Semi-Physical Simulation Design of UAV Simulation Training System

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Semi-Physical Simulation Design of UAV Simulation Training System

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Abstract. The UAV simulation training system simulates the pre-flight ground commissioning and in-flight operation monitoring of UAV. The UAV semi-physical simulation training system is built by integrating mathematical model, physical model, simulation computer, simulation software and other auxiliary equipment. This paper describes the functions and structure of the UAV simulation training system based on semi-physical simulation technology, and specifies the approach to implementation of simulation module algorithm, design and key technologies of the system.

1. Introduction
System simulation (or system emulation) refers to scientifically constructing a model that reflects the characteristics and basic features of the actual system, for the purposes of system experiment, analysis and research. With the development of technologies, the system simulation has been applied in development, production and training of various large weapon platforms.

The UAV semi-physical simulation training system that integrates mathematical model, physical model, simulation computer, simulation software and other auxiliary equipment, is significant for the UAV training. It not only has lower cost and risk than the actual equipment training, but also with same functions as the actual equipment, improves and maintains the performance and reliability of the equipment to extend its service life.[1-2]

2. System Function and Structure
This UAV simulation training system is capable of simulating the UAV pre-flight ground test and actual flight, the motion of stabilized platform and the change in visual angle of photoelectric sensor. In the simulated actual flight environment, this system allows the trainee to control the UAV and task equipment in flight through flight control software, pilot control software, task control software, etc., and to conduct training on target location and burst point spotting; also, allows the monitoring personnel to set flight failure through integrated training control software to train on how to deal with emergencies, and to monitor and evaluate the training process.[3]

It consists of two parts: ground control simulation and airborne simulation. As key components of the training system, the simulation computers with different functions transmit information flow by means of distributed network communication, to manage the ground control equipment and task equipment and monitor their conditions,[6] as shown in Figure 1.
The main functions are as follows:

- Simulation program training on ground testing of airborne system, including but not limited to individual equipment testing, testing in levels, and system testing.
- Simulation training on UAV control and flight; setting of flight environments and development of flight plans; simulation of the whole flight process from flight preparation, ground inspection, take-off and climb, approaching and flight adjustment, long-distance flight, antenna tracking (loss, search, capture and auto tracking), platform control, parachute recovery, to UAV self-destruction.
- Simulation training on UAV task control, including picture taking, television, IR reconnaissance, target location.
- Setting of training courses and taking any of them.
- In the simulated flight, change in the flight environment, setting and removal of flight control failure, and monitoring of the training process.
- Evaluation of the performance of the trainees.

3. Key Technologies and Implementation

3.1. UAV Flight Simulation and Modeling
The flight attitude of UAV is changed through remote commands. Based on this changing data, the UAV control personnel identify the flight conditions and provide the basis on which the flight attitude is changed. As the core of this UAV simulation training system, the flight simulation system builds the

![Diagram of UAV simulation training system]

Figure 1. Composition block diagram of UAV simulation training system.
UAV equation, control law and mathematical model using such parameters as aerodynamic parameters, aerofoil parameters and dynamic parameters; with time as the coordinate, generates the simulated flight attitude, flight distance and other parameters; and by means of mathematical simulation, simulates the flight control computer, navigation computer, aircraft power and pneumatic system, servo and other actual equipment.\textsuperscript{[5,6]}

3.1.1. UAV Flight Equation. The small-disturbance linear equation of the UAV motion is targeted at small deviators under certain conditions. This equation is based on the following assumptions: the earth is non-rotating and flat; the atmosphere is static (the force or torque from the atmospheric disturbance would be introduced in the equation if the effect of atmospheric disturbance on the aircraft motion requires to be considered); the UAV is a rigid body with no need to consider structural elastic deformation; the longitudinal symmetry plane of the UAV is symmetrical in terms of geometry, mass distribution and aerodynamic characteristics; in the reference motion, the longitudinal symmetry plane of the UAV is in a vertical state and the motion parameters of the UAV do not change with time; and in the disturbed motion, the motion parameters change so slightly that the second-order term is negligible. These assumptions are practical, since the emphasis of target control is placed on maintaining the observation effect and the UAV may not maneuver to a large extent when reconnaissance starts.

3.1.2. The Equation with Disturbance Introduced. The linear equation of the motion when there is a wind and turbulence is established by introducing the effect of atmospheric disturbance as an external disturbance into the disturbance model based on analysis of effect of wind and turbulence on the UAV motion.

The longitudinal small-disturbance linear equation of UAV with wind disturbance is as follows:

$$\dot{X} = AX + BU + Fd$$

$$F = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \end{bmatrix}^T, \quad d = \begin{bmatrix} \Delta V \\
\Delta \alpha \\
\Delta q \end{bmatrix} = \begin{bmatrix} -W_x \\
W_x / U_0 \\
\partial W_x / \partial \alpha \end{bmatrix}; \quad U_0 \text{ represents airspeed component along the vertical axis; } W_x, W_y \text{ and } W_z \text{ are three components of the wind speed; } X = [\Delta V \Delta \alpha \Delta q]^T; \quad U = \delta_c.$$ 

The lateral small-disturbance linear equation of UAV with wind disturbance is as follows:

$$\dot{X} = AX + BU + Fd$$

$$F = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \end{bmatrix}^T, \quad d = \begin{bmatrix} \Delta \beta \\
\Delta \rho \\
\Delta \gamma \end{bmatrix} = \begin{bmatrix} W_x / U_0 \\
\partial W_x / \partial \gamma \\
\partial W_x / \partial \beta \end{bmatrix}; \quad U_0 \text{ represents airspeed component along the vertical axis; } W_x, W_y \text{ and } W_z \text{ are three components of the wind speed; } X = [\beta \rho \gamma]^T; \quad U = [\delta_\alpha \delta_\beta]^T.$$ 

Based on PID control, the module takes the difference between the system output feedback quantity and the expected value or a set value as the input, and with a proper algorithm, calculates a controlled quantity to make the output quantity change with the input quantity.

3.2. Flight Control Simulation Module
This module includes two major parts: front-end real time processing software and integrated parameter display software. It simulates the operation control interface through Windows operating system, LabWindows/CVI and VC++ programming.
3.2.1. **Front-end Real Time Processing Software**
- Remote control coding. Provide control codes for various control information and data, in accordance with the flight control, task control, data link management and servo control commands or data flows issued from the flight and task control consoles.
- Telemetry decoding. Receive the telemetry information from the airborne simulation platform that is acquired by the airborne equipment.

3.2.2. **Integrated parameter display software.** Parameters such as information about the aircraft in flight, airborne sensing equipment and datalink state are displayed, in the graphic or character form.

3.3. **Pilot Control Simulation Module**
This module includes two parts: task planning software and track map display software.\(^7\) It simulates the operation control interface through Windows operating system, LabWindows/CVI and VC++ programming.

The task planning software sets and modifies the task planning; the track map display software provides map display and zooming, multi-mode map roaming, and three-dimensional coordinate display of point locations.

3.4. **Scene Simulation Module**

3.4.1. **Composition.** Main function of this simulation training system is to simulate the scenery images of UAV and cameras on the ground during training. For that reason, the fidelity of the scene simulation is based on the principle of transmitting sufficient plane visual information of camera, rather than an extreme sense of presence and immersion. Hence, the scene generation equipment (imaging unit and graphics system) may be composed of highly configured PC and high-performance graphics card with capability of dual-head display. The scene display equipment may consist of large screen LCD or CRT display and high resolution projection system.

3.4.2. **Software technology.** The scene simulation software is developed using VC++ and OPENGL and operated on Windows platform. The scene driving needs support by real-time driver software Vega and OPENGL. MultiGen Creator and Vega are used as the development tools of scene database.

The scene simulation module displays the 3D scene in real time based on the UAV pose parameters and terrain information in the scene provided by the flight simulation computer. The 3D scene is composed of various sceneries. Also, different scene simulation environments are simulated by different models. The 3D simulation of each scenery is processed separately and shall be implemented depending to the scenery type.\(^8\) Depending on the modeling methods, the scenery model in the software is divided into the following:
- Modeling and processing of UAV scene model.
- Modeling and processing of large terrain.
- Modeling and processing of surface buildings and target points.\(^9\)
- Modeling and processing of clouds and sky.
- Processing of special effect such as explosion, flame and smoke.

3.5. **Airborne Control Simulation Platform**
The airborne control platform simulates the working state of the UAV-borne equipment, executes the pre-flight on-line test of the UAV-borne equipment, and responds to the control signals from the control computers in flight.\(^10\) It is built based on a type of UAV model. Of the UAV-borne equipment, some is actual equipment while others are the functional simulation equipment, so as to simulate the actual equipment training program. Figure 2 shows the structure of the platform.
3.6. Integrated Training Control Module

In this simulation training system, the integrated training control module as a console allows the trainer to monitor the performance of the trainees. Its operation interface is designed based on Windows operating system and LabWindows/CVI. The training courses, fault point parameters and trainee data are managed by means of database technology.

3.6.1. Training course setting module. Bind the training courses, environmental conditions, reconnaissance target setting, air route setting, and etc. Set fault points whenever necessary in the process of training, to assess the ability of the trainees to respond to emergencies.

3.6.2. Training performance monitoring module. Display the in-flight main parameters and trainees’ actions in real time, and correct the improper or wrong action timely.

3.6.3. Result evaluation module. Automatically record, evaluate and determine the training results in accordance with specific rules.

4. Conclusion

In a laboratory, the UAV semi-physical simulation training system allows setting of various initial conditions to simulate the actual flight of UAV; provides the training of UAV ground control system and airborne control system; and replicates some failures in the actual flight of UAV to enhance the specific training and improve the emergency response. Utilization of the UAV semi-physical simulation training system that is suitable for repetitive training could bring substantial savings and extend the service life of equipment.

5. References
[1] Wang Hongjie, Chang Guocen, Li Xuejun and Du Jingzhu. Study on military general simulation model and integrative framework 2007 Journal of System Simulation 19 486-490
[2] Long Yong, Huang Xianxiang, Zhang Zhi-li, Gao Qin-he and Tang Hongqi. Design of distributed simulation system for some weapon based on virtual simulation 2006 Journal of System Simulation 18 1820-23
[3] Dong Juzhong and Kang Fengju. Semi physical simulation for a pilotless plane 1997 Acta Aeronautica et Astronautica Sinica 2 30-35
[4] Gao Bofeng. Design of serial communication module for UAV hardware-in-the-loop simulation system 2019 China Science and Technology Information 1 54-55
[5] Xing Zheng, Chuanmei Bao and Zhongzhu He. Design of simulation test platform for UAV flight control system 2018 Britain: Journal of Physics 161-166
[6] Chen Xin, Xia Yuncheng and Dong Xiaohu. A digital hardware-in-the-loop real time simulation system for flight control 2001 Journal of Nanjing University of Aeronautics & Astronautics 33 200-202
[7] Feng Limin. Simulation of UAV test flying path planning based on secondary development platform 2018 Intelligent Computer and Applications 8 91-94
[8] Lin Dongsheng, Zheng Xing and Bao Chuanmei. Design and implementation of visual simulation system for UAV simulated training 2007 Journal of Computer Applications 27(z1) 107-108
[9] Neil R. Watson, Nigel W. John and William J. Crowther. Simulation of unmanned air vehicle flocking 2003 Proceedings of the Theory and Practice of Computer Graphics 20-24
[10] Li Cheng, Li Gun, He Xiaobo and Liu Qiang. Implementation of UAV data acquisition interface 2012 Ordnance Industry Automation 31 93-96