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Development Steps of Avionics and Flight Control System of Flight Vehicle

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Abstract

The success of a research is highly dependent on the method adopted, especially research related to dangerous and expensive matters which will certainly require special handling in the development or maintenance steps. One of them is research related to space technology such as aviation and rocketry technology which is very dependent on the design model of the flying vehicle and in general will always use simulation to ensure that the entire system being built is carried out safely and can be implemented properly according to plan. In the development of the flying vehicle prototype, especially the development of the avionics and flight control system, the vehicle will go through sequential simulation steps from Software in the Loop Simulation (SILS), Hardware in the Loop Simulation (HILS), and Ready to Fly System (RTFS). In this paper, the simulation steps will be described with the intention of facilitating integration and testing of each sub-system being developed, testing the control strategy applied or eliminating bugs if something goes wrong. And in the end, with a series of flying vehicle simulations, it can be developed quickly, cost-effectively, including saving human resources.

Keywords: *software in the loop simulation (SILS); hardware in the loop simulation (HILS); ready to fly system (RTFS)*

1. Introduction

The success of a research is highly dependent on the method adopted in completing the research. In particular, research related to dangerous matters such as nuclear will certainly require special handling in the development, management and maintenance steps, as was done in the case study of the Democratic Republic of the Congo [1], about prevention and management of risks related to radiological and nuclear materials. In addition, expensive research also often requires indirect simulation before entering the actual development step. One of them is that research related to space technology such as aviation and rocketry will always require the use of a model or simulation to ensure that the entire system to be built is categorized as safe and can be implemented properly according to plan. This has been widely used in dynamic modeling of sounding rockets related to wind compensation method [2], or in research related to modeling the performance, numerical and experimental anaylsis of liquid rocket motors [3], [4]. Therefore, the development step of a technology related to Unmanned Aerial Vehicle (UAV) or rocketry must be developed by simulation in steps up to a prototype or even success in its flight test. In addition, support for the development environment / software environment such as simulation rockets developed using open-source software for rocket motors made from sugar composite propellant to measure apogee [5], as well as the hardware used will be very decisive in the simulation step and its implementation directly on the hardware used, as the author himself has done in developing an autopilot system for UAVs using optimal flight control system [6].

The development of a flying vehicle such as a UAV or rocket is built from many scientific fields, such as aerodynamics, flight dynamics, materials & structures, propulsion, mechanics & electronics, and others. For example, KAIST (Korea Advance Institute of Science and Technology) is in the development of a hybrid rocket, involving several other companies that are experts in their field. KAIST Satellite Technology Research Center itself develops the non-pyrotechnic recovery system, while the company Naraspace Technology develops the avionics part of the rocket [7].

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Therefore, it would be a very fatal mistake, when the development of the vehicle's avionics and flight control system was carried out in a hurry. This will raise the level of danger that arises when there is a malfunction or failure in software or hardware of the vehicle being developed.

As one example of the flying vehicle discussed in this paper is the rocket, which is a flying vehicle that moves 6 Degree of Freedom (DOF), meaning that all translational and rotational motion of the rocket is a critical point that can result in flight failure if an error occurs in the sensor reading or program in the rocket system. This 6DOF condition becomes a reference to the use of appropriate control strategies in maneuvering a flying vehicle such as the development of guidance and control of 2ndstage missile using proportional and navigation approach [8]. Especially in the development of a flight control system (FCS) on a guided-missiles, it is not possible to develop it directly in a flight test, but must be carried out in steps and completed in a simulation first. In this research, efforts have been made in order to achieve success and safety in the development of a rocket, by conducting simulation steps that guiding research to be carried out step by step in order to cut time, costs and human resources. Hopefully, the sequences and simulations that involve software, hardware in this paper can become a role in the development of a flying vehicle, UAV or rocket.

2. Research Methods

In the development of each rocket subsystem, an in-depth study of the components of the rocket must be carried out. Simulation is the most important part to show that each of the sub-systems developed has passed the ground test through the techniques and tests that should be carried out. Furthermore, it is also necessary to carry out integrated testing of all sub-systems, to ensure that the relationship between the sub-systems is running well, and that all flight test preparation procedures have been carried out. This means that the test parameters in the sub-system and integrated test scale must be met and in accordance with the planned parameters. Especially in the development of multi-stage or guided rockets, it is necessary to add step by step procedural testing of events that occur during the flight test later. These testing stages can be carried out by developing self-made test simulation software or using simulation software that is already on the market, such as design, analysis and simulation of a Single Stage Rocket (Launch Vehicle) using RockSim software [9].

In developing a rocket avionics system (RAS) and flight control system (FCS) from a ballistic missile or guided missile, it must be developed in steps, connected to flight parameters and mechanical structural conditions by carrying out several simulation sequences: Software in the Loop Simulation (SILS); Hardware in the Loop Simulation (HILS); Ready to Fly System (RTFS); and Integrated Rocket Test System (IRTS).

Domestic rocket development is fully carried out by BRIN, National Research and Innovation Agency of Indonesia (formerly LAPAN, Indonesian National Institute of Aeronautics and Space) which also adheres to this method for the avionics and flight controls of the rocket. However, actually the science of rocket development consists of many lines of science, from aerodynamics, structure, chemistry, mechanics, electronics and others. BRIN is collaborating with all relevant research institutions, universities and the defense industry to jointly develop this rocket to increase national resilience and technological independence, especially rocket technology.

3. Results and Discussions

Before carrying out the simulation steps, it is necessary to collect all the requirements specifications and variables that accompany the development of a rocket or guided missile. Dimensions, aerodynamic variables and the position of the moving fin (canard) as well as the control strategy to be used, must be known from the outset and ready to be involved in the simulation later.

3.1. Software in the Loop Simulation System (SILS)

This SILS is an initial stage that is developed from a whole series of simulations until the rocket is ready to launch, as illustrated in the block diagram of Figure 1 (a). The data required at this step is the result of the design in the form of the dimensions of the rocket and all of its specifications, such as thrust, burning time, launch angle, flight time, speed, apogee, down range and others. For the initial stage of this simulation, it is assumed that the rocket will only launch ballistically without being controlled first. At this step, 2 computers are needed that are connected using the User Datagram Protocol (UDP) to communicate with each other (Figure 1 (b)).

The dynamic computer, which functions as a flight simulator, uses the X-Plane software as a means of simulating the movement of the entire rocket during flight. This dynamic computer will show a detailed view of the rocket's flight dynamics (attitude) and flight visualization of the surrounding environment in real time. This will make it easier for researchers or non-researchers to understand rocket motion and analyze it for subsequent developments [10]. This X-Plane software is also equipped with facilities for making visual models of rockets using the X-Plane Maker. With it, you can make adjustments to the dimensions of the fuselage, fixed fins and rocket canards, engine propulsion settings, control geometry, weights and balances (Figure 2 (a)), according to the design of the rocket being developed. The rocket design can be

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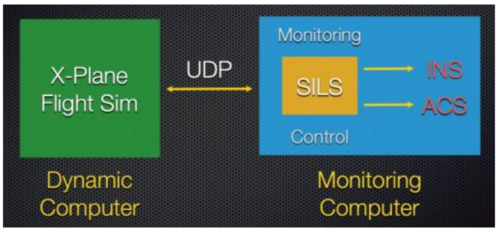
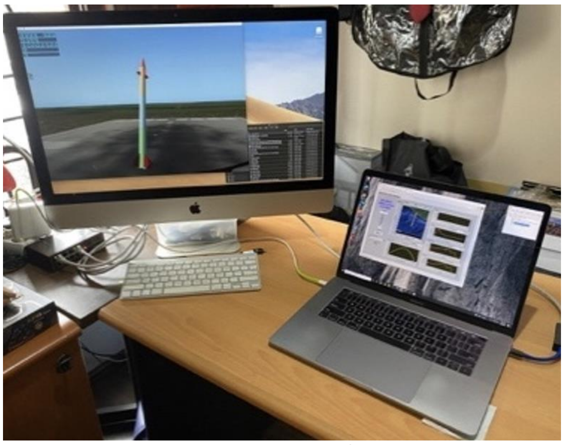
implemented in detail in this visual model, so that later it can produce rocket performance according to the calculations in the predictions. The use of X-Plane as a flight simulator has also been carried out in the development of rocket simulations as in the article on analysis ballistic flight and Design of Control System RKX-200TJ Booster [11].



(a) SILS block diagram



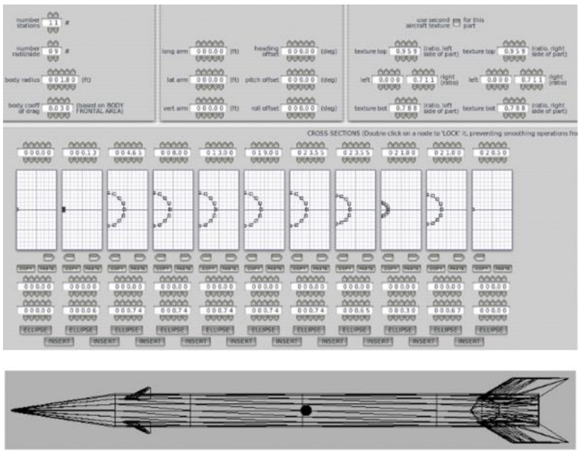
(b) Implementation of SILS

Figure 1. Software in the Loop Simulation System

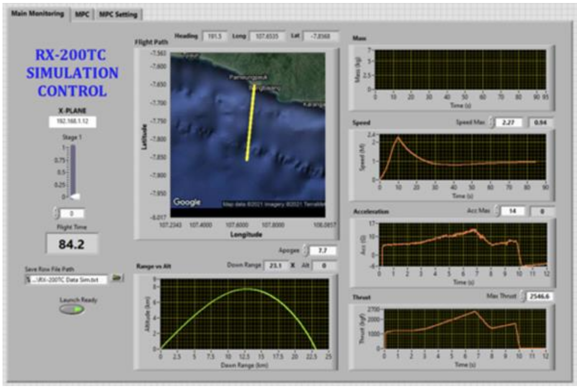
However, in this case, the X-Plane is analogous to a black box system which provides output in the form of attitude and position data, and receives input in the form of engine throttle data to produce thrust according to the actual rocket propulsion static test results, as shown in Figure 2. (b). The X-Plane as black box system needs attention in future studies. Because the state space model of the rocket's mathematical prediction results is definitely not the same as the mathematical model produced by X-Plane, so the control strategy applied to it will not be the same as the original rocket later. At least in the process of using the X-Plane as a flight simulator, in the early steps of implementing strategy control such as the Model Predictive Control (MPC), you can see its responsiveness in controlling the pitch and yaw of the rocket flying at super-sonic speed.

Attitude and position data are sent via UDP to a monitoring computer developed using Labview software. So that the close loop communication between the dynamic computer and the monitoring computer can be utilized other than as a rocket avionics system (RAS), it can also be developed into a rocket flight control system (FCS) in trajectory correction missions and even to maneuver rockets in achieving targets like on guided missile. With another method, X-Plane as a generator of attitude data and rocket flight position can be replaced with Matlab. An example of cooperation between Matlab and Labview in the development of a simulation system has been carried out in the development of swing-tracking sliding mode controller design [12].

Figure 2 (b) illustrates that the rocket's conditions from launch until touch down again to land or sea in real time in the form of a display of flight coordinates, also the data of altitude, range, thrust, acceleration and speed of the rocket. All of rocket flight data from X-Plane is displayed in chart form to facilitate analysis and improvement for further development.



(a) Rocket design using X-Plane Maker



(b) Simulation results monitoring

Figure 2. Rocket visualization model and simulation monitoring system

3.2. Hardware in the Loop Simulation System (HILS)

The next step after SILS is HILS, namely the involvement of main controller hardware that will be used as an avionics and flight control system of the rocket's itself into the simulation. This means that the entire process that was previously carried out by the monitoring computer is transferred to the main controller of the rocket to ensure that all sensor readings by the avionics system can be handled properly. As well

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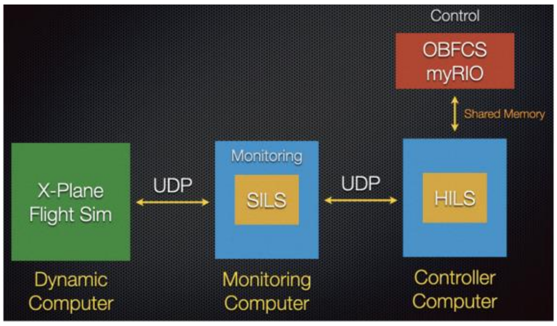
as the application of control strategies of conventional control strategies such as PID and optimal control strategies such as Model Predictive Control, Fuzzy Logic [13], Adaptive Sliding Mode [14] or Robust Control can be maximally processed in the real main controller.

In this HILS, the controller computer communicates with the main controller using shared memory provided by Labview as development software in this research, as illustrated in the block diagram of Figure 3 (a). In this research, the National Instrument product, NI myRIO-1950 was used as the main controller for the rocket, because it was sufficient to fulfill the number of I/O, analog input, control signals using PWM (Pulse Width Modulation), TTL serial communication and communication using other protocols such as I_2C or SPI. The most interesting specification of myRIO-1950 as main controller is the use of a Xilinx Z-7010 Field Programmable Gate Array (FPGA) with a processor speed of 667 MHz, 512MB of nonvolatile memory and 256MB of DDR3 memory. So that it can process a type of control strategy that is quite complicated and heavy, such as the optimal control strategy above. This HILS implementation is as illustrated in Figure 3 (b) which connects 3 computer units and the main controller rocket hardware that will be used later.



(a) HILS block diagram

(b) Implementation of HILS

Figure 3. Hardware in the Loop Simulation System

The HILS method is used by combining high performance computers [15], [16] to produce detailed and real time simulations to implementation of system and control software. Or also applied to the design and validation of rocket control systems [17] and attitude control systems [18],[19]. Including, the author also applies this HILS in controlling the FPV-2600 UAV using optimal flight strategy control [6] before the actual flight test.

3.3. Ready to Fly System (RTFS)

After successfully reaching the HILS step, it means that the simulation phase has been completed, and entering the RTFS step, where the main controller is ready to be integrated with other sub-modules such as the Inertial Navigation System (INS), Power Management System (PMS), Actuator Control System (ACS) and Data Communication System (DatComS) to become a complete ready-to-launch rocket system. Similar efforts have been made by the authors with system development from simulation to flight test using UAVs [20], [21]. In this RTFS step, the rocket avionics system has been able to communicate with the Ground Control System (GCS) and display all attitudes and rocket positions on the GCS monitoring display in real time. And if later this rocket is intended as a ballistic missile or guided missile, this RTFS step must also function all canard fins to respond with the attitude of the rocket in the form of pitch up or pitch down action and also head right or left or even a couple of the two types of movement. This means that the implementation of an automatic or periodic control strategy based on flight sequence time is already embedded in the main controller, as shown in Figure 4 which shows the RAS and FCS rockets have been integrated and connected by wiring between subsystems to each other and are ready to be launched.

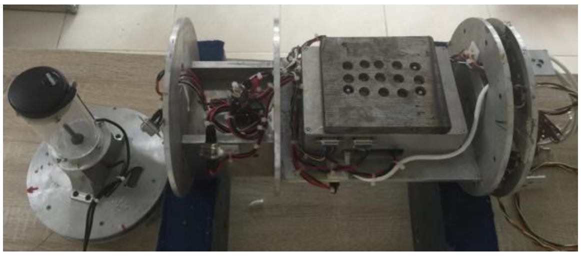


Figure 4. Ready to Fly System

In addition to laboratory-scale testing at this RTFS step, usually RAS and FCS rockets are also tested in their flying environment conditions. Namely shock test, vibration test, antenna testing in the anechoic chamber, distance test to ensure the radio telemetry function and many other tests required before the flight test so that the rocket development is successful.

3.4. Integrated Rocket Test System (IRTS)

This system is used to test laboratory-scale rocket avionics and flight control systems, before the rocket is launched. Tests using this system are carried out thoroughly related to the readiness of the rocket in a procedural step before the launch, techniques for releasing the umbilical connector (UC), communication with the GCS and communication links with the dynamic computer in integrated simulations and others.

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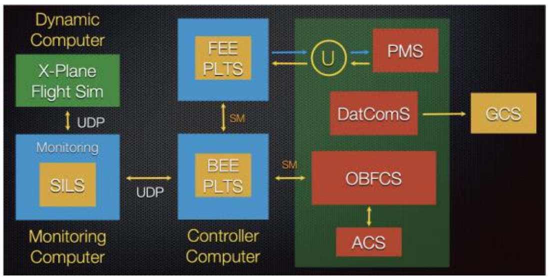
A more detailed review of IRTS will be presented in a separate paper.

In general, this IRTS is divided into 2 parts, namely IRTS-F (front) which is in direct contact with the rocket before it is launched through the umbilical connector, which is only 20 m from the launcher. Furthermore, from IRTS-F, the rocket data is relayed directly to IRTS-M (monitoring) and displays the condition of the rocket before flying to determine Go or No Go. For safety purposes, the distance between IRTS-F and IRTS-M is at least 200 m or more and they are connected wirelessly at the 5.8 GHz frequency. IRTS-F provides an external power supply sourced from the Programmable Power Supply (PPS) to replace the internal LiPo battery inside the rocket during testing or before launching which is channeled through the UC. And through IRTS-M too, UC can be released wirelessly from the rocket before it is launched.



(a) IRTS block diagram

(b) IRTS hardware

Figure 5. Integrated Rocket Test System

The development of rocket avionics and flight control systems, IRTS and GCS was carried out using the same software, namely Labview. With the similarity of the program, communication and interfacing between modules can be carried out in steps, quickly and safely. Meanwhile, the use of X-Plane as a flight simulator can also be replaced with other similar software such as Microsoft Simulator, Flight Gear and others, or it can even be communicated with Matlab using the same UDP protocol.

A series of simulations involving software and hardware from the SILS, HILS and RTFS stages as well as testing using IRTS will greatly assist research in data communication between sub-systems as well as testing the right control strategy as a flight control system for the vehicle being developed. These simulations in software will be tested for feedback in a close loop simulation and implemented directly on the hardware system.

4. Conclusion

The development of rocket avionics and flight control systems or other flying vehicles such as airplanes or UAVs can be carried out in stages using the SILS, HILS methods up to the ready-to-fly RFTS stage. This step has been implemented quickly and provides confidence in the readiness of the system safely before flying. This research can be carried out further by replacing the X-Plane flight simulator using Matlab Simulink so that the models created and controlled have the same mathematical models, so that the controls applied will be more accurate.

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