Research Paper

Journal of Aerospace System Engineering
Vol.15, No.6, pp.42-49 (2021)

EISSN 2508-7150
http://dx.doi.org/10.20910/JASE.2021.15.6.42

SW Program Development of a Real-Time Flight Data Acquisition and Analysis System for EO/IR Pod

Songhyon Kim[1], Donghyurn Cho[2], Sanghyun Lee[2], Jongbum Kim[2,†], Taekyu Choi[3] and Seungha Lee[3]

[1]Department of Computer Science, Korea Air Force Academy
[2]Department of Aerospace Engineering, Korea Air Force Academy
[3]Mechanical Convergence Laboratory, LIG Nex1

Abstract

To develop a high-resolution electro-optical/infrared (EO/IR) payload to be mounted on a high-speed and performance fighter aircraft in an external POD for acquiring daytime and nighttime image information on tactical targets, simulations, including flight environments and maneuvers, should be performed. Such simulations are pertinent to predicting the performance of several variables, such as aerodynamic force and inertia load acting on the payload. This paper describes the development of a flight data acquisition and analysis system based on flight simulation software (SW) for mission simulation of super-maneuverability fighter equipped with EO/IR payload. The effectiveness of the system is verified through comparison with actual flight data. The proposed flight data acquisition and analysis system based on FlightGear can be used as an M&S tool for system performance analysis in the development of the EO/IR payload.

Key Words: ISR Fighter Aircraft, EO/IR POD, Flight Data Acquisition and Analysis System, Flight Simulation

1. Introduction

The tactical reconnaissance performs a collection of intelligence on the enemy status, such as scouting whether the enemy is moving or stationary, which has an immediate effect on the battlefield. During reconnaissance, a fighter aircraft is exposed to the risk of anti-aircraft attacks, which necessitates the use of modified fighters with excellent maneuverability and survivability. The Air Force of the Republic of Korea is also equipped with a domestically developed a tactical electro-optical/infrared (EO/IR) reconnaissance system (Tac-EO/IR) to acquire daytime and nighttime image information on tactical targets [1]. The military applications of the Tac-EO/IR are also increasing with the usage of fixed-wing unmanned aerial vehicles (UAVs) [2]. For the next-generation fighter aircraft KF-21, which is under development using domestic technology, the electro-optical targeting pod (EO TGP) will be developed for installation. To develop a payload that enables reliable acquisition of high-resolution EO/IR images in a flight environment requiring super-maneuverability, such as tactical reconnaissance mission, a flight dynamic modeling and simulation (M&S) system is necessary. Such systems should be capable of predicting several variables, such as aerodynamic force and inertia load acting on the payload, and analyzing performance for various flight environments and maneuvers [3].

The methods of flight data acquisition for M&S system development include performing an actual test flight, data acquisition through a wind tunnel test, and flight dynamic modeling and simulation based on the theory of flight mechanics [4, 5]. Among these methods, the simulation method based on a flight dynamic model offers the advantage of the ease of acquisition and analysis of flight data, with the extended application of diverse flight conditions [6, 7].

To verify the efficacy of the flight data obtained from the flight dynamic model simulation, real-world flight data acquired under the same flight conditions are used to perform a comparative analysis. However, the flight data derived through the flight dynamic model simulation for a fighter aircraft under the mission of tactical reconnaissance in a super-maneuverability flight environment tends to have strong non-linearity. Thus, obtaining a solution with convergence is difficult, and verification of the effectiveness of the acquired flight data poses another challenge. In addition, for comparative analysis of the simulation data and real-world flight data measured from the sensors of the reconnaissance aircraft, real-world flight data need to be processed into a

---

Received: Aug. 31, 2021 Revised: Oct. 20, 2021 Accepted: Oct. 29, 2021

† Corresponding Author
Tel: *** - **** - ****
E-mail: kafa.jongbumkim@gmail.com

format that enables the comparison with the simulation data. However, this data processing also incurs practical difficulties.

Therefore, to acquire flight datasets similar to those obtained during a real-world tactical reconnaissance mission and to verify the effectiveness of the system, a new flight data acquisition and analysis system that can address the limitations of existing simple 6-degree of freedom (DOF) flight dynamic simulation should be developed. Thus, in this study, among a variety of flight simulation software (SW), FlightGear (which is based on a 6-DOF flight dynamic model and includes control logic), is used to develop a real-time data acquisition and analysis system that generates real-time flight data in various maneuvers and converts the generated data into the preferred data format [8]. Several studies have been conducted in South Korea and abroad [9, 10] to compare FlightGear simulation results and flight data. The distinct contribution of this study is that, through the developed system, the authors aimed to acquire and analyze various flight data through the development of real-time embedded SW. Furthermore, to verify the effectiveness of the developed system, real-world flight data obtained from the tactical reconnaissance mission are used for a comparative analysis of the results.

2. Development of the flight data acquisition and analysis system

First, the available flight simulation SW was analyzed comparatively. The optimal flight simulation SW was selected, and a corresponding real-time flight data acquisition and analysis system was developed.

2.1 Comparison of flight simulation software

In this study, among different types of flight simulation SW frequently used by researchers or general users for flight experience in virtual space, FlightGear, X-Plane, and Digital Combat Simulator (DCS) programs were selected for comparative analysis [11]. Among commercial flight simulators, X-Plane offers the advantage of the established credibility as a flight simulation tool that is used to receive the certificate of Federal Aviation Administration based on its own flight model. DCS is a program developed for combat flight simulation games and regarded as a study simulator for real pilots to learn the methods of operating an aircraft. Unlike X-plane and DCS, FlightGear is a free-of-charge, open-source, multi-platform, collaborative flight simulator development project that serves as a sophisticated flight simulator framework for research or academic environments.

In the selection of suitable SW for research, considering the characteristics of the simulation environment, flight dynamic model, physical analysis of objects, weather simulation, and simulation cycle that can be implemented in each commercial simulator seems reasonable. However, in the current study, the flight dynamic model characteristics and source code availability were considered as key factors for the selection of flight simulator SW. A comparison of different types of SW is presented in Table 1.

Table 1 Comparison of Varying Flight Simulation SW

Category	FlightGear	X-Plane	DCS
FDM*	JSBSim	Unpublished	Unpublished
Source code availability	Open-source	Commercial	Commercial

*Flight Dynamic Model

As presented in Table 1, FlightGear employs a 6-DOF flight dynamic model called JSBSim, and its effectiveness has already been verified [12] with active usage in numerous research publications. Therefore, FlightGear was used to build the flight data acquisition and analysis system in the present study due to its availability and effectiveness.

As FlightGear is employed in this research, simulation of the entire flight section from take-off to landing is possible. Further, the use of FlightGear made it relatively easier to reflect the characteristics of various types of aircraft. In addition, the generated flight data can be readily extracted and converted into the desired data format in real time.

2.2 Generation and conversion of real-time flight data

For the simulation of a super-maneuverability fighter mission, various flight datasets required by the user should be generated in real time based on a precise flight dynamic model. For the utilization and analysis of the generated flight data, additional information such as aircraft velocity and angle of attack may be required.

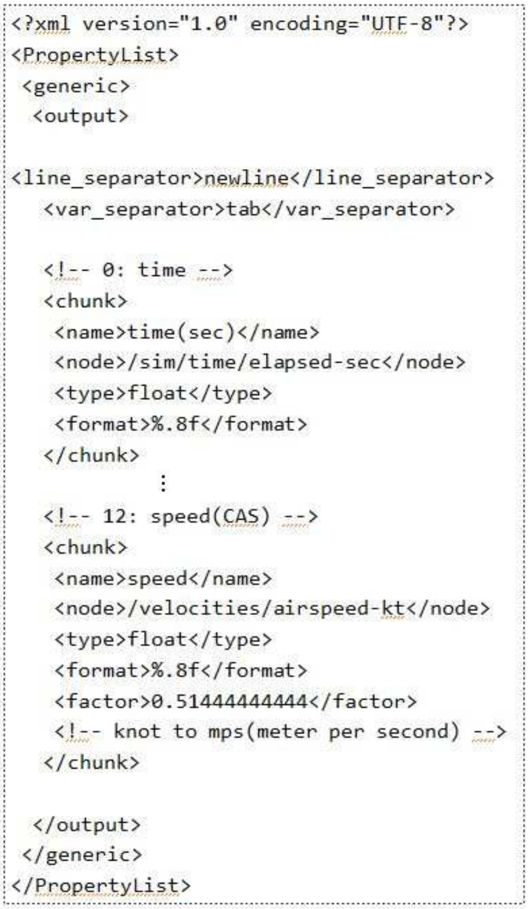
In this study, the property tree provided by FlightGear was used to generate various real-time flight datasets. The property tree is a tree-type storage system that manages all status information in the FlightGear program. The property tree paths for roll, pitch, and yaw angle that represent the orientation of the aircraft and for latitude, longitude, and altitude that represent the aircraft position are outlined in Table 2.

Table 2 Property Tree (Ex.)

Flight data	Property Tree Path
Roll	/orientation/roll-deg
Pitch	/orientation/pitch-deg
Yaw	/orientation/yaw-deg
Latitude	/position/latitude-deg

Longitude	/position/longitude-deg
Altitude	/position/altitude-ft

In addition, FlightGear provides the generic protocol that was used for real-time transmission of data.



```
<?xml version="1.0" encoding="UTF-8"?>
<PropertyList>
 <generic>
  <output>

<line_separator>newline</line_separator>
   <var_separator>tab</var_separator>

   <!-- 0: time -->
   <chunk>
    <name>time(sec)</name>
    <node>/sim/time/elapsed-sec</node>
    <type>float</type>
    <format>%.8f</format>
   </chunk>
             ⋮
   <!-- 12: speed(CAS) -->
   <chunk>
    <name>speed</name>
    <node>/velocities/airspeed-kt</node>
    <type>float</type>
    <format>%.8f</format>
    <factor>0.51444444444</factor>
    <!-- knot to mps(meter per second) -->
   </chunk>

  </output>
 </generic>
</PropertyList>
```

Fig. 1 XML Setting File

The generic protocol is an input–output (IO) support tool that enables the transmission of data generated by FlightGear to external programs using UDP socket communication. The XML setting file for the generic protocol used in this study is shown in Fig. 1.

It is possible to extract the required data, such as simulation time, Mach number, and aircraft orientation from FlightGear in the desired format. In particular, given that feet is used at a unit for altitude within FlightGear, it was extracted after converting into meters. Further, as knot is used as the unit for calibrated air speed within FlightGear, it was converted into meters per second (mps) for extraction.

2.3 Saving and transmission of flight data

The relay SW was developed to (1) enable the simulation of the super-maneuverability fighter mission in the form required by the user without direct modification of FlightGear and (2) to generate various types of flight data required from FlightGear and convert them into the format preferred by the user. The block diagram of the flight data transmission system using the relay SW is presented in Fig. 2.

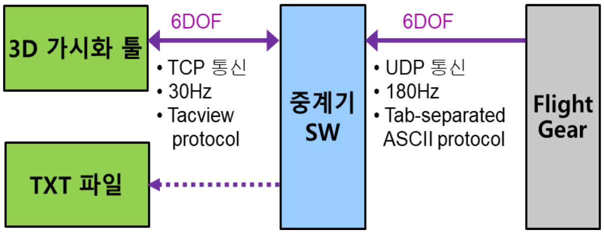


Fig. 2 Real-Time Flight Data Transmission

Figure 3 demonstrates the real-time generation and visualization of the diverse flight data using the proposed flight data acquisition and analysis system. In the developed system, FlightGear, the flight simulation SW, is run first, and then the relay SW, shown at the top of the figure, is executed to start communication with FlightGear. At the top of the demonstration screen, the generated flight data can be viewed through the relay SW. In addition, when a 3D visualization tool (Tacview), shown in the right bottom panel, is executed to start communicating with the relay SW, the flight data generated in FlightGear were visualized in the 3D visualization tool through the relay SW.

Fig. 3 Real-time Demonstration of Flight Data Acquisition System

As observable from Fig. 3, when the fighter aircraft is turned 90° to the right (FlightGear in the left bottom panel) through the maneuvering of HOTAS, the flight data are transmitted and saved in real time through the relay SW. The flight data transmitted to the 3D visualization tool are visualized in real time (Tacview in the right bottom panel), and the demonstration of turning to the right can be observed in the same manner as in the aircraft shown in FlightGear.

2.4 Analysis of flight data

The assortment of flight data saved in TXT files through the relay SW can be utilized for flight data analysis using software, such as Excel and Matlab.

Figure 4 presents a graph for the analyses of the flight data of the TXT file saved through the developed relay SW of the proposed flight data acquisition system. Among the data corresponding to aircraft orientation with time, the graph shows roll, pitch angle, and heading. Similarly, various flight conditions and information with time can be presented and viewed.

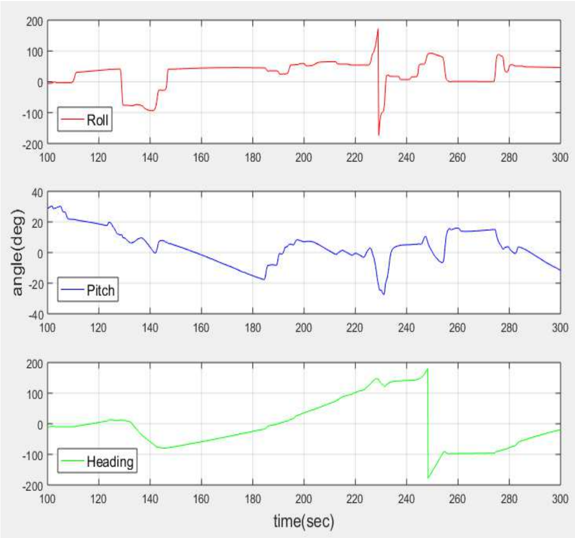


Fig. 4 Flight Data Analysis

In addition to the data analyzed in Fig. 4, for various flight datasets desired by the user, included in the saved TXT file, such as temporal change, minimum and maximum values, and rate of the temporal change can be additionally extracted. These values can be analyzed for utilization as data required for the development of a weapon system.

3. Validation of the acquired flight data

Based on the 6-DOF flight dynamic equation of motion, the values of various variables of the developed flight data acquisition system are derived. To verify the validity of the flight data extracted through the flight data acquisition system, the data were compared with the real-world flight data obtained from the mission with the payload mounted during the development of the reconnaissance Tac-EO/IR POD.

3.1 Flight dynamics model

To compare the data extracted from the flight data acquisition system and the real-world flight data under the same conditions, 5-DOF flight dynamic modeling was applied, which offers the advantages of fast computation speed and ease of performing simulations. Further, for the simulation of the rate of change for the pilot's inputs, there is a difficulty of additionally considering the input of the change in the roll angle through the additional calculation of the rate of change according to the roll angular velocity from the first roll angle at the start of the steady turning to the final roll angle displacement. Therefore, to implement a more direct simulation of the pilot's inputs without additional considerations, a flight dynamic model that reflects the dynamic characteristics of the pilot's inputs through the time delay model was considered, as presented in Eqs. (1)–(8) [13].

$$T_{cmd} = \delta_{th} T_{max,mil}, 0 < \delta_{th} < 1 \tag{1}$$

$$\ddot{\alpha} + 2\varsigma_{\alpha}\omega_{n_{\alpha}}\dot{\alpha} + \omega_{n_{\alpha}}^{2}\alpha = \omega_{n_{\alpha}}^{2}\alpha_{cmd} \tag{2}$$

$$\dot{\mu} = \frac{\mu_{cmd} - \mu}{\tau_{\mu}} \tag{3}$$

$$\dot{T} = \frac{T_{cmd} - T}{\tau_{T}} \tag{4}$$

$$\dot{V} = \frac{T cos\alpha - D}{m} - g sin\gamma \tag{5}$$

$$\dot{\gamma} = \frac{(L + T sin\alpha) cos\mu}{mV} - \frac{g}{V} cos\gamma \tag{6}$$

$$\dot{\chi} = \frac{(L + T sin\alpha) sin\mu}{mV cos\gamma} \tag{7}$$

$$\dot{m} = -TSFC \cdot T \tag{8}$$

where T denotes thrust, δ_{th} represents throttle input, α is the angle of attack, $\dot{\alpha}$ is the rate of change for the angle of attack, ς is damping coefficient, ω_n is natural frequency, μ is bank angle, τ is the time constant for time delay, V is aircraft velocity, γ is flight path angle, m is mass of the aircraft, χ is azimuth angle, L is lift, D is drag, and TSFC is the thrust-specific fuel consumption of the engine.

In the 5-DOF flight dynamic model with the application of the time delay function as described above, the angle of attack is modeled using the second-order plus time delay model that has a damping coefficient and natural frequency. The equation of motion for the roll angle and thrust is modeled using the first-order plus time delay model with the time constant (τ). The parameters of the pilot's inputs are set as the angle of attack (α_{cmd}), bank angle (μ_{cmd}), and thrust (T_{cmd}). At this time, for more accurate reflection of the pilot's input for the thrust, the relationship of change in thrust according to the throttle input (δ_{th}) is used, as represented by Eq. (1). For the throttle input, when the afterburner is not used (military thrust), a value between 0 and 1 is taken. The lift and drag, which reflect the flight dynamic characteristics of an aircraft, affect changes in the velocity, flight path angle, and azimuth angle, as represented by Eqs. (5)–(7).

Figure 5 shows the input/output diagram for the 5-DOF flight dynamic model with the time delay function.

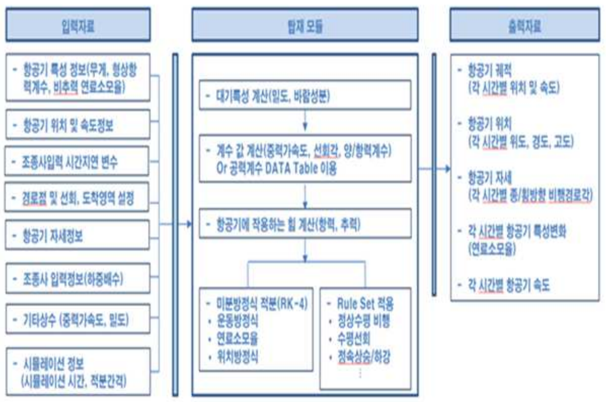


Fig. 5 Input–Output Diagram

3.2 Comparison of real-world flight data and 5-DOF simulation

A simulation program was implemented using Matlab for 5-DOF flight dynamic modeling with the application of the time delay function derived above. The simulation data were compared with the real-world flight data obtained from the mission with the Tac-EO/IR POD for reconnaissance.

Among the real-world flight data, time, velocity, aircraft orientation, and trajectory data applicable to the simulation were extracted. The data with sudden changes or inaccurate measurement of frequency (Hz) were regarded as noise and excluded from the valid data. The total 2D flight trajectory for the extracted valid data is illustrated in Fig. 6.

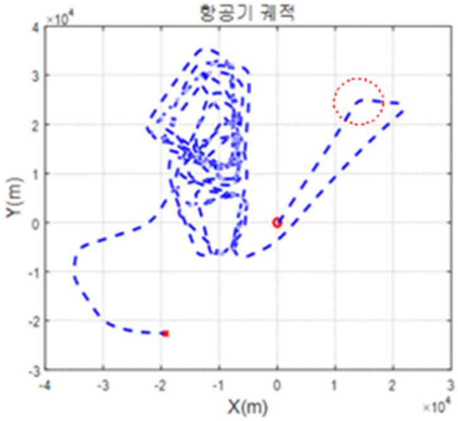


Fig. 6 Total Flight Trajectory

As the total flight trajectory is difficult to compare, the area indicated by the dotted line, which is the flight area section from the steady level flight to level turn, the main region of interest for the mission performance was extracted, as shown in Fig. 7.

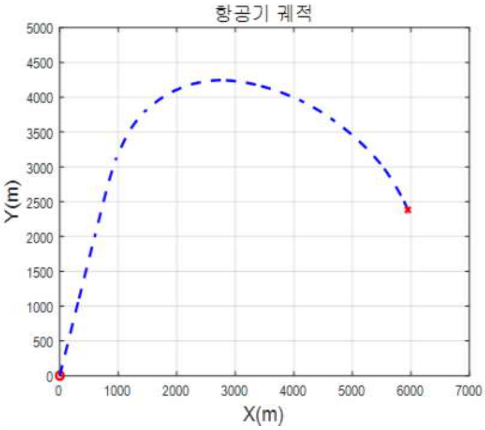


Fig. 7 Extracted Flight Trajectory

To facilitate comparison and analysis of the flight trajectory when the initial state variable values are applied, for the initial position of the flight trajectory, the x- and y-axes were set to start from the origin, and the z-axis was set to start from the altitude of the flight data. Considering the characteristics of the 5-DOF flight dynamics model, the angle of attack was assumed to be 0° in the condition of steady and level flight. In addition, based on the assumption that the changes in the thrust and the aircraft velocity are proportional, the pilot's input for thrust change was estimated. The flight sections were divided into two: steady level flight section and level turn section. The coefficient value of the engine throttle input (δ_{th}) of the pilot was adjusted to set δ_{th} so that it was similar to the rate of change of velocity of the Tac-EO/IR flight data. The δ_{th} input applied to the 5-DOF flight dynamics model obtained by reflecting the rate of change of velocity of the Tac-EO/IR flight data is presented in Eqs. (9)–(11).

$$\delta_{th} = 0.26\frac{V}{V_0} \quad \text{(Steady level flight section)} \tag{9}$$

$$\delta_{th} = 0.14\left(\frac{V}{V_0}\right)^{10} \quad \text{(Level turn section1)} \tag{10}$$

$$\delta_{th} = 0.27\left(\frac{V}{V_0}\right)^{3} \quad \text{(Level turn section2)} \tag{11}$$

Here, V_0 is the initial velocity of the aircraft. By setting the throttle input to be similar to the velocity change of the real-world flight data, a graph was obtained after comparing the velocity of the aircraft, as shown in Fig. 8.

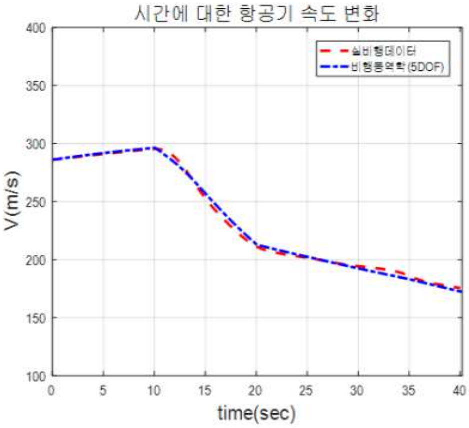


Fig. 8 Aircraft Velocity Comparison

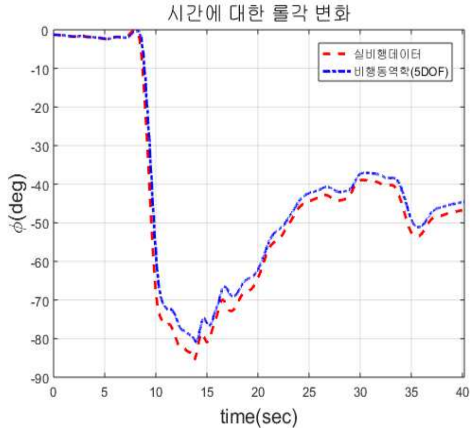


Fig. 10 Roll Angle Comparison

The simulation was performed by applying the values of the initial state variables of the real-world flight data and input variable to the 5-DOF flight dynamic model. As shown in Fig. 9, the Tac-EO/IR flight data (indicated with a red dotted line) and the 5-DOF simulation trajectory (indicated by a blue dotted line) are similar.

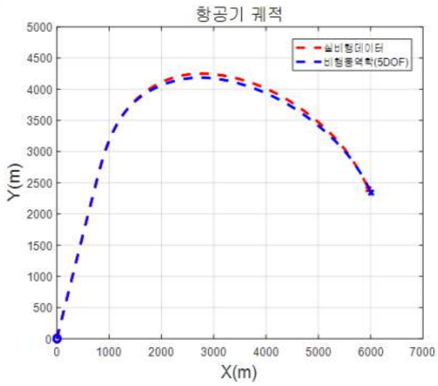


Fig. 9 Aircraft Trajectory Comparison

Figure 10 shows the comparison of the roll angle change between real-world flight data and 5-DOF flight dynamic simulation results.

As shown in Fig. 10, the data values of the graph for the roll angle change during the turning section between the two results have a highly similar trend. However, after 10 s, a slight difference was observed between the real-world flight data and the 5-DOF simulation result. At 13.8 s, the roll angle of the real-world flight data was -85.58°, and the roll angle of the 5-DOF simulation was -80.25°, showing the maximum difference, corresponding to the error of 6.23 % with reference to the real-world flight data.

The reasons for the difference between the two sets of values can be inferred as follows: the measured frequency (Hz) of the flight data was not constant, and some error values were included. Meanwhile, in the flight dynamic model, the engine throttle input of the pilot was not accurately estimated, or the values of coefficients such as the time delay coefficient used in the dynamic model were not precisely adjusted. It is thought that, if the simulation is performed according to the measurement frequency of the real-world flight data and if the parameters of the flight dynamic model are adjusted more precisely, results in greater agreement with the actual flight data values can be obtained.

3.3 Verification of the flight data acquisition system

In the previous section, the effectiveness of the flight dynamic model was verified through a comparative analysis of the orientation and trajectory results of real-world flight data and the simulation results obtained through the 5-DOF-based flight dynamic model. Comparing the real-world flight data with the results of the developed flight data acquisition system would be the most suitable method to verify the effectiveness of the proposed system. However, as there is a difficulty in performing simulations similar to real-world flight data and limitation in the acquisition of real-world flight data, in this section, a 6-DOF-based flight simulation was performed using FlightGear. The results were compared with the 5-DOF simulation results, thereby indirectly verifying the effectiveness of the proposed flight data acquisition system.

In FlightGear simulation, to set up an environment similar to the actual flight of a fighter mounted with the Tac-EO/IR POD, a fuselage pylon sniper was installed in the payload setting of FlightGear simulation. The climb after take-off, level flight, and level turn flight were performed, and the developed data relay program was used to save the results in TXT files.

Similar to the previous comparison between the real-world flight data and 5-DOF simulation, the proposed flight data acquisition system was used, and the FlightGear values of initial state variables and input variables were applied to the 5-DOF flight dynamic model. To facilitate the comparison and analysis of flight trajectory, the data of level flight and turning flight were extracted. For the initial position of the 5-DOF model, the x- and y-axes were set to start from the origin, and the z-axis was set to start from the altitude derived from the FlightGear simulation.

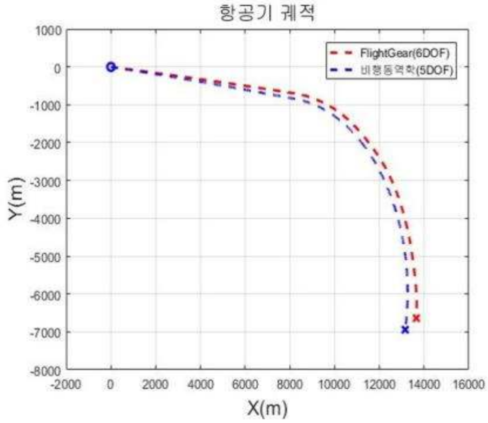


Fig. 11 Trajectory Comparison

The graph corresponding to the flight trajectory results derived by performing the simulation is presented in Fig. 11. When comparing the two flight trajectory results, little error was found in the level flight section. However, significant errors occurred from entering the turning section.

The results of the comparison of the aircraft velocity and bank angle are presented below in Figs. 12 and 13, respectively.

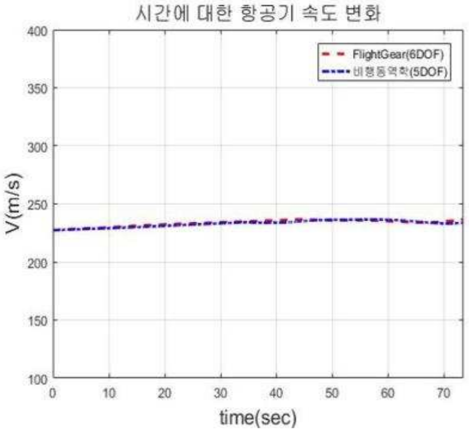


Fig. 12 Velocity Comparison

As shown in Fig. 13, the results derived from the 5-DOF simulation and those derived using the flight data acquisition system are under agreement in terms of the change of bank angle with time.

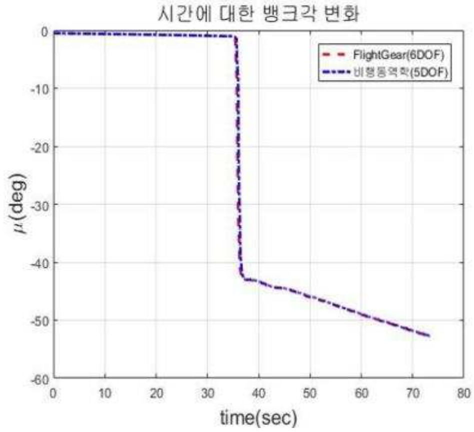


Fig. 13 Bank Angle Comparison

In addition to the flight trajectory, velocity, and bank angle, various types of flight data, such as velocity, altitude, and pitch angle, were compared. The result of the comparison indicates that the 5-DOF flight dynamic simulation and the data of FlightGear simulation performed based on the 6-DOF flight dynamic model have similar trends. From these results, the authors were able to verify the similarity of the data obtained by using the developed flight data acquisition system, 5-DOF simulation, and real-world flight data, as well as the effectiveness of the developed system and acquired data.

4. Conclusions

In this study, the authors developed a flight data acquisition and analysis system, a tool of system performance analysis used for the development of high-resolution EO/IR POD to be mounted on a fighter under mission in a high-speed, super-maneuverability flight environment.

As collecting real-world flight data in various environments faces practical difficulties and limitations, the method of deriving flight data through simulation and the use of the derived data would be effective in the acquisition of flight data. However, the existing simulation method using the 6-DOF flight dynamic model poses the difficulty of securing the aerodynamic database of the aircraft and the design of a controller.

Therefore, in this study, flight data for the extreme environment required for weapon system development were obtained by the maneuver of a pilot. Based on FlightGear, an open-source flight simulation SW with the database of various aircrafts and controller design, a program was developed in which flight data were generated and transmitted in real time according to the data transmission format.

It was confirmed that the acquired flight data can be analyzed using SW, such as Matlab. To verify the effectiveness of the acquisition system, a comparative analysis was performed between the real-world flight data and the flight data extracted from the level and turning flight sections among the total flight data stored in the relay SW, the developed system. However, as there is a limitation in performing flight simulation under the same conditions as real-world flight data, the real-world flight data and the results of 5-DOF flight dynamic simulation obtained by using the real-world flight data as input values were compared. Further, for similar flight conditions, the 6-DOF flight dynamic simulation was performed, and from the results, some of the variables were used as the input variables of the 5-DOF simulation, and the derived results were compared.

The results of various variables derived from each simulation showed quite similar trends, despite the existence of some errors. Thus, the effectiveness of the flight data acquisition and analysis system developed in this study was verified. The verification was performed only in the flight section consisting of level flight and turning flight, as the proposed system uses a validated 6-DOF nonlinear modeling and is based on an open-source tool that can perform simulation considering various environmental factors, such as wind. In future research, it is expected that the developed system can be used for efficient acquisition of flight data for various high-speed and super-maneuverability flight environments, as desired by developers of weapon systems, and utilized for effective analysis of the system performance.

Acknowledgments

This study was conducted with the support of LIG Nex1 (Project name: super-maneuverability aircraft-mounted image acquisition system) with funding from the Government (Agency for Defense Development).

References

[1] Agency for Defense homepage, URL: https://www.add.re.kr/board?menuId=MENU02878&siteId=SITE00003

[2] S. Jang and J. Kim, “Survey of electro-optical infrared sensor for UAV,” *Current Industrial and Technological Trends in Aerospace*, vol. 6, no. 1, pp. 124-134, 2008.

[3] D. Kim and C. Lee, “The study on development of defense M&S system,” *Korea Information Processing Society Review*, vol. 15, no. 6, pp. 14-24, 2008.

[4] G. Woo, J. Kim, K. Cho and D. Lee, “A study of the dynamic characteristics of airship through the flight test,” *Journal of the Korean Society for Aeronautical & Space Sciences*, vol. 32, no. 5, pp. 97-103, 2004.

[5] C. Lee, Y. Park and H. Choi, “Study of flight simulation using real-time aerodynamic model,” *Journal of Aerospace System Engineering*, vol. 9, no. 4, pp. 49-54, 2015.

[6] B. Stevens, F. Lewis and E. Johnson, Aircraft Control and Simulation: Dynamics, Controls Design, and Autonomous Systems. John Wiley & Sons, 2015.

[7] M. Napolitano, Aircraft Dynamics from Modeling to Simulation, John Wiley & Sons, 2012.

[8] A. R. Perry, “The flightgear flight simulator,” *Proc. of the USENIX Annual Technical Conf.*, vol. 686, 2004.

[9] L. Wang, F. Zhang, W. Gao and L. Yi, “Data acquisition and processing based on flightgear simulator software,” *Electronic Design Engineering*, 2011.

[10] J. Kim, S. Cho and K. Choi, “Development of control law debugging, data plot and simulation(flight replay, plot, simulation) tool,” *Proc. of the Korean Society for Aeronautical & Space Sciences fall conf.*, 2014.

[11] G. Ricardo, C. Daniel, P. Luis and O. Eugenio, “Using flight simulation environments with agent-controlled UAVs,” *Autonomous Robot Systems and Competitions: Proc. of the 8th conf.*, 2008.

[12] J. Berndt and A. Marco, “Progress on and usage of the open source flight dynamics model software library, JSBSim,” *AIAA Modeling and Simulation Technologies Conf.*, 2009.

[13] S. Jang, Study of intelligent pilot model based on basic fighter maneuvering for air combat simulation, Ph.D. Dissertation, Inha University, 2012.