Acta Technica 62 (2017), No. 6A, 27–36

Research and implementation of a simulation method of electric transmission line inspection using UAV based on virtual reality

Li Junfeng[1], Wang Peng[2], Xu Jieqiang[3], Wang Qinruo[1], Liu Xiao[2], He Shuangbai[2]

Abstract. This paper aims to introduce a simulation method of electric transmission line inspection of UAV (Unmanned Ariel Vehicle) based on virtual reality. This method makes a successful combination of the technology of flight simulation of UAV and the computer graphics technology, and establishes a brand new UAV flight simulation system based on simulation performance requirements. The system can not only simulate the control and interaction of real UAV realistically but also interact in virtual scenes based upon real geographic information environments. The system can help effectively improve the simulation level of UAV transmission line inspection, and has great importance to the industrial application development of the UAV.

Key words. UAV, transmission line inspection, physical simulation, interaction.

1. Introduction

In the training process of UAV power inspection, simulator training is an indispensable part of the UAV power application training, helping operator to get familiar with the basic operations of UAV as soon as possible [1]. However, the author found that there are many deficiencies in the practical applications: being unable to simulate the PTZ (Pan Tilt Zoom on UAV) image transmission function, lack of industry application scenes, impossible interaction between UVA models and

[1]1School of Automation, Guangdong University of Technology, Guangzhou, Guangdong, 510090, China

[2]Education Training Evaluation Center, Guangdong Power Grid Co., Ltd, Guangzhou, Guangdong, 510520, China

Corresponding Author, e-Mail: 6724757114@qq.com

[3]Dongguan Power Supply Bureau, Guangdong Power Grid Co., Ltd, Dongguan, Guangdong, 523106, China

virtual scenes, etc. Because electric transmission lines have many points, long lines and wide coverage, the development technology of large-scale 3D scenes is quite difficult. There is no flight simulation system which aims at UAV transmission line inspection yet.

This paper introduces a simulation method of transmission line inspection using UAV based on the virtual reality technology. This plan mainly consists of flight control, PTZ simulation, visual simulation, training and assessment management and some other modules [1–3]. Application of this plan will enable the operation and drilling of transmission line inspection in the large-scale electric transmission line 3D simulation scenes. The simulation system developed based on this method can not only help the power grid UAV inspection workers to quickly get familiar with the UAV inspection equipment, but also can help them to do the simulation training before their work, thus to avoid unnecessary losses of personnel, power grid lines or UAVs caused by improper operation in special situations. Therefore, it is of great importance to improving the level of electric transmission line UAV inspection.

2. Design and implement

The method targets at the deficiencies of the former simulators and combines with specific applications of UAV transmission line inspection. The core of the overall simulation method is simulating the flight control of UAV according to the flight principle of multirotor UAV [4, 5]. Then, based on the above conditions, feedback the status parameter got from the simulated calculation to the operator in the form of virtual scenes. The principle of simulation process of the whole UAV transmission line inspection is shown in Figure 1.

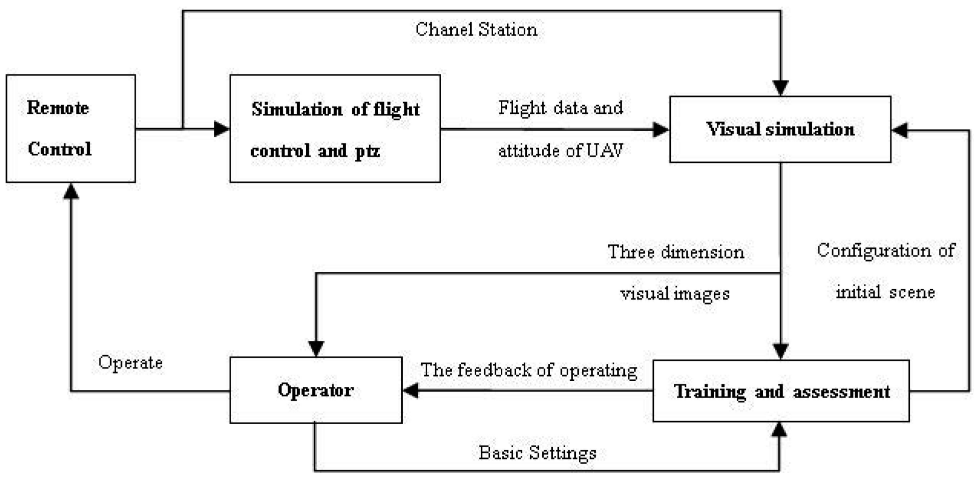

Fig. 1. Functional block diagram of the simulation proces

The Fig. 1 shows that, the remote control receives the operational order from the manipulator, and sends the orders from each channel to the server. The server analyses the current operational orders of the simulation cycle and delivers them to the flight control simulation and PTZ simulation module. Through the attitude estimation, the current flight parameters and attitude parameters of the UAV and its PTZ will be calculated. The visual simulation module loads corresponding visual images according to the status of the remote control channel, the current flight position, the attitude parameter and the PTZ attitude [6]. On the one hand, the training and assessment module loads the setting information of the initial scene to the visual module according to the basic settings of the operator. On the other hand, based on the current visual images, the training and assessment module achieves the functions of PTZ image storage, safe flight tests (crash test and regional test) in the whole process, and carries out the visual output to the operator.

2.1. Remote control

The plan fully considers the verisimilitude of the simulation system from the bottom hardware. It is based on the remote control of the real UAV system. First, connect the Train port of remote control with the simulation server, and then the server analyses the operation orders. In order to ensure that the system is easily deployed and applied, the connection of the remote control and the simulation server should take full use of the most common input port of the server, which means that the signals can be transmitted by the USB cables. Generally, the signals sent by the Train port of remote control are PPM (Pulse-Position Modulation) signals or PCM (Pulse-Code Modulation) signals. In order to make it easier for simulation servers to distinguish, it is necessary to simply map the channels to make them simulator input which can be read by the simulation servers. Then the remote control configuration is finished after calibration.

2.2. Flight control module

Flight control and PTZ simulation model mainly accept the information of channel status from the remote control. After calculation by the flight control simulation model and the PTZ simulation model, the flight position, attitude parameters, PTZ attitude and some other information can be obtained.

The appearance simulation model of the UAV flight control system is mainly based on the most common four-axis rotor UAV used in UAV power inspections. The structure is shown in Fig. 2. In the figure, oxyz are three axes on the aircraft-body coordinate system. The UAV can do the rolling angular motions around the x-axis, do the pitching angular motions around the y-axis, and do the yawing motions around the z-axis.

This type of UAV changes its lift and flight attitudes by adjusting the rotational speed of its propeller through controlling the rotational speed of the four electric motors. In practical simulation applications, the simulation manipulators pay more attention to the changes of the UAV attitudes instead of the changes of propeller's rotational speed in virtual scenes. Therefore, the key points of flight control simulation are firstly establishing a UAV physical model which is suitable for simulation

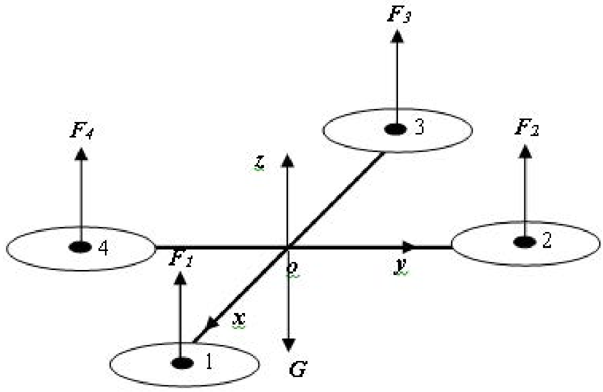

Fig. 2. Structure diagram of UAV

training, and determining the configuration information and basic settings of the quadrotor UAV and its sensors. Then, the computer uses the parameters of the four channel control sticks (throttle control stick, yawing control stick, pitching control stick and rolling control stick) as the control inputs and also takes use of the input value of the previous simulation cycle to calculate the model. Finally, the flight parameters, attitude parameter and some other data of the UAV can be obtained. The calculating results are used as the initial values of the next simulation cycle to achieve the real-time simulation.

Mini quadrotor UAV is a kind of six degrees of freedom air vehicle. Its independent variables and controlled variables are the inputs of the four remote control channels. The number of its independent controlled input is fewer than that of its degree of freedom of system, so the system of Mini quadrotor UAV is the typical underactuated and nonlinear system [2, 7]. Therefore, its mathematical model is relatively complicated and has the characteristics like instability, strong coupling and nonlinear structure [8]. In order to make it convenient to simplify the mathematical model allowed by the simulation training, it is necessary to firstly make assumptions and define as follows:

a) The UAV model is a uniformly symmetrical rigid body;

b) The origin of the inertial coordinate system E is coincide with the geometric center and the barycenter of the UAV model;

c) In the transmission line inspection, the relative takeoff height is usually fewer than 300 meters. So it can be considered that the resistance and gravity experienced by the UAV model during the whole training are constants and will not be influenced by the flight height and other factors.

Define m as the weight of the UAV simulation model; ν is the linear velocity of the UAV model; F is the sum of the outside forces experienced by the quadrotor UAV model; F_x, F_y, F_z are F's vector components on the three coordinate axes of the air vehicle coordinate system.

The motions of the quadrotor UAV model can be divided into linear motion and angular motion. Generally speaking, the ground coordinate system is used when calculating the linear motions and the body axis system is used when calculating the angular motions. Finally, describe the results in the form of the ground coordinate system through the matrix. According to Newton's law and the flight dynamics equation, the following vector forms can be obtained:

$$\begin{bmatrix} F \\ M \end{bmatrix} = \begin{bmatrix} m\dot{V} \\ \dot{H} \end{bmatrix} . \tag{1}$$

In (1), M is the sum of the outside force moment experienced by the UAV model, and H is the absolute moment of momentum of the UAV model relative to the ground coordinate system.

According to the principle of propeller mechanical motion, the lift of a rotor wing can be described as:

$$F = \frac{1}{2}\rho C_t A R^2 \Omega^2 . \tag{2}$$

In (2), ρ refers to air density, C_t is tension coefficient, A is area of a paddle wheel and R is radius of a propeller. In order to simplify calculation, ρ, C_t, A, and R can be considered as constants in the simulation process. Therefore, the lift generated by the propeller satisfies:

$$F_i = C_1 \Omega_i^2 . \tag{3}$$

C_1 is the lift constant. Since the propeller rotates, according to Newton's law, air resistance experienced by UAV can be described as:

$$F_{zi} = C_2 \Omega_i^2 . \tag{4}$$

C_2 is the resistance constant. Under the certain conditions allowed by the simulation training, according to Newton's second law of motion and the air vehicle dynamics equation, the simplified linear acceleration equation can be described as:

$$\begin{cases} \ddot{x} = (\cos\psi \cos\phi \sin\theta + \sin\phi \sin\psi)\, F/m \,, \\ \ddot{y} = (\cos\phi \sin\psi \sin\theta - \sin\phi \cos\psi)\, F/m \,, \\ \ddot{z} = (\cos\phi \cos\theta)\, F/m - g \,. \end{cases} \tag{5}$$

In (5), ψ is yaw angle $(-\pi, \pi)$, ϕ is roll angle $(0, \pi/2)$, θ is pitch angle $(0, \pi/2)$, and g is gravitational acceleration.

According to the relation between Euler angles and angular velocity of a UAV model as well as the angular motion equation, the formula can be described as follows:

$$\begin{bmatrix} \ddot{\phi} \\ \ddot{\theta} \\ \ddot{\psi} \end{bmatrix} = \begin{bmatrix} [lC_1 \left(\Omega_4^2 - \Omega_2^2\right) + \dot{\theta}\dot{\psi}\,(I_y - I_z)]/I_x \\ [lC_1 \left(\Omega_3^2 - \Omega_1^2\right) + \dot{\phi}\dot{\psi}\,(I_z - I_x)]/I_y \\ [C_2 \left(\Omega_3^2 + \Omega_1^2 - \Omega_4^2 - \Omega_2^2\right) + \dot{\phi}\dot{\theta}\,(I_x - I_y)]/I_z \end{bmatrix} . \tag{6}$$

In (6), I_x, I_y and I_z are three axial moments of inertia and l refers to the distance from a quad rotor UAV model to the center of a propeller.

In the UAV simulation training, the flight parameters of a UAV simulation model are mainly controlled by adjusting the parameters of control sticks. Take the left operating level throttle/yaw and the right one roll/pitch as examples, controlled input is defined as follows: throttle channel input is U_1, yawing channel input is U_2, pitching channel input is U_3 and rolling channel input is U_4. According to force analysis, formula 7 can be described as:

$$\begin{bmatrix} U_1 \\ U_2 \\ U_3 \\ U_4 \end{bmatrix} = \begin{bmatrix} F_1 + F_2 + F_3 + F_4 \\ F_1 - F_2 + F_3 - F_4 \\ F_3 - F_1 \\ F_4 - F_2 \end{bmatrix} = \begin{bmatrix} C_1 \sum_{i=1}^{4} \omega_i^2 \\ C_2 \left(\omega_1^2 - \omega_2^2 + \omega_3^2 - \omega_4^2\right) \\ C_1 \left(\omega_3^2 - \omega_1^2\right) \\ C_1 \left(\omega_4^2 - \omega_2^2\right) \end{bmatrix} . \tag{7}$$

Put controlled input variable U_i into (5) and (6), (8) is worked out:

$$\begin{cases} \ddot{x} = (\cos\psi \cos\phi \sin\theta + \sin\psi \sin\phi)\, U_1/m\,, \\ \ddot{y} = (\sin\psi \cos\phi \sin\theta - \cos\psi \cos\phi)\, U_1/m\,, \\ \ddot{z} = (\cos\phi \cos\theta)\, U_1/m - g\,, \\ \ddot{\phi} = \left[lU_4 + \dot{\theta}\dot{\psi}\,(I_y - I_z)\right] /I_x\,, \\ \ddot{\theta} = \left[lU_3 + \dot{\phi}\dot{\psi}\,(I_z - I_x)\right] /I_y\,, \\ \ddot{\psi} = \left[C_2U_2 + \dot{\phi}\dot{\theta}\,(I_x - I_y)\right] /I_z\,. \end{cases} \tag{8}$$

In (8), the change of the resistance constant C_2 can simulate the control status of UAV in different wind scales. In the course of real simulation calculation, the selection of specific parameters can refer to the frequently used training UAV models and relative parameter measurement results, which are shown in Table 1.

Table 1. Relevant parameters of UAV flight simulation model

Parameters	Value	Unit
m	0.8	kg
l	0.28	m
Ix	0.014	kg·m2
Iy	0.014	kg·m2
Iz	0.016	kg·m2
g	9.8	m·s-2
C_2	(0.4, 1.2)	\

According to the simplified mathematic model of (8) and the parameters in Table 1, the simulation server can calculate the status parameter of UAV in virtual scenes according to the control inputs of remote control, and realizes the semi-physical simulation controlled by UAV. C++ is adopted to fulfill functions like hardware-in-loop simulation controlled by UAV. The Intel i3 processor is the operation platform and the delay of data calculation process is less than 20 ms, so that the simulation server can satisfy the high-speed need of the real-time system and basically reflect the accurate control results of the UAV.

2.3. PTZ simulation module

PTZ is important inspection equipment carried by power inspection UAV and has many PTZ mission equipment like visible light equipment, infrared equipment, UV devices, and 3D scanners. PTZ can enhance the efficiency of transmission line inspection. Thus, PTZ functional simulation is crucial for the simulation training system of UAV electric transmission line inspection.

The first step of the PTZ simulation cycle is that, the simulation server needs to read and analyze the order of remote control and judge whether the transfer button of graphic transmission in analytic protocol is effective or not. If it is effective, the BVR (Beyond Visual Range) graphic transmission model is activated. When the graphic transmission model is activated, the simulation server will act according to the angle of a dial knob of analytic protocol and the PTZ view carried by the UAV. Meanwhile, simulation server will check the shooting button of the remote control whether effective or not at any time. When the channel data is effective, 3D simulation scene image under the PTZ simulation angle will be captured and uploaded to the simulation server.

2.4. Visual scene simulation module

Visual scene simulation module is used to present the scenes of UAV transmission line inspection simulation system. The module can simulate in three dimensions of line channels, and information about terrain and vegetation around the power line channels. What's more, it can present the real-time flight status and flight data based on the calculation results of flight control and PTZ simulation module. Since the scene size of electric transmission line is huge, when building the visual scene resources, it is necessary to take many linked steps including mass satellite data processing, 3D reconstruction preprocessing, point-cloud reconstruction, grid reconstruction, texture reconstruction [9].

As for the course of realizing what has been mentioned above, the paper uses language development underlying resources like OpenGL and GLSL as well as utilize billboard and mesh simplification to describe approximate contour of objects so as to save mapping resources, expand the mapping size, save GPU resources and guarantee the overall effect of large scene. Based on the LOD (Level Of Detail)processing of geometry, providing relative LOD according to different viewpoint position can be done. Fig. 3 is the simulation effect when UAV model take off in virtual scene.

3. Conclusion

Based on Virtual Reality technology, the UAV line inspection simulation method integrates with UAV flight control simulation technology, computer graphics technology, large-scale modeling technology. UAV flight physical model which is suitable for simulation training is put forward with the foundation of the theory upgrading of UAV flight dynamics. The system based on this method solves the problems, such as, the disparity between past simulator and real UAV, bad scene experience. Besides,

Fig. 3. Visual scene simulation

the system based on this method make the simulation of electric transmission line inspection using UAV more real and could support the feedback of operation process and inspection results. What's more, the control experience is more authentic.

Based on the UAV inspection simulation system of electric transmission line which is designed by the paper, trainees can train themselves in short time and gain auto evaluation. This can enhance the efficiency of the training of UAV line inspection skills quickly and decrease the safety risk of real UAV operation training. It surely has great significance for relative industries to apply UAV and for employees to master UAV operating skills.

References

[1] D. X. Zhou, T. D. Ma: *Research on simulation platform of quadrotor aircraft flight control system*. Computer Measurement& Control *22* (2014), 424–426.

[2] L. Q. Sun, G. F. Zhang, X. R. Wang: *UAV simulation training system*. Computer Simulation *23* (2006), 44–46.

[3] Q. P. Zhao: *Design of a quad-rotor UAV simulation control system*. Electronics Optics & Control *22* (2015), 27–30.

[4] S. Bl, L. Fl: *Aircraft control and simulation*. Aircraft Engineering & Aerospace Technology *5* (2016), 76.

[5] A. H. Goktogan, E. Nettleton, M. Ridley: *Real time multi-UAV simulator*. IEEE International Conference on Robotics and Automation *2* (2003), 2720–2726.

[6] Y. Gao, S. X. Guo: *Virtual reality visual simulation technology*. Northeastern Polytechnical University Press (2014), 198–294.

[7] J. K. Liu, X. R. Shen, L. Zhao: *System identification theory and MATLAB simulation*. Publishing House of Electronics Industry (2013), 6–18.

[8] Y. Yang, X. Chen, C. T. Li: *Robust flight control law design of unmanned aerial vehicle based on baseline-augmented control structure*. Journal of South China University of Technology *9* (2014), 90–95.

[9] Y. Wu, T. Yu, D. H. Xie: *Fast automatic stitching for unmanned aerial vehicle in emergency response*. Journal of Computer-Aided Design & Computer Graphics *25* (2013), 410–416.

Received September 19, 2017