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Experimental of Quadcopter Trajectory Tracking Control Based ROS

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Abstract

Nowadays, quadcopters are widely used in various needs, such as research, exploration, image taking, as well as observation. Quadcopter have received a great attention from researchers and the general public, as a platform on which various ideas can be easily demonstrated. However, from the control side, there are drawbacks, namely in general, the quadcopter is still controlled by someone with a remote control. Therefore, a program control system was designed to maintain the lateral motion of the quadcopter. The aim of this paper is to determine the parameters k_p, k_i, and k_d when the quadcopter moves towards the trajectory using manual tuning. PID (Proportional, Integral, Derivative) controller is used as the controller method for the trajectory tracking control system. The trajectory tracking control is evaluated through simulation and implementation with ROS. From the test results, it was found that the responses to translational motion simulation results on the X and Y axes still contained an error of ± 0.03-meter and ± 0.04-meter when the quadcopter walked along the track. Finally, the quadcopter Waypoint system was successfully implemented with an average distance difference between the quadcopter's final position and the actual destination position in the field of 1.49 meters.

Keywords
ROS, Quadcopter, Waypoint, PID Control

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INTRODUCTION

The development of science and technology has progressed in recent years to provide benefits for all aspects of human life. Moreover, the rapid developments in the fields of computers, electronics, mechanics, and robotics over the past few years have convinced us that more human-robot interaction is not a dream but a possibility that could occur in the future [1,2,3,4,5]. One of the developments in science and technology in today's digital era is unmanned aircraft [6,7]. Unmanned aircraft, Unmanned Aerial Vehicle (UAV), or drones in general, are currently experiencing a very fast revolution. Technology related to drones has experienced very significant progress, starting from systems, control [8,9], security [10], and communication [11,12].

In [13], the types of Unmanned Aerial Vehicles divided into five categories, based on their design characteristics: Fixed-wing, Rotary-wing, Blimps, Flapping wing, Parafoil-wing. The rotary-wing UAVS, also called rotorcrafts, offer the advantages of steady flying at one place while keeping the maneuverability attribute. A UAV of this type may be an unmanned helicopter and multi-rotor. Multi-rotor includes rotary-wing UAVs with four or more rotors (quadcopter, hexacopter, octocopter, etc.).

The quadcopter has a GPS (Global Positioning System) which functions as a coordinate and location tracking component. So that the quadcopter can maintain its position while flying and this can be implemented for aerial photography, aerial mapping, and aerial monitoring. Despite the advantages and disadvantages in aerial photography and mapping, quadcopters are generally still controlled by pilots with radio control for mapping [14].

Based on these problems, a quadcopter will be designed with the ability to move based on the waypoints that have been determined in the program that has been made. The purpose of this research is to apply the control function to the drone by entering the waypoint program so that the drone with 4 rotors can move to predetermined coordinates. Design of control laws forced a quadcopter to reach and follow a time parameterized reference (i.e., a geometric path with an associated timing law).

METHOD

PID control is the most widely used because it combines the advantages of each type of control. This includes faster response times due to P-only control, along with a decrease/zero offset from the combined integral and derivative controllers. This offset was removed by additionally using I-control. The application of a PID controller is to regulate temperature, flow, pressure, speed, and other process variables. In designing a PID control system, what must be done is to set the P, I or D parameters so that the output signal response from the system to certain inputs is as desired.

System Design

The purpose of this research is to be able to control a quadcopter drone with a control system that uses the PID method so that it can move towards a specified coordinate point. In making this system used robot operation system (ROS) which is an open-source robotics middleware. The description of the system created can be seen in Figure 1.

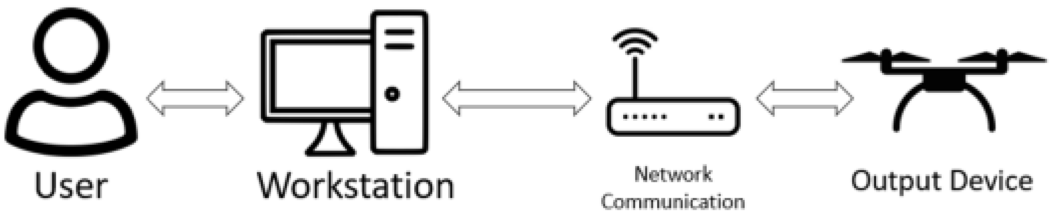

Figure 1. System Design

Figure 1 is an illustration of the control system that is made. the design system aims to make the quadcopter move according to predetermined coordinates. To obtain coordinate information, the system requires GPS to determine the quadcopter's location and uses that location as a feedback sensor to compare the transmitter's location coordinates with the quadcopter's current coordinates. The quadcopter will periodically send location data so that the quadcopter's position can be monitored.

Path-Planning System

The application of the Trajectory-Waypoint concept to control the quadcopter can be seen in Figure 2. The workstation will be wirelessly connected to the local network to the router attached to the quadcopter. The workstation functions to launch control and integration programs on the quadcopter in which there are waypoint-trajectory coordinates. The quadcopter is planted with a Raspberry Pi 4 which functions to exchange data.

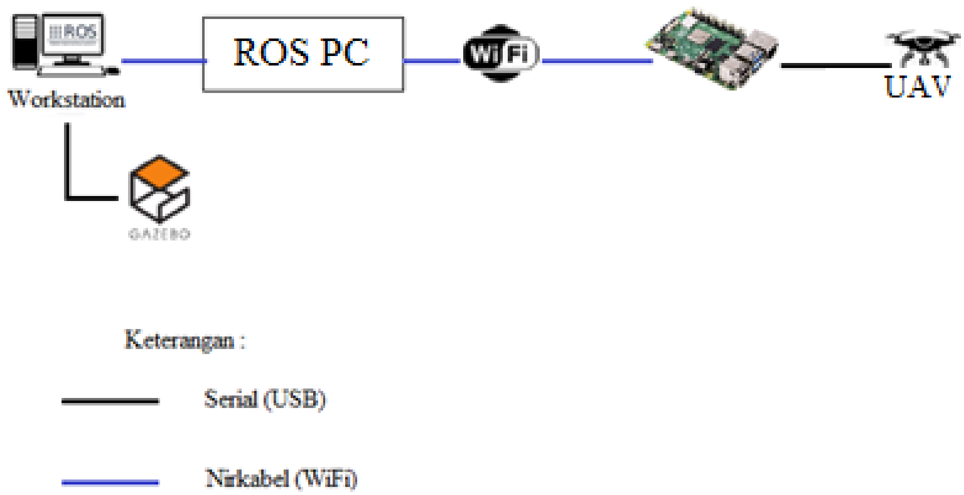

Figure 2. Path-Planning System

Flowchart

The system can be seen in the flowchart Figure 3. The system is started by setting up a wireless/serial network on a laptop/pc and Raspberry Pi-4 to connect. Then proceed with running mavros ROS on a laptop/computer to connect with FCU Autopilot on the quadcopter. Then the program for Trajectory is run on the laptop/computer. The system is complete if the quadcopter has landed at the specified destination point.

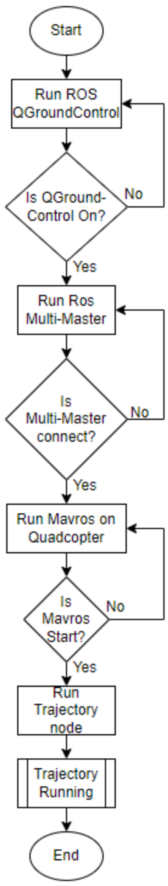

Figure 3. Flowchart System

RESULTS AND DISCUSSION

System testing is done by simulation and experiment. This is done to analyze whether the tuned PID control parameters provide the appropriate trajectory tracking output based on input to the system. In testing, the drone was moved using forward, right, left, and rear programs. Each direction is moved 2m, 3m and 4m. The system will be tested first in the simulation. The purpose of this test is to compare the results using PID and without PID. The tuning results of the PID parameters are as follows: for Roll, parameters k_p= 5,838; k_i=0,238; and k_d=0,004. For Pitch, parameters k_p= 5,164; k_i=0,246; and k_d=0,004.

Simulation Results

The first simulation is carried out by moving the quadcopter in the simulation 10 times to the destination coordinates as far as 2m, 3m and 4m on **the positive Y axis**. The average results are shown in Table 1, Table 2, and Table 3.

Table 1. Results Comparison of positions with a set point 2m to the positive Y axis.

Forward Movement (Y+)		
Set Point [2m]	**Results (without PID)**	**Results (with PID)**
Average	2,2426	1,9929
Average Error	0,6470	0,0153
Error (%)	28,8%	0,8%

Table 2. Results Comparison of positions with a set point 3m to the positive Y axis.

Forward Movement (Y+)		
Set Point [3m]	**Results (without PID)**	**Results (with PID)**
Average	3,1681	3,0251
Average Error	0,7721	0,0416
Error (%)	24,4%	1,4%

Table 3. Results Comparison of positions with a set point 4m to the positive Y axis.

Forward Movement (Y+)		
Set Point [4m]	**Results (without PID)**	**Results (with PID)**
Average	4,2059	4,0457
Average Error	1,0066	0,0479
Error (%)	23,9%	1,2%

In Table 1, the drone moves from point (0,0) to (0,2) which means the drone moves according to the axis (moves towards the Y axis). Because the drone only moves forward (Y+), the focus of the error calculation is only on Y. The average error is the result of 10 simulations that have been carried out. The average error on the 2m goal is 28,8% without a PID controller and 0,8% when using a PID controller. In Table 2, the average error on the 3m goal is 24,4% without a PID controller and 1,4% when using a PID controller. In Table 3, the average error on the 4m goal is 23,9% without a PID controller and 1,2% when using a PID controller.

Then, second simulation is carried out by moving the quadcopter in the simulation 10 times to the destination coordinates as far as 2m, 3m and 4m on **the positive X axis**. The average results are shown in Table 4, Table 5, and Table 6.

In Table 4, the drone moves from point (0,0) to (2,0) which means the drone moves according to the axis (moves towards the X axis). Because the drone only moves forward (X+), the focus of the error calculation is only on X. The average error on the 2m goal is 27,1%

without a PID controller and 0,8% when using a PID controller. In Table 5, the average error on the 3m goal is 24,4% without a PID controller and 1,3% when using a PID controller.

In Table 6, the average error on the 4m goal is 24,7% without a PID controller and 0,6% when using a PID controller.

Table 4. Results Comparison of positions with a set point 2m to the positive X axis.

Forward Movement (X+)		
Set Point [2m]	**Results (without PID)**	**Results (with PID)**
Average	2,1536	2,0070
Average Error	0,5840	0,0160
Error (%)	27,1%	0,8%

Table 5. Results Comparison of positions with a set point 3m to the positive X axis.

Forward Movement (X+)		
Set Point [3m]	**Results (without PID)**	**Results (with PID)**
Average	3,0759	3,0366
Average Error	0,7500	0,0391
Error (%)	24,4%	1,3%

Table 6. Results Comparison of positions with a set point 4m to the positive X axis.

Forward Movement (X+)		
Set Point [4m]	**Results (without PID)**	**Results (with PID)**
Average	4,1781	4,0196
Average Error	1,0302	0,0245
Error (%)	24,7%	0,6%

Next, third simulation is carried out by moving the quadcopter in the simulation 10 times to the destination coordinates as far as 2m, 3m and 4m on **the negative Y axis**. The average results are shown in Table 7, Table 8, and Table 9. In Table 7, the drone moves from point (0,0) to (0, -2) which means the drone moves according to the axis (moves towards the Y axis). Because the drone only moves forward (Y-), the focus of the error calculation is only on Y. The average error is the result of 10 simulations that have been carried out. The average error on the 2m goal is 27,8% without a PID controller and 1,6% when using a PID controller.

Table 7. Results Comparison of positions with a set point 2m to the negative Y axis.

Forward Movement (Y-)		
Set Point [2m]	**Results (without PID)**	**Results (with PID)**
Average	2,2110	2,0321
Average Error	0,6145	0,0334
Error (%)	27,8%	1,6%

Table 8. Results Comparison of positions with a set point 3m to the negative Y axis.

Forward Movement (Y-)		
Set Point [3m]	**Results (without PID)**	**Results (with PID)**
Average	3,1654	3,0742
Average Error	0,7694	0,0748
Error (%)	24,3%	2,4%

Table 9. Results Comparison of positions with a set point 4m to the negative Y axis.

Forward Movement (Y-)		
Set Point [4m]	**Results (without PID)**	**Results (with PID)**
Average	4,1636	4,0411
Average Error	1,0166	0,0566
Error (%)	24,4%	1,4%

In Table 8, the average error on the 3m goal is 24,3% without a PID controller and 2,4% when using a PID controller. In Table 9, the average error on the 4m goal is 24,4% without a PID controller and 1,4% when using a PID controller.

The last simulation is carried out by moving the quadcopter in the simulation 10 times to the destination coordinates as far as 2m, 3m and 4m on **the negative X axis**. The average results are shown in Table 10, Table 11, and Table 12.

Table 10. Results Comparison of positions with a set point 2m to the negative X axis.

Forward Movement (X-)		
Set Point [2m]	**Results (without PID)**	**Results (with PID)**
Average	2,0179	2,0244
Average Error	0,4958	0,0275
Error (%)	24,6%	1,4%

Table 11. Results Comparison of positions with a set point 3m to the negative X axis.

Forward Movement (X-)		
Set Point [3m]	**Results (without PID)**	**Results (with PID)**
Average	3,0974	3,0055
Average Error	0,7195	0,0223
Error (%)	23,2%	0,7%

Table 12. Results Comparison of positions with a set point 4m to the negative X axis.

Forward Movement (X-)		
Set Point [4m]	**Results (without PID)**	**Results (with PID)**
Average	4,2556	4,0415
Average Error	1,0556	0,0419
Error (%)	24,8%	1,0%

In Table 10, the drone moves from point (0,0) to (0, -2) which means the drone moves according to the axis (moves towards the X axis). Because the drone only moves backward (X-), the focus of the error calculation is only on X. The average error on the 2m goal is 24,6% without a PID controller and 1,4% when using a PID controller.

In Table 11, the average error on the 3m goal is 23,2% without a PID controller and 0,7% when using a PID controller. In Table 12, the average error on the 4m goal is 24,8% without a PID controller and 1,0% when using a PID controller.

Experimental Trajectory Tracking Results

Experiments were carried out to find out the results of implementing waypoint controllers from workstation to quadcopter. Figure 4 shows the movement graph results and Figure 5 shows the waypoint-trajectory results. The graph results show that the system starts with the quadcopter moving upwards as high as 2m. Then the quadcopter moves forward 2m. After that go right 2m. Then the quadcopter moves 2m backwards and 2m leftward so that it returns to its original point. After that the quadcopter moves to the left for 2m. Then move backwards 2m. After that, move 2m to the right and 2m forward so that the quadcopter returns to its original point. So, the picture shows that the system makes a figure eight at a height of 2m. In response to translational motion simulation results on the X and Y axes there are still errors of ± 0.03m and ± 0.04m when the quadcopter walks along the track.

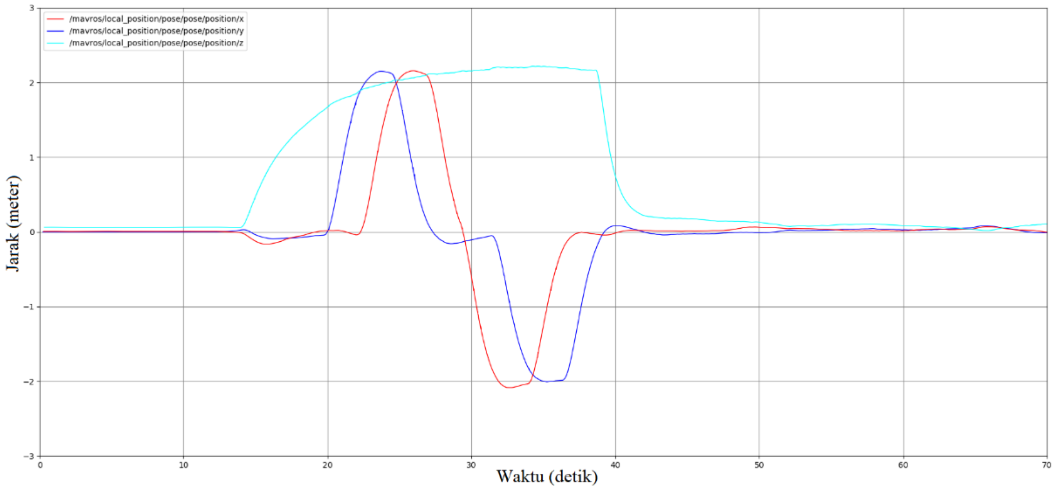

Figure 4. The Movement Graph Results

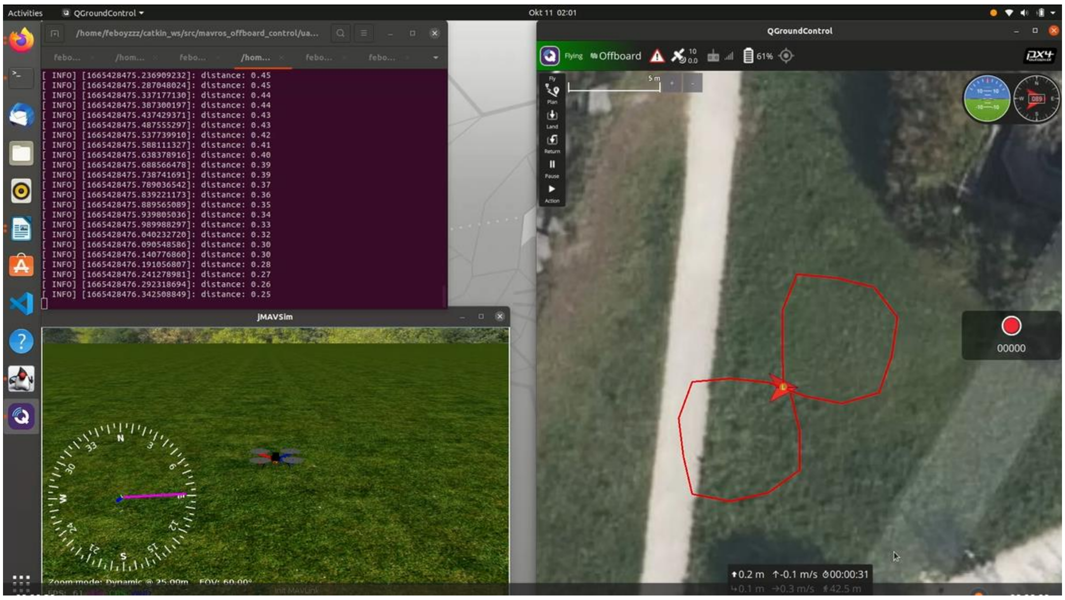

Figure 5. The Movement of Waypoint-Trajectory Experimental Results

Discussion

Based on the simulation results, it can be analyzed that the PID controller is functioning properly. This can be seen when the drone moves towards the positive Y-axis, without PID, the average error is 27.7% and if using PID, the average error is 1.1%. meanwhile when the drone moves towards the Y-negative axis, if without PID then the average error is 25.5% and if using PID then the average error is 1.8%. Then when the drone moves in the direction of the positive X-axis, without PID, the average error is 25.4% and if using PID, the average error is 0.9%. After that, when the drone moves towards the X-negative axis, without PID, the average error is 24.2% and if using PID, the average error is 1.0%.

So, the total average error of system test results without PID is 25.2% and 1.2% if using PID. The results show that the PID controller reduces system errors. It is proved that the PID controller can be applied to the trajectory tracking control system. Shown from the movement of the quadcopter according to predetermined waypoint coordinates.

CONCLUSION

Based on the testing results both simulations and experiments as well as the analysis that has been carried out on the quadcopter trajectory tracking control using ROS, it shows that the PID of control used is suitable to be applied and work well. Responding to the simulation results of translational motion on the X and Y axes, there is still an error of ± 0.03 meters and ± 0.04 meters when the quadcopter travels along the track. The quadcopter waypoint system has been successfully implemented in a system with an average distance difference between the quadcopter's final position and the actual destination position in the field of 1.49 meters.

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