy Logic; GS-PID; Payload; Quadrotor; Search and Rescue.**

I. INTRODUCTION

With the advent of the recent disaster and calamities the Philippines is currently facing, the demand for disaster mitigation has been steadily increasing. With this said, dire demand for research in the field of disaster mitigation has also been steadily increasing which includes search and rescue operations. One notable problem of search and rescue operations is the delivery of life saving equipment to the victims of the calamity. There are instances wherein the location is not accessible by vehicles or by any personnel. Therefore, we propose the idea of using quadrotors to deliver lifesaving payload to the target area.

A quadrotor is a 6DOF underactuated UAV (Unmanned Aerial Vehicle) using only four motors for its movement along the XYZ plane and the Euler angles (please see Figure 1). As seen in figure 1, the four motors of the quadrotor has corresponding contributions to the movement of the quadrotor along the Z-axis of the body frame and the rotation along the Euler angles. The quadrotor, being a rotorcraft type vehicle, has the capability to hover and vertically lifting off and landing. It has also the characteristic of being mechanically simpler as compared to other types of rotorcrafts and it, inherently, has good maneuverability due to its dynamic nature [1].

Quadrotor UAV has also garnered attention among research groups. Stanford, for example, has created their own quadrotor system called STARMAC [2]. Massachusetts Institute of Technology created a multiple autonomous vehicle system, which includes several quadrotors, termed as RAVEN [3]. Lastly, the University of Pennsylvania has done numerous control algorithms, ranging from perching, and flight through windows, to cooperative manipulation of payload [4]

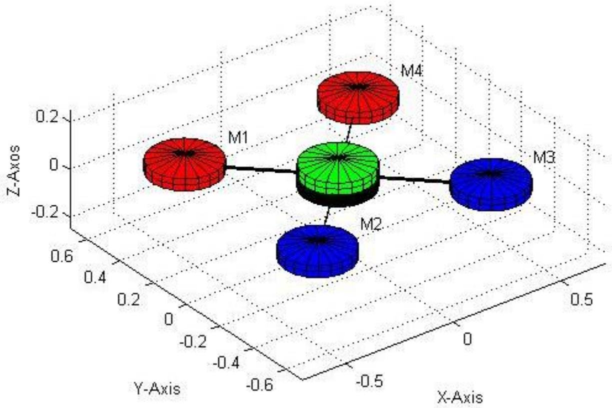

Figure 1: Quadrotor Model

Applications can range from scientific surveillance, military applications, and to search and rescue missions. More recently, the quadrotor system has entered the field of package delivery. Such is the concept of Matternet, wherein the quadrotor will be used to deliver medical supplies among the vilages across Africa [5]. Meanwhile, RTS Labs proposed the idea of using quadrotors to deliver floatation deliveries in scenarios of people drowning in the Caspian Sea [6].

Quadrotor systems are no stranger to GS-PID and Fuzzy GS-PID control algorithms. A GS-PID controller was implemented by Fang et al. (2011) [7]. Their work focuses on the stability of the quadrotor using the GS-PID control algorithm. Meanwhile, the Fuzzy GS-PID controller was implemented by Sangyan et al. (2010) and Amoozgar et al. (2013) [8] [9]. Their works focuses on using the algorithm to build a fault-tolerant quadrotor system. Sangyam et al. (2010) implemented the control algorithm for force disturbance scenario while Amoozgar et al. (2013) implemented it for actuator faults. Lastly, Sadeghzadeh et al. (2012) implemented a GS-PID algorithm for the payload drop application of the UAV [10]. Normally, a Proportional Derivative Controller (PID) controller is suitable for controlling the altitude of a quadrotor, due to its simplicity, however, when it executes a payload drop maneuver, there is a high chance there will be a large overshoot. In their work, they compared three control algorithms, which were the Model Predictive Control, the PID algorithm, and the GS-PID algorithm. They've found that the GS-PID algorithm was able to achieve the least overshoot when executing the payload drop maneuver.

This paper extends the previous studies by implementing a new Fuzzy GS-PID controller for reducing the overshoot of the system, while executing a payload drop maneuver. The system will also have the capability to identify and handle variable payload drops different from the previous studies. Unlike most studies using Fuzzy GS-PID, however, the proposed controller would have mass as its input rather than its tracking error.

II. METHODOLOGY

A. *Fuzzy GS -PID*

Equation 1 shows the theoretical equations behind a PID controller. In the equation, K_P, K_I, and K_D are the PID gains, e(t) is the tracking error, while u(t) is the control output. Gain Scheduling (GS)-PID control algorithm is an extension of the PID algorithm wherein the parameters of the Kp, Ki, and Kd can change its value dependent on the conditions imposed to the controller, an example of the control algorithm can be seen in the work of Fang et al. (2011) [7]. The advantage of such algorithm is its capability to adapt in cases wherein the system experiences changes on its parameters. The switching parameter can either follow a mathematical equation or a lookup table. Meanwhile, the fuzzy logic algorithm is a decision technique used for extending Boolean conditional logic. It could handle values that are found between ‘true’ and ‘false’ logic.

$$u(t) = K_P e(t) + K_I \int_0^t e(t)dt + K_D \frac{d}{dt} e(t) \qquad (1)$$

In the work of Sagdezadeh et al. (2012), they proposed the use of a GS-PID control algorithm for reducing the overshoot during the payload drop maneuver [10]. The limitation, however, is the algorithm only considers one type of payload. To expand this algorithm to multiple payload would require a look-up table for each payload weight. However, creating such look-up table would be only useful for distinct types of payload weights. By proposing the use of a fuzzy logic, instead, parameters would not be limited on a distinct payload weight and can then be instead used for any variable payload weight. Also, the advantage of using a fuzzy logic is its capability to have designing rules based on human reasoning.

The Fuzzy GS-PID for this study follows the idea of using Fuzzy Logic in controlling the gains of the PID algorithm. As shown in figure 2, the Fuzzy GS-PID have a single input which is the mass of the payload and outputs the PID gains of the altitude PID controller. When the payload drop maneuver is executed, the PID controller would change its gains according to the gains dictated from the fuzzy logic algorithm.

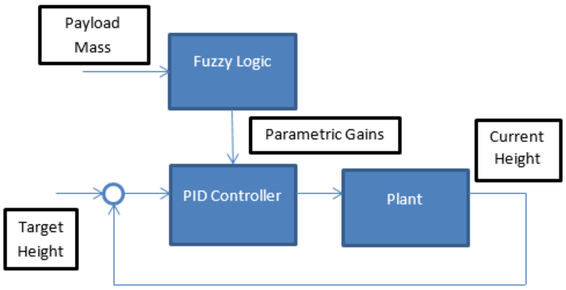

Figure 2: Fuzzy GS-PID Overview

The membership functions of the fuzzy logic are based on a mix of experiments done on the quadrotor and human reasoning. Figure 3 shows the input membership function used while figure 4 shows the output membership function used. In this study, the Kp gains were used since it produces the most impact in changing the properties of the system compared to Ki and Kd values based on simulation and experimental results. We also would like to limit the complexity of the rules for easier implementation without sacrificing the response of the system. Kp gains were the only the one tackled due to the added complexity when Ki and Kd gains are also considered. Lastly, the fuzzy rules used for the control algorithm are:

Rule 1: If Mass is Light then Kp is Small
Rule 2: If Mass is Medium then Kp is Medium
Rule 3: If Mass is Heavy then Kp is Large

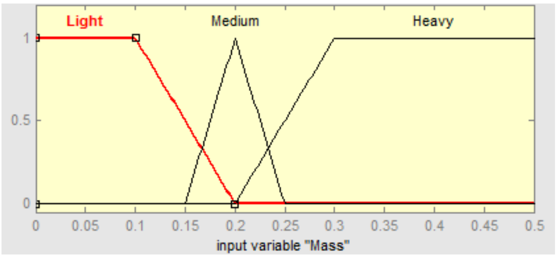

Figure 3: Input Membership Function

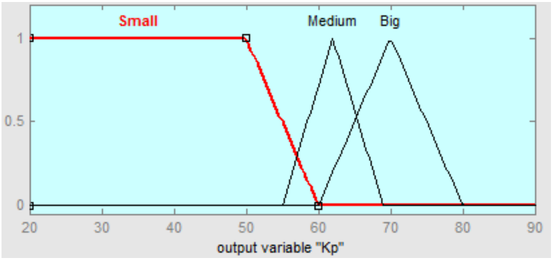

Figure 4: Output Membership Function

B. *Quadrotor Payload Drop Test*

The quadrotor, used for the experiment, has a frame made from carbon fiber, four 12 inch propeller with rotated by 620kV motors and 50A ESC, and a 6s battery. Meanwhile its avionics system is composed of an Arduino MEGA2560 as its MCU, an accelerometer, a gyroscope, an ultrasonic sensor, and an Xbee module. The quadrotor rotorcraft is shown in figure 5. Partnered with the quadrotor is a ground control system for data acquisition and user input. A GUI, shown in figure 6, was created for a real-time display on the current attitude and altitude as well as the target attitude and altitude.

Figure 5: Quadrotor Rotorcraft

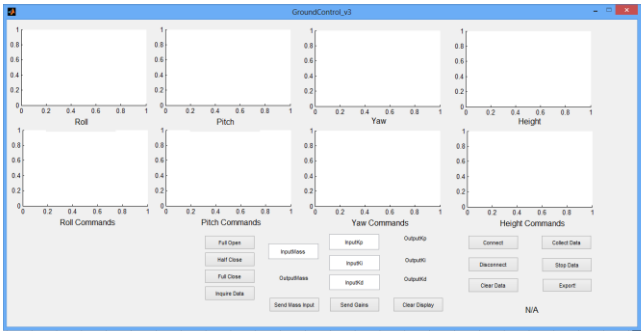

Figure 6: Ground Control GUI

Figure 7 shows the system diagram of a quadrotor rotorcraft. The readings from the three sensors are sent to the MCU after which it is processed and sent to the ESC to control the force output of the motors. Data are also received from the Xbee module to be sent to the MCU to process with the sensor readings and send the corresponding signal to the ESC.

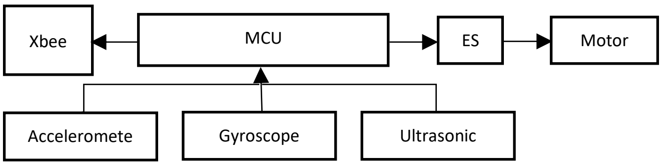

Figure 7: Quadrotor Schematics

Quadrotors do not have a built-in capability of delivering payloads. As such, a payload drop mechanism was designed and implemented on the quadrotor, using a slider crank mechanism, as shown in figure 8.The crank mechanism is connected to a motor for the drop action which is activated through the Xbox controller.

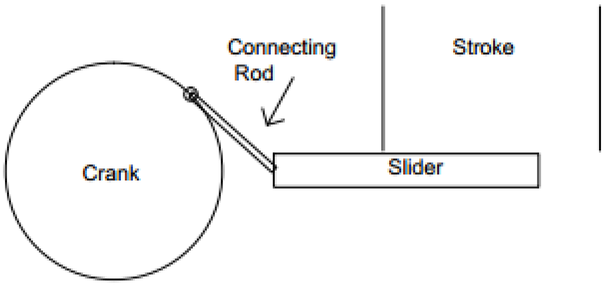

Figure 8: Payload Drop Mechanism (with crank connected to a servo unit)

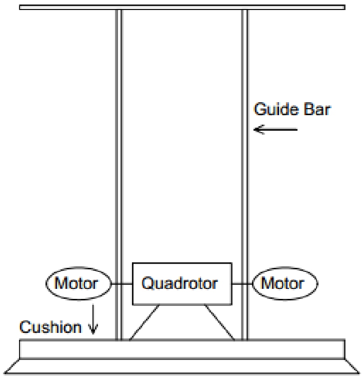

Figure 9: Payload Drop Test Rig

The quadrotor, being an underactuated system, has coupling effects amongst its degrees of freedom. To isolate the coupling effects of the motor was designed and used to determine the performance of the control algorithm. As shown in figure 9, the use of two vertical bars was proposed to lock the quadrotor in place while giving it the freedom to move along the Z-axis. The actual quadrotor test rig can be seen in figure 10.

Figure 10: Payload Drop Test Rig

III. RESULT AND DISCUSSION

The quadrotor was tested with payload drops of 100g, 200g, and 300g. Three control algorithms were tested for the payload drop maneuvers. These are the PID, the GS-PID, and the Fuzzy GS-PID. The difference between the GS-PID and the Fuzzy GS-PID controller used in this experiment is that the GS-PID has only one set of gains when payload drop occurs while the Fuzzy GS-PID controller controls the values of the gains dependent on the payload weight. The results of the experiments are summarized in figure 11.

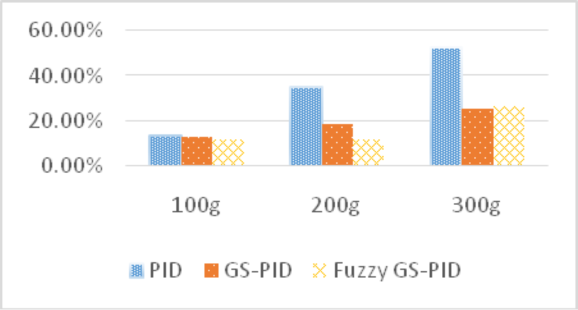

Figure 11: Payload Drop Results

For the 100g payload, all controllers have an overshoot of approximately equal to 12%. For the 200g payload, the PID controller has an overshoot of 35.23%, the GS-PID controller has an overshoot of 18.40%, while the Fuzzy GS-PID controller has an overshoot of 11.94%. For the 300g payload, the PID controller has an overshoot of 52.89%, while the GS-PID controller and the Fuzzy GS-PID controller has an overshoot of approximately equal to 26%. The results show us that due to the dynamic capability of the Fuzzy GS-PID controller to adapt based on the payload of the quadrotor, it was able to achieve the minimum possible overshoot for all controllers on each payload.

IV. CONCLUSION

This study showed the effectiveness of a Fuzzy GS PID controller in the Payload Drop Mission with variable payloads. The Fuzzy GS-PID controller, the GS-PID controller, and the PID controller were all tested with payload drops of 100g, 200g, and 300g. Comparisons between all controllers were made based on the overshoot of its altitude. As compared to the GS-PID controller, the Fuzzy GS-PID controller was able to 'adapt' to the mass of the payload and further reduce the overshoot of the system for each payload weight.

With the data presented, the idea of using UAV for payload drop mission is not that much far anymore. As we progress more on the study of UAVs, we will soon meet the end goal which is to use UAVs during search and rescue operations for disasters within the Philippines.

For future studies, the different gains of the PID can be explored to further reduce the overshoot of the system. Also, implementation of the controller to an actual flight is considered to verify its application for payload drop missions.

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