The Flight Control System of FanWing Uav Design and Simulation

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ABSTRACT

The FanWing concept makes use of a cross-flow fan to accelerate oncoming airflow over a relatively thick aerofoil section, producing lift and thrust simultaneously. FanWing aircraft have the ability like: short range take-off, good low speed and high lift characteristics, etc. Therefore, it may widely used in military and civil field. Due to FanWing aircraft has the lift and thrust coupling effect, it is difficult control in manual flight. Then the flight control device used in this vehicle is required. FanWing aircraft have the same flight operation control method and the similar fly mode with the fixed wing aircraft. The aim of the work was to build and test a FanWing flight control system based on the simulator model and the radio controlled (RC) model which referenced to the design method of the fixed wing UAV. The project consisted of three phases. First of all, according to the FanWing aircraft’s flight characteristics, establish the FanWing simulation model and simulation it in the X-Plane simulator platform. Secondly, design the pitch and roll stability PID controller with the common PID parameter setting method; Finally, Developed the stability augmentation flight controller hardware and software, acquired the control parameters in hardware in the loop (HIL) simulation environment, verified the feasibility of the flight control system software and hardware in the actual FanWing uav.

1 INTRODUCTION

FanWing is an aircraft configuration that uses a simple cross-flow fan mounted in the wing to provide distributed propulsion and augmented wing lift at very low flying speeds (see figure 1 and figure 2). One of the current flight-test vehicles has been modified to accept both a novel OHS twin-tail arrangement and a new wing section and this has shown both increased flight stability and reduced drag, leading to significantly higher cruise speeds. The good slow flight capability, inherent safety and relatively quiet propulsion of the FanWing rotorcraft could fit well with cargo operations close to urban areas. A comparison with aircraft and helicopters showed that the recent developments of the FanWing concept could now uniquely offer short-field performance close to that of helicopters and tilt-rotor aircraft, but with operating economies close to that of conventional aircraft. It has many advantages, for example: Very short take-off and landing capability with potential VTOL, Efficient fuel consumption, Simple, economical construction, controls, maintenance, Stability and resistance to turbulence, No stall and Quiet operation. Therefore, if we can design and made a usefull Fanwing aircraft can make a big influence in the world.

Figure 1 Fanwing Sport aircraft
One of the main functions of UAV is its autopilot. It consists of high level navigation algorithm and low level control law. The common way to developing control law is based on mathematic model of the airframe. This way to obtain the model is quite difficult and proved to be long term effort. Moreover, if you use system identification modeling based on data recorded from real world flight test to build model. Unfortunately the model we obtain is not easy and have a high risk procedure. Fortunately we can available flight simulation software package of the plane model we want to use and modify. So, in this project, a rapid methodology will be proposed to develop control system of FanWing UAV based on the availability of mathematic model embedded inside X-Plane model package by Oliver Ahad (2006, Imperial College).

### 2 MODEL DEVELOPMENT

The simulator model was built using X-Plane9’s “Plane-Maker” Software. Early wind-tunnel testing at Imperial College documented the impressive aerodynamic characteristics of the early test model (Foreshaw, 1999). Further, wind-tunnel and flow visualization tests were carried out in 2002. These documented the aerodynamic data of a new, optimized model, and showed a 50 percent increase in efficiency, and an improvement in the device’s autorotation characteristics. The findings of the tests, recorded in a report Kogler (2002), served as the main source of aerodynamic data for this project. The aerodynamic characteristics of the simulator model were to be matched as closely as possible to those listed in his report.

First we design the simulator model in X-Plane. Based on AutoCAD drawings of the FanWing RC plane prototype, the visual model was input using 18 fuselage cross-sections along the longitudinal axis, and generic input parameters for the tail-plane, undercarriage, endplates (housing and ailerons) and sideplates. The FanWing casing and rotors were built using generic inputs and are purely cosmetic. They were customized to provide no drag or lift contribution to aerodynamics, as these are represented fully by the combination of vectored thrust and the aerofoil. Four virtual vectored thrust engines were modeled, one at either wingtip, and two evenly spaced between them. The engines were positioned so that the thrust angles for the correct lift to drag ratio were between 75°and 85°to the horizontal. The aerofoil, of equal span to the rotor casing, was made transparent and located so that the centre of lift acted at the rotor centre. Basic steps as shown in the figure 3 to figure 9.
Although in some ways, model may not be very ideal, but it is an accurate reflection of the flight characteristics of the aircraft. The model will likely be used as a preliminary training tool for the FanWing’s first pilots. It is also a useful publicity tool for the aircraft, and provides an insight into how this unusual aircraft flies, from a pilot’s perspective.

3 PID CONTROL DESIGN

PID (proportional integral derivative) controller is a generic control loop feedback mechanism (controller) widely used in industrial control systems. A PID controller calculates an "error" value as the difference between a measured process variable and a desired setpoint. The controller attempts to minimize the error by adjusting the process control inputs. This controller takes many structures but the most important one as in
the follow form:

\[ MV(t) = K_p \left( e(t) + \frac{1}{T_i} \int_0^t e(\tau) d\tau + T_d \frac{d}{dt} e(t) \right) \]

Where \( MV(t) \) is the input signal to the plant model, the error signal \( e(t) \) is defined as \( e(t) = r(t) - y(t) \) and \( r(t) \) is the reference input signal.

In general, the control consists of two layers. The first relates to the position control while the second is that of the attitude control. This paper will focus on the attitude control through the hardware in the loop flight simulation to set the PID parameters. Based the setpoints (roll pitch and yaw angle) we give. These information will be read by PID controller as its setting point and will be compared with actual value using PID algorithm to produce servo command value that will actuate the airframe’s surface control (aileron, elevator and rudder) and throttle. In this project, the throttle is manual controlled. Design of the control law is as shown in the figure 10.

![Figure10 PID functional block diagram](image)

4 HARDWARE AND SOFTWARE DESIGN

FanWing unmanned control system based on conventional fixed-wing UAV flight control system design method. The control system is mainly composed of flight control computer (FCS) system, the peripheral sensor, servo system and power supply system. The hardware system architecture is shown in figure 11.

Based on the control algorithm development step. Several measurements needed by the PID control scenarios. These measurements are position measurements and attitude measurements. In our case, we need attitude that include pitch, roll and yaw. In order to know the aircraft’s flight path in the computer. A GPS receiver can be achieved. That is to say We typically need 3D axiometers, 3D gyros, 3D magnetometers, altimeter, GPS, airspeed indicator, rotate speed sensor and other sensors. Xsens MTI-G is an Attitude and Heading Reference System (AHRS) which can provide attitude and position data. This integrated sensor can make the system become simple and improve efficiency.

The flight control computer software program’s writing is divided into two pieces as shown in figure 12. One for semi physical simulation, another is in actual flight. one of the two single pole switch software running processes to flying model or simulation model, so that ensure flight control board always perform an operation mode. Simulation mode and flight mode is the difference between the simulation flight without physical sensors to provide data information, and directly obtained from the simulation software platform.
5 FLIGHT SIMULATION AND TEST

HIL simulation can save over hundred hours of field experimenting. In a well made HIL system, the PID’s and flight algorithms can be tested. Even takeoff, landing, and flying mission can be simulated. We will describe how we made and how it can be used. This will also be used in the real FanWing uav as described.

In the flight simulation we do as follows (see figure 13): connect the RC receiver to the FCS board. Connect the usb/serial from the FCS board to the port used by ground control station (GCS, figure 14 to figure 16). Turn the safety pilot transmitter, and start X-Plane9 in the computer. Now, switching to simulation mode on the FCS board. In this project we run X-Plane and GCS in one computer. It is easy to connect them by network. At this point, the HIL simulation system has been set up. The idea with a HIL simulation is to include as much of the real hardware and software as possible. All hardware except for the sensor is used, and all software is running like this was a real flight. While the GCS receives live data from the simulator, not knowing it is just simulation. That is to say, when the computer fly’s the model, it believes this is for real and uses it’s controller algorithm.
We use GCS to change the PID values of roll, pitch and yaw. We use engineering tuning parameter method. If we use manual method to tuning the value is inefficient. Lucky, our GCS PID tuning software (figure 17) can communicate with the simulator model to choose the suitable value. But it is not so perfect, we still need to slightly modify the value. Figure 18 shows that FanWing simulation model’s elevator pull up when in low speed, else in high speed push down to maintain level flight. The simulation shows that the set of parameter values can guarantee the stability of the FanWing simulation model flight well. Next, we will test the system on a RC FanWing scale model.
The total length of the prototype demonstrator, including the wing’s tails, is 1.6 meter, and its total width with its outboard aileron is as same as the length, including 1.4 meter of rotor span. Documented efficiencies for the prototypes were 2.9 kilograms of lift per kilowatt of shaft power. The rotor speed will be 2,500 rpm. Its takeoff distance is expected to be 10 meters or less. Here are the specifications of our test FanWing RC model (see figure 19, 20):

1. Wing span: 1.6 m
2. Rotor span: 1.4 m
3. Rotor diameter: 20 cm
4. Weight: 6 kg
5. Flight speed: 30-50 Km/h
6. Engine: 2.3 Kw
7. Power voltage: 22.2V & 11.1 V
8. Remote control: Hitec 9 2.4G

As shown in figure 21 for FanWing uav under the condition of half stabilization, 0-300 seconds period, the attitude Angle and direction Angle of the stable situation. Its pitch and roll angle within plus or minus
5 degrees. Heading angle is very good, not more than 2 degrees. Therefore, the flight control system and PID values simulator in HIL, in the actual flight test, has reached the expected goal.

6 CONCLUSION AND OUTLOOK

The designed FCS in this article, from the establishment of simulation model, the establishment of the flight control law and the hard software design etc, have referred to the success of a large number of domestic and foreign experience. There have many places need to improve, such as the design of control law can use intelligent algorithm, neural network algorithm, fuzzy algorithm and so on. Hardware can choose architecture of ARM R series chips or other high speed real-time processing chips. Robustness of software also need to further strengthen. The program code can be optimized to perform more efficiently. We also can add the operating system to manage each subsystem. Relative to a set of complete function of flight control system (figure 20), in this project, the designed flight control system is still in the preliminary stage. Autonomous navigation, path planning and fault detection and repair, and redundancy backup haven't joined in our FCS. Although it has obtained some good result, but still need to in-depth study to realize flying FanWing aircraft easily.

REFERENCES

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