Correlation of Hardware in the Loop Simulation (HILS) and real control vehicle flight test for reducing flight failures

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Abstract. After development of simulation system in laboratory tests has been completed, before implementing an autonomous flight control system directly in a high speed UAV, the system needs to be tested in a ‘transitional’ vehicle namely Clouds aeromodeling, to make sure all devices of the control system function well in manual mode, stability and auto pilot by way point. Compatibility of setting gain PID in the simulation test with the real flight test becomes a challenge to ensure the success of the vehicle in flying, as probability of flight failures or target missing is reduced. This research has successfully proven the compatibility of the gain PID in an auto pilot by way point flight condition.

1. Introduction
1.1. Background
LAPAN now has the competence in development of aerospace technology, especially in Rocket Technology Center. It has the chance to develop technology of rocket in Indonesia, from ballistic type to controlled rocket in order to develop the Satellites Launching Vehicle (Roket Peluncur Satelit/RPS). RPS is not only a layered ballistic rocket but also a one in need of control for speed and direction when entering the targeted orbit. Thus, a development of a control system for high speed vehicle is absolutely needed.

The flight test of high speed UAV (called RKX-200TJ, figure 1) has been repeatedly done with the result of crashes and some are successful. But all flight tests are still using a flight controller that is ready on the market (Ardu Pilot), and just need a few settings as a user in general to fly the high speed UAV.

Figure 1. High speed UAV, RKX-200TJ.
The development of autonomous control system consisting hardware and software for high speed control flying vehicle (minimum speed 200 km/h) was started from the development stage of hardware in the loop simulation to the direct test in a flight test in Pandanwangi, Lumajang by the end of 2016. It was completed but did not succeed because the booster exploded [1]. It means that the system had not been tested in the flight test.

The test leapt from HILS to the real flight test of high speed UAV, which was too risky since the entire setting relied merely on the results from laboratory test. Thus, it needed a ‘transitional’ flight test that could precede a costly and highly dangerous flight test using high speed UAV. This transitional vehicle should be pursued as close as possible to its control model approaching high speed UAV which will become the ultimate vehicle testing of this autonomous control system.

1.2. Problem identification
It is generally known that in scientific research, theories may not be similar to the real research results. In other words, simulation results may not be used directly in the real flight test, in terms of development of controlled vehicle. Consequently, it needs a significant approach to make simulation results applicable directly in a ‘transitional’ vehicle flight test (aeromodeling aircraft). It should cover how to make the entire setting gain PID applied in the simulation useable in the flying vehicle, both in stability and auto pilot by way points mode.

It is very important to make sure that the entire simulation results in integrated manner can become a reference in setting gain PID for use in the real flight [2]. Therefore, HILS needs to use directly the exact controller for the real flight test, so the attitude of vehicle in the simulation can be analyzed and compared in the same condition as in the real flight test.

The use of PID control in controlling flight vehicle in simulation tends to have ideal parameters [3]. However, when the program is realized for the real flight test, it becomes over sensitive (creating oscillation) and not accurate for certain processes, including pitch control.

1.3. Research significance
Technology mastering in autonomous control system is a complex research because the system has to overcome flight vehicle problems in terms of its stability inner loop and navigation outer loop. Thus, this research is intended as:
1. Simulation of modeling approach with the real flight vehicle.
2. Simulation of setting gain PID approach with the gain PID in the real flight.
3. Concept of control system for the UAV with minimum flight failure.

2. Methodology
This research is a ‘transitional’ research before an autonomous control system is used directly in a high speed UAV. The ‘transitional’ vehicle used in this test was an aeromodeling craft, Clouds. Stages completed in this research were:
1. Vehicle modeling in Flight Simulator

![Figure 2. Clouds aeromodeling.](image)

Clouds is a very stable aeromodeling vehicle, having 2 propellers and a V tail (figure 2). Its aerodynamic motion field was functioned limited to aileron and elevator. It had wing span of 1880 mm and length 960 mm, and was able to fly with maximum speed 80 km/h. Clouds had to
be modelled in X-Plane Flight Simulator [4][5] using all specifications it had, in order to create a simulation as similar as possible as its real flight condition.

The Clouds modeling (figure 3) featured all specifications of Clouds that were included as parameters of simulation vehicle model. Those parameters included vehicle dimension, motion field, engine specification and location, and simulation landing gear replacing hand launch using JATO (Jet Assisted Take Off). And only use the aileron and elevator as a field of motion for stability and auto pilot flight, as used by our high speed UAV.

This model’s ability to fly stable needed to be ensured using a mouse computer or a joystick. Moreover, data communication between flight simulator and system control computer used UDP (User Datagram Protocol), which sent position data (Longitude, Latitude and Altitude), IMU (Roll, Pitch and Yaw), angular velocities, speed, throttle command and engine force, as well as received command in the form of data aileron, elevator, throttle and landing gear.

2. Setting system in Integrated Simulation System

The control system used in Clouds was similar to that being developed for high speed UAV [6], namely NI-MyRIO completed with IMU sensor 3DM-GX3-25 product MicroStrain, GPS, MaxStream telemetry system and Remote Control. All manual program, stability and auto pilot were developed using LabView software [7][8]. This system had to be connected by hardware in the loop simulation (HILS) [9] in the previously developed Integrated Simulation System (ISS).

Block diagram in figure 4 is a simulation system consisting of 3 microprocessors. One of them was a dynamic computer acting as flight simulator system, another one was a controller computer acting as bridge between flight simulator and main controller of the vehicle connected using shared memory, and the other was the main controller (MyRIO) [10] that processed all input data of attitude, position, and made output data of motion field in close loop using PID control.

Real GPS and IMU sensor in the block main controller in this simulation was intendedly shut down, and replaced with position and attitude data from X-Plane flight simulator. The simulation needed to use the real Remote Control when flying a vehicle in the simulation. It means that the change in manual mode, stability and auto pilot could be directly done using the remote control.

![Figure 4. Block diagram of Clouds simulation on HILS.](image)

3. Implementation of gain PID in the real flight test of Clouds

The control strategy implemented in the test used PID control which was programmed in FPGA (Field Programmable Gate Array) controller [11][12]. Thus, the entire stability process and
maneuver could be done in parallel and real time. This result simulation of setting PID was used as optimum as possible to be implemented in the real flight test of Clouds.

3. Results and Discussion

Programming of Clouds autonomous control system was developed using software LabView in an FPGA-based micro controller. The control PID strategy implemented to control several processes in parallel at the same time. Thus, the programming structure became easier, starting from implementation of manual mode, stability, until the most complex one, the auto pilot mode.

As the entire flight procedure—from take off until auto pilot—was considered done in the simulation, including switching manual mode, stability and auto pilot, so the pressure point to tackle to ensure the success of the vehicle flight was the direction issues of moving fin and gain PID in each process, including speed control [13]. Misdirection of moving fin might be fatal; for example, when it was supposed to be roll left, it went roll right; or when it was supposed to pitch up, it went pitch down instead. Moreover, this Clouds elevator had servo with different direction, so it needed additional program to synchronize command of elevator move. All processes above used many kinds of PID, as stated in table 1 below.

| No | PID   | Input            | Variable | Function                                      |
|----|-------|------------------|----------|-----------------------------------------------|
| 1  | Roll 1| 0                | Roll     | Control roll in auto take off mode and stability |
| 2  | Roll 2| Banking Angle    | Roll     | Control roll in auto pilot mode               |
| 3  | Altitude | Altitude Target | Altitude | Control altitude in auto pilot mode           |
| 4  | Pitch 1| 0                | Pitch    | Control pitch in stability mode               |
| 5  | Pitch 2| Altitude         | Pitch    | Control pitch in auto pilot mode              |
| 6  | Banking| 0                | Heading  | Control heading when maneuvering in auto pilot |
|    |       |                  | Target   | mode                                          |
| 7  | Speed | Desire Speed     | Speed    | Control speed in auto pilot mode              |

A right setting gain PID is needed to ensure that the vehicle would not fall in the real flight test. Thus, all setting gain PID and other settings need to be simulated to check its attitude result (figure 5). More detailed analysis for all output of the simulation is needed and the result must be compared with the real flight test, to gain an optimum closeness for all modes being tested, especially in stability and auto pilot mode.

The real flight test was done in Cibubur Aeromodeling Club (CAC), located in Taman Wiladatika Cibubur area. It had a not too long air strip. Because of limitation in the remote control in use, the Clouds flight test had radius within not more than 300 to 400 meters.

3.1. Stability mode

After the entire flight test was considered successful in all maneuvers, by doing trimming especially in roll and pitch conditions, the next step was stability mode. This mode was functioned to ensure that the micro controller was able to put the vehicle in zero roll and zero pitch position. It means that the vehicle might fly straight despite wind disturbance or any other intentionally disturbing conditions. In this mode, throttle was still functioned manually.

After several improvements in gain PID control in simulation and real flight test, the vehicle could complete the stability mode well, though it had to face unexpected conditions. However, because of narrow testing field and limited range of the remote control, the flight test was done within an area with radius 300 to 400 m. Thus, stability time was

Figure 5. Monitoring flight test.
passed around 16 seconds. Figure 6 shows the roll and pitch data in stability mode; both tended to come near the point zero position, according to its program. However, the vehicle’s altitude always went down in the stability mode, though it finally sloped to 132 km/h, as seen in figure 7. This means that the aileron and elevator, according to the each gain, try to perform level conditions and fly straight (level on roll and pitch). Although there is a decrease in altitude for a moment, but the elevator tries to level conditions, so it can be seen that the vehicle can maintain its altitude.

**Figure 6.** Roll and pitch in stability mode in real flight test. **Figure 7.** Altitude in stability mode in the real flight test.

If compared with the simulation result in stability mode and followed by auto pilot mode (figure 8 and 9), it showed similar symptoms, under which the altitude decreased, but then the micro controller could maintain its flying height. It should be noted that in this simulation, there was no limitation of range and narrow location, as in Cibubur. So, the simulation and test needs to be held in Rumpin airport.

**Figure 8.** Roll and pitch in the simulation. **Figure 9.** Altitude in the simulation.

3.2. Auto Pilot Mode

The next step was Testing Clouds in the real flight test using the auto pilot mode by way point, as seen in the figure 10. The flight test area in Cibubur was very narrow, with densely populated area on the northern side and view-limiting big trees (figure 11). Because of the condition in Cibubur and concern of possible loss of range of remote control, the test both in simulation and real flight test was adjusted and set for 1 point as the target.

The test was done several times to get the right gain PID for the auto pilot mode, by comparing the gain PID of the simulation result. The flight test result explains in the figure 12, roll data directed the vehicle to the target, roll left and roll right. Similar to stability mode, this time the aileron movement is
not maintained as leveler but it is attempted to direct the vehicle to the point target which causes left and right of the roll. At the same time, pitch data showed the system efforts in maintaining altitude according to the target, though the altitude had got down for a moment (figure 13), similar to moment of stability mode.

The validity of all roll data, pitch, and altitude was confirmed by range and heading data. As seen in figure 14, the distance from the vehicle to the target became narrower, until not more than 100 m. It means that the vehicle, which was about 400 m from the target, flew automatically to the target until reaching point of 100 m away from the target. Referring to the number 100 m, the vehicle was considered reaching the target with accuracy of 100 m range. The number may be adjusted, depending on the accuracy of its GPS.

![Figure 10. Preparation for Clouds flight test.](image1.png)

![Figure 11. Location of flight test in Cibubur.](image2.png)

![Figure 12. Roll and pitch in auto mode in the real flight test.](image3.png)

![Figure 13. Altitude in Auto mode in the real flight test.](image4.png)

![Figure 14. Range in auto mode in the real flight test.](image5.png)

![Figure 15. Heading in auto mode in the real flight.](image6.png)
Apart from heading data (figure 15) also showed that vehicle heading to the target reaching and maintain 0 deg. It means that the vehicle, in such a way, was directed by the micro controller automatically facing the target, and always corrected to head to 0 deg.

All efforts in the autonomous control system development successfully made the vehicle of Clouds fly using auto pilot mode heading to the target although with only 1 way point. There were little differences in gain PID number 2 (roll) and 5 (pitch) seen in table 1, while other gain PID were the same value for the simulation and the real flight test.

4. Conclusion and recommendation
The simulation test and the real flight test were supporting each other in developing the autonomous control system before being applied in the real high speed UAV, because the autonomous flight control system used in the transitional vehicle, Clouds are the same as the high speed UAV flight control system that will be used later. Development of simulation system and modeling approach with the real flight vehicle, and setting PID for this simulation managed to provide convenience (time, cost, man power, etc.) in several procedures and settings in the real flight test. The aeromodeling Clouds flight control system succeeded in the maneuver heading and reaching to the point target was in line with the procedure of development and setting gain PID in the simulation. This means that the simulation system approach to real flight testing will help a lot in reducing flight failure rather than being tested directly without simulation. Hopefully, there may be other chances to test this autonomous control system in further flight tests, so steps to reach mastering in high speed UAV and rocket control system can be realized.

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Author Statement
The author hereby declares that the entire contents of this paper are on the responsibility of the author.

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