Glidding system for a fixed wing aircraft using PID control algorithm

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Abstract. In every Unmanned Aerial Vehicle (UAV) task, the power supply used is limited. UAVs are often forced to land when the battery runs out before the mission is completed. The gliding controller is proposed in this paper so that Fixed Wing Aircraft (FWA) can fly with minimal power and can adjust direction, altitude, zero pitch and zero roll stability. The FWA uses a Barometric Pressure Measure (BMP) 180 sensor at the tip of the wing to detect the difference in pressure experienced by both wings, therefore, the direction of the wind can be determined. The information of the wind direction was then used to maintain the desired altitude of the FWA. The Proportional Integral Derivative (PID) control algorithm was implemented to stabilize the FWA altitude to keep cruising or flying in a flat position. Real-time experiments using FWA have been conducted. It can be observed that the FWA was able to air with automatic glider mode for almost 2 minutes. Tests carried out include altitude data, roll and pitch movement from BMP180 sensor readings, the glidding performance has been observed with respect to the altitude, roll and pitch errors. It was measured that the altitude, the roll and the pitch errors were 1.74%, 0.23% and 0.34%, respectively.

1. Introduction
Unmanned Aerial Vehicle (UAV) otherwise known as a drone is an aircraft that is controlled without humans inside, and is controlled by a device from a remote control system via radio waves [1]. The UAV system is based on electro mechanics. UAVs can be used for programmed missions like a flying machine that is used as a remote control by a pilot. The UAV can be programmed to control itself and use the law of aerodynamics in the UAV so that it can lift itself and allow carrying loads such as certain items or a weapon [1]. There are 2 controls on UAV namely manual control and autopilot. Manual control is that UAVs carrying out flight missions require operators as UAV controllers to use communications remotely. While autopilot control is a UAV that performs its mission without being driven by the operator. This is because of the presence of the Global Positioning System (GPS) in UAVs where the operator only provides destination coordinates, the UAV aircraft will move to carry out the mission of flying the autopilot according to the specified coordinates [1]. Interest in UAVs continues to increase every year. This is marked by the increasingly widespread research that presents various types of UAV designs [2-6]. One UAV model that has been widely developed is the type of Fixed Wing Aircraft (FWA). FWA has the form of an ordinary airplane equipped with a wing system. Some applications from FWA such as for the military field are used to carry out an attack or defense mission of a country. In addition to the military field, the use of unmanned aircraft is also widely used in aerial
photography, documentary film [3], mapping an area [7], exploration data collection, regional monitoring / supervision [8] and identifying polluted air [6]. FWA is used to carry out a specific work mission but has limitations on the power used, so FWA is required to land when the battery is depleted, then a battery is replaced or re-charging. Increasing the duration of flights at FWA is necessary to be able to carry out the tasks of the mission to the maximum. Currently new ideas for autonomous soaring have been proposed to extend the durability of FWA flights. Soaring could be defined as flight in which a propulsion system is not used and favourable wind conditions are exploited to extend flight duration.

Soaring techniques are inspired by bird flight patterns [9]. This requires FWA to be able to extract wind energy to be at an elevated position [10]. We intend to implement FWA which can control the glider automatically so that FWA can air without using power. FWA is equipped with controls to maintain direction, altitude, zero pitch and zero roll stability. The FWA uses a BMP 180 sensor at the tip of each the wing to detect the difference in pressure experienced by both wings, thus FWA is able to determine the direction of the wind and maintain altitude towards the arrival of the wind direction. For stabilizing FWA using PID control which is able to help work from the aircraft stabilizer when exposed to wind both from above and below so that the aircraft is able to stabilize its position to keep cruising or flying in a flat position.

2. Proposed method
The FWA design proposed in the study is shown in figure 1.

In designing the UAV Glider, we must pay attention to various key aspects such as aspects of safety, flight reliability, durability, and accuracy. This study used a PID control method to make the direction of the fuselage to remain stable according to the set point based on the yaw angle. The stability of the direction of the fuselage is very important for stabilizing flight, therefore we need a control to set the direction of the fuselage in accordance with the given set point, the change in direction of the fuselage is a change in the plane angle obtained from balance the control of the actuator on the aircraft's rudder, so that the change in direction of the fuselage is obtained from the adjustment of the rudder's movement degree (-90˚ s / d + 90˚) by comparison with the set point given. Control of pitch stability is implemented on the aircraft so that stability is maintained at the pitch angle. When there is interference or air turbulence, the position of the elevator angle is changed until stability at a zero degree pitch angle, then the elevator position is straight to zero degrees. Control of roll angle stability is implemented on the aircraft to maintain stability on the roll angle. If there is interference or air turbulence then the position of the aileron angle is changed until stability at a zero degree roll angle. Data acquisition is the collection of BMP sensor reading data sent to the Ground station to be managed and analyzed. This collection technique is shown in figure 2.
This data acquisition technique starts from the data captured by the sensor sent every 1 second from NRF (TX) to NRF (RX). The data will be displayed on the laptop monitor to get data and graph results. The data variables include h namely height (meters); pitch (degree); roll (degree); yaw (degree); v is the speed of the plane (meter / second); degree (degree, degree); VBMP is wind speed (meter / second); and T is the power of the propeller (kv).

2.1. FWA design architecture
The FWA design architecture used in this study is shown in figure 3.

The embedded system used is Arduino Mega 2560 which functions as the main controller for processing the sensor data with the PID method to control the actuator and transmits the data to the NRF 24L01 transmitter. Gyro sensor (Accelerometer) MPU6050 functions as a tilt sensor which has stability sensitivity to yaw, pitch, and roll angles. Servo motors function as actuators to drive elevators, two ailerons and rudder. The NRF 24L01 serves to send and receive sensor data when the aircraft is in the air. Right and Left BMP 180 sensors are used to compare wind pressure from the left and right side. Set gliding mode is to activate gliding mode from the remote control below manually.
2.2. **Glider control system on FWA**

The Glider Control System in FWA proposed in this study is shown in figure 4.

![Diagram block of the glider control system](image)

**Figure 4.** Diagram block of the glider control system (a). Stability control of face direction (b). Stability control of pitch angle (c). Stability control of roll angle.

In Figure 4.a. there is a left BMP 180 that serves as a comparison with feedback. Right BMP 180 as a comparison with the left BMP 180 to detect the direction of the plane that will be feedback on the system. PID controller functions to set the direction of the plane with the servo motor actuator on the rudder according to the feedback on the system. A servo motor is used as an actuator to change the rudder motion. Whereas in Figure 3.b. Zero pitch is used as a set point. Gyro pitch sensor is a detector for pitch angle which will be feedback on the system. PID controller functions to set the direction of the plane with the servo motor actuator on the elevator according to the feedback on the system. A servo motor is used as an actuator to change the motion of the elevator. In Figure 3.c. there is a Zero roll used as a set point. Gyro roll sensor as a detection roll angle that will be feedback on the system. PID controller functions to set the direction of the plane with a servo motor actuator in the aileron according to the feedback on the system. Servo motors were used as actuators to change the motion of the aileron.

3. **Result and discussion**

FWA was tested flying for almost 10 minutes. Furthermore, the results of the test data were obtained, namely h, height (meters), roll (degrees) and pitch (degrees). This test was carried out in 3 stages started from the high testing of FWA for the reading of BMP180 sensors. In this test, the "height set point" was set at 155 meters. Then, roll movement tested on reading of the BMP180 sensor and finally, the Pitch movement against reading of the BMP180 sensor. These data were described in the graphic form shown in the figure below:

3.1. **Testing the stability of the FWA height**

This test is carried out to determine the performance of FWA in maintaining the set height when gliding mode is activated. The results of this test are shown in Figure 5.
Figure 5. Result testing the gliding mode (a) FWA height stability performance (b) Retrieving data in the gliding mode section.

In figure 5(a) shows that FWA was tested flying for almost 10 minutes. When the Gliding mode was activated and the set point set was 155 meters, the FWA shows stability at an altitude of 155 meters. In the conditions of the sliding mode, the FWA takes almost 2 minutes to maintain high stability. Then retrieving data in the gliding mode section refers to the one in figure 5(a) to be able to clearly see the ability of FWA stability in maintaining the height during gliding mode. This is done to find out in detail the height error when gliding mode and analyze it. This is shown in figure 5(b). Based on Figure 5(b), set the value of $K_p = 2.7; K_i = 0$ and $K_d = 0$ and the settling time was set to 1 second so that the time needed to reach the Setpoint state is 339 seconds with a height of “$h$” = 155.56 meters. The actual time duration when gliding mode was activated was 78 seconds (from 339 to 417 seconds). In this condition, the FWA gliding system will run automatically. But there is still oscillation which results in steady state error. Next, the height error value was computed during gliding mode. The calculation uses the following equation:

$$\bar{h} = \frac{\sum_{i=339}^{n} h_i}{n}$$

(1)

Where $\bar{h}$ is the average height data, $h_i$ = height data and $n$ = Amount of time. While Maximum Max $h$ (max) / $K_p$ is obtained $\pm 2.7$. Then look for the percentage (%) of the height error when gliding mode can be searched by:

$$\text{Height Error} (\%) = \left( \frac{h_{\text{max}}}{h} \times 100\% \right)$$

(2)

Where, $h_{\text{max}}$ = Maximum height value and $\bar{h}$ = Average height value. The $h_{\text{max}}$ value is 2.7 m and the mean height is known to be 155.15 m. Then, the height error percentage is obtained by:

$$\text{Height Error} (\%) = \left( \frac{2.7}{155.15m} \times 100\% \right) = 1.74\%$$

The height error percentage is used to determine the performance of the sensors used. The calculation results obtained by the percentage of altitude error is 1.74%, the error occurs due to the sensitivity of sensor readings based on air pressure, air speed when the aircraft and the speed of the plane itself and gravity factor.

3.2. Testing the movement of roll against BMP sensors

Testing the movement of the Roll against the BMP sensor is described in the graphical form shown in Figure 6. Figure 6(a) shows that FWA was tested flying for almost 10 minutes. In the conditions of the sliding mode, the FWA takes almost 2 minutes to maintain angle stability of Roll movement. Then retrieving the data in the gliding mode section refers to the one in figure 6(a) to be able to clearly see
the ability of FWA stability in the Roll movement in maintaining stability during the gliding mode shown in figure 6(b).

![Figure 6](image)

**Figure 6.** Results Testing of Roll movement against BMP sensors (a) The overall results of roll movement testing (b) Retrieve data in the gliding mode section of the Roll movement.

Based on Figure 6(b), set the value of Kp = 0.21, Ki = 0 and Kd = 0 and the settling time is 1 second. The time needed to reach the set point is 339 seconds with an angle $\phi = 89.27$ degrees. The actual time duration when gliding mode is activated is 78 seconds (from 339 to 417 seconds). In this condition, the FWA gliding system will run automatically. But there is still oscillation which results in steady state error. Next, the calculation of the percentage error angle on the roll movement during gliding mode. this can be done by:

$$\text{Roll angle error (\%)} = \frac{+ \phi_{\text{max}}}{\phi} \times 100\%$$  \hspace{1cm} (3)

$$\text{Roll angle error (\%)} = \frac{- \phi_{\text{max}}}{\phi} \times 100\%$$  \hspace{1cm} (4)

Where, $\phi_{\text{max}}$ = Maximum Peak Roll Value and $\bar{\phi}$ = Roll average value. Roll average value obtained $89.27$ degrees and the maximum peak value was $0.21$ and the minimum peak value was $-0.21$. then the percentage value of roll angle errors can be obtained:

$$\text{Roll angle error (\%)} = \frac{0.21}{89.27} \times 100\% = 0.23\%$$  \hspace{1cm} (5)

$$\text{Roll angle error (\%)} = \frac{-0.21}{89.27} \times 100\% = -0.23\%$$  \hspace{1cm} (6)

The results of the above calculations found the percentage of roll angle errors obtained at $\pm 0.23\%$. The error is still relatively small so that the FWA is categorized as still stable.

3.3. Testing the movement of pitch against BMP sensors

Testing the movement of the pitch against the BMP sensor is described in the graphical form shown in Figure 7. In Figure 7(a) shows that FWA was tested flying for almost 10 minutes. In the conditions of the sliding mode, the FWA takes almost 2 minutes to maintain angle stability of pitch movement. Then retrieving the data in the gliding mode section refers to the one in figure 7(a) to be able to clearly see the ability of FWA stability in the pitch movement in maintaining stability during the gliding mode shown in figure 7(b). Based on Figure 7(b), set the value of Kp = 0.29, Ki = 0 and Kd = 0 and the settling time is 1 second. The time needed to reach the set point is 339 seconds with an angle $\theta = 84.05$ degrees. The actual time duration when gliding mode is activated is 78 seconds (from 339 to 417 seconds). In this condition, the FWA gliding system will run automatically. But there is still oscillation which results in steady state error. Next, the calculation of the percentage error angle on the pitch movement during gliding mode. this can be done by:
Pitch angle error (%) = \( \frac{\theta_{\text{max}} - \bar{\theta}}{\bar{\theta}} \times 100\% \) \hspace{0.5cm} (7)

Pitch angle error (%) = \( \frac{-\theta_{\text{max}} - \bar{\theta}}{\bar{\theta}} \times 100\% \) \hspace{0.5cm} (8)

Where, \( \theta_{\text{max}} \) = Maximum Peak Pitch Value and \( \bar{\theta} \) = Pitch average value. Pitch average value obtained 84.05 degrees and the maximum peak value was 0.29 and the minimum peak value was -0.29. Then the percentage value of pitch angle errors can be obtained:

\[
\text{Pitch angle error} \ (%) = \frac{0.29}{84.05} \times 100\% = 0.34\%
\] \hspace{0.5cm} (9)

\[
\text{Pitch angle error} \ (%) = \frac{-0.29}{84.05} \times 100\% = -0.34\%
\] \hspace{0.5cm} (10)

The results of the above calculations found the percentage of pitch angle errors obtained at ± 0.34%. The error is still relatively small so that the FWA is categorized as still stable.

![Figure 7](image)

(a) Result of testing the movement of Pitch. (b) The overall results of pitch movement testing. Retrieve data in the gliding mode section of the Pitch movement.

4. Conclusion

FWA has been designed to fly with automatic glider mode for almost 2 minutes. Tests carried out include height stability, roll and pitch movements from BMP180 sensor readings. Gliding mode performance has been observed based on height, roll and pitch errors. It was measured that the percentage of height, roll and pitch errors were 1.74%, 0.23% and 0.34% respectively. The error occurs due to the sensitivity of sensor readings based on air pressure, air speed when the aircraft and the speed of the plane itself and gravity factor.

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References

[1] Valavanis K P and Vachtsevanos G J (Eds.) 2015 *Handbook of unmanned aerial vehicles* pp. 2993-3009 (Dordrecht, The Netherlands: Springer)

[2] Saroinsong H S, Poekoe V C and Manembu P D 2018 Rancang Bangun Wahana Pesawat Tanpa Awak (Fixed Wing) Berbasis Ardupilot *Jurnal Teknik Elektro Dan Komputer* 7(1) 73-84

[3] Li X and Yang L 2012 Design and implementation of UAV intelligent aerial photography system *Proc. 2012 4th Int. Conf. Intell. Human-Machine Syst. Cybern. IHMSC 2012* 2 200–203
[4] Setiawan J D, Ariyanto M, Munadi, Prabowo T and Haryanto I 2018 Design of a Low-Cost Fixed Wing UAV MATEC Web Conf. 159 02057

[5] Hu X and Huang X 2018 Orthogonal design and optimization of flight stability test for the quadrotor unmanned aerial vehicle Proc. 2017 IEEE Int. Conf. Unmanned Syst. ICUS 2017 2018-Janua 343–346

[6] Prisacariu V, Boscoianu M and Circiu I 2013 Design and construction a flying wing unmanned aerial vehicles Int. Conf. Mil. Technol. 2013 1–7

[7] Lee J, Min B and Kim E 2007 Autopilot Design of Tilt-rotor UAV Using Particle Swarm Optimization Method International Conference on Control, Automation and Systems 1629–1633

[8] Trost L C 2000 Unmanned Air Vehicles (UAVs) for Cooperative Monitoring (Sandia National Laboratories)

[9] Rayleigh L 1883 The soaring of birds Nature (27) 534–535

[10] Patel C and Kroo I 2008 Theoretical and Experimental Investigation of Energy Extraction from Atmospheric Turbulence 26th Int. Congr. Aeronaut. Sci. 1–11