Robust Model for the Design of Controller in Saucer UAV

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Abstract—**The saucer UAV (Unmanned Aerial Vehicle) features both helicopter and traditional fixed-wing airplane, is capable of hovering, takeoff and landing vertically. The configuration of the UAV in this paper which is comprised of a propeller and there pairs of control vanes enclosed in the duct is new-style aircraft. In order to research the attitude control of the saucer UAV, this paper mainly focuses on the dynamic analysis and control model design of the vehicle. The dynamics of all the components of the UAV configuration is analyzed respectively first and then the complete nonlinear model is constructed from the forces and moments analysis of the vehicle. The model is simplified in the flight node of hovering. After that a robust model based on H_2/H_∞ is designed to handle the parameter uncertainty and disturbance while in the hovering condition, and the simulation results are presented at last. Simulated results show the controller designed can guarantee the saucer UAV has good stable feature for operation and certain robustness.**

Index Terms—**saucer unmanned aerial vehicle (UAV); modeling; H_2/H_∞ theory; flight mechanics; flight simulation**

I. INTRODUCTION

In recent years, UAV (Unmanned Aerial Vehicle) is equipped more and more in the army because of their special performances and capacities. Countries pay more attention to develop their own UAV systems. Compared with traditional aircraft, UAV has many advantages, such as light weight, flexibility, low cost, safe and reliable performance. The saucer UAV is a vertical takeoff and landing air vehicle utilizing ducted fan technology to hover and fly forward. The configuration consists of a ducted fan and control vanes at the duct exit plane. The duct both increases the propulsion efficiency and provides direct lift in forward flight similar to a conventional planar wing. However, there are many other benefits inherent in this design. They can be very small with a compact layout. In term of safety, the duct protects personal from exposure to the propeller. So it can be competent for some special missions [1].

Military and commercial uses for the UAV capable of hovering and forward flight while remaining small are countless. In military, operations on urbanized have become an area of concern within recent years, and it can be utilized to accomplish the tasks of search and rescue in battlefield. Commercial interest has also been seen by companies and organizations looking for stable camera and surveillance platform, bridge inspection and traffic monitoring can benefit from a small UAV capable of hovering flight. Although the ducted fan UAV has been developed in recent years by American researchers, and the representative production is the iSTAR unmanned air vehicle designed by Allied Aerospace which is a developer of affordable, high-speed, scalable, VTOL unmanned air vehicles (UAVs). Compared with iSTAR UAV, the saucer UAV discussed in this paper have less area into the wind so that it will suffer less influence as the shorter duct, and it will be more suitable for hovering and disturbance rejection.

The control of the saucer UAV presents many problems. Firstly, a reasonably accurate model is helpful for simulation, and this allows designer to estimate the performance of their design before flight testing. Another problem is that saucer UAV is usually highly unstable with complex aerodynamics, so the controller must be very robust to deal with the uncertainty present in the available models of the vehicle dynamics [2]. Also the saucer UAV is, as almost every physical system, usually affected by some kinds of noises. The sources of the noise are often many but in most cases just a few of them affect the system enough to be needed in a mathematical model. Weather phenomenon, like wind and rain, effects from the ground, like a pull on the tether, wind vortices below the fan and electrical disturbance in wires and control units can all be regarded as sources of noise in this project. As the compact configuration of the saucer UAV, so the controller must have the ability to overcome the disturbance.

Many works have been done by scholar recently based on vectored thrust ducted propeller. The characters of the

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ducted fan system have been developed mainly by experiments.

Rigid-body dynamical model is derived with the knowledge of rigid-body dynamics and aircraft dynamics. The nonlinear vehicle dynamic model is given below, followed by the robust controller design based on control theory, and then the simulation results are presented at last.

II. VEHICLE DESCRIPTION

As shown in figure 1, the most evident character of the vehicle is that it consists of a duct with an outer diameter of 1500 millimeters that make the vehicle looks like a saucer. The duct both increases propulsion efficiency and produces lift in the forward flight, similar to a conventional planar wing. The vehicle is 500 millimeters high, with a maximum takeoff weight of 10 kilograms. It is powered by a small engine driving a four-bladed, fixed propeller. The propeller is enclosed within the annular wing duct.

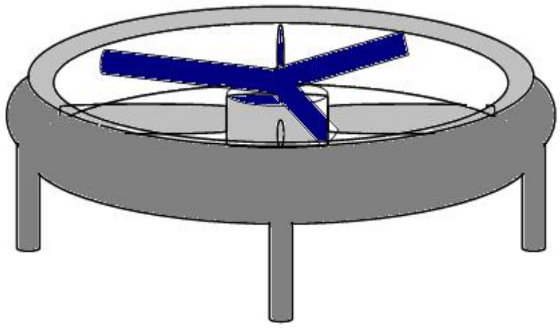

Figure1. The saucer UAV

The UAV features both helicopter and airplane flight modes. It takes off, lands, and hovers in the helicopter mode in which the propeller provides direct thrust to support the vehicle. The vehicle can translate at low speeds in this configuration by tilting the thrust vector. In airplane mode, the vehicle is tilted by a large angle up to 30°. The propeller creates forward thrust while the duct creates lift, allowing the vehicle to move at up to 40 km/h. Several fixed stators located in the middle of the duct for flow straightening and over the control vanes. Two pairs of control surfaces are located at the end of the fuselage along the x and y axis respectively. These control surfaces work in pairs to create moments that rotate the vehicle about its centerline for rolling and pitching attitude control. Four vanes located on the cross at the end of the duct are immersed in the outflow. These vanes move together in the same sense to rotate the vehicle about its centerline to control the yaw attitude. The control vane size and distance can vary greatly in different vehicles.

III. DYNAMIC ANALYSIS AND MODELING

Before a mathematical model of the vehicle can be constructed, reference frames and angles need to be defined. Two reference frames will be used, the inertial reference frame and the body fixed reference frame. A ground frame could be approximated as the inertial reference frame for the local flight to derive the equations of the vehicle motion. The ground reference frame has its origin fixed to the ground, generally at the starting point, and the three axes constitute NED (North-East-Down) coordinate. The body fixed reference frame has its origin fixed in the center of gravity of the vehicle. The body fixed reference frame is shown in Figure 2. The Euler angles ϕ 、 θ and ψ is defined to describe the orientation of the body frame changing with time relatively to the inertial frame. The body fixed angles are called pitch, roll and yaw and the angles usually used when the rotation of an aircraft is described. Pitch is the angle originating from a rotation about the y axis, roll is the angle originating from a rotation about the x axis and yaw is the angle originating from a rotation about the z axis.

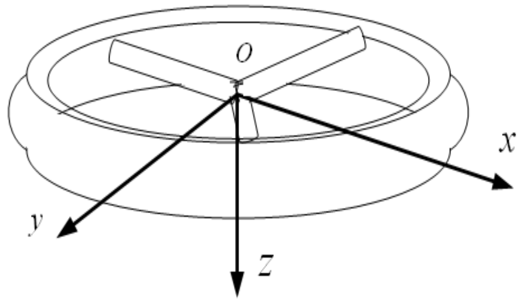

Figure2. The body-fixed frame

The motion of the vehicle in the air can be decomposed to the transfer along the reference frame and turning around the vehicle center of gravity. The transfer dynamic equation can be expressed as:

$$\begin{aligned} m(\dot{u}+qw-rv) &= \Sigma F_x \\ m(\dot{v}+ru-pw) &= \Sigma F_y \\ m(\dot{w}+pv-qu) &= \Sigma F_z \end{aligned} \tag{1}$$

where m is the mass of the vehicle; u 、 v and w are the velocities along body axis; ϕ 、 θ and ψ are the Euler angles; p 、 q and r are the angular velocities along each axis in the body fixed reference frame.

Turning dynamic equations are as follows:

$$\begin{aligned} I_x\dot{p}-(I_y-I_z)qr+I_{xz}(pq+\dot{r}) &= \Sigma M_x \\ I_y\dot{q}-(I_z-I_x)rp-I_{xz}(p^2-r^2) &= \Sigma M_y \\ I_z\dot{r}-(I_x-I_y)pq-I_{xz}(\dot{p}-qr) &= \Sigma M_z \end{aligned} \tag{2}$$

where I_x , I_y and I_z are the moments of inertia along X、Y and Z axis; I_{xy} is the moment of inertia product of the vehicle. Torques in the body fixed reference frame are denoted $\sum M_x$, $\sum M_y$ a nd $\sum M_z$ respectively.

The relationship of the angular velocity between the body fixed frame and the inertial reference frame is as follows:

$$\begin{bmatrix} p \\ q \\ r \end{bmatrix} = R_x(\varphi)R_y(\theta)R_z(\psi)\begin{bmatrix} 0 \\ 0 \\ \dot{\psi} \end{bmatrix} + R_x(\varphi)R_y(\theta)\begin{bmatrix} 0 \\ \dot{\theta} \\ 0 \end{bmatrix} + R_x(\varphi)\begin{bmatrix} \dot{\varphi} \\ 0 \\ 0 \end{bmatrix} \quad (3)$$

where $R_x(\varphi)$, $R_y(\theta)$, $R_z(\psi)$, are the rotation matrix, and their expressions are:

$$R_x(\varphi) = \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos\varphi & \sin\varphi \\ 0 & -\sin\varphi & \cos\varphi \end{bmatrix} \quad (4)$$

$$R_y(\theta) = \begin{bmatrix} \cos\theta & 0 & -\sin\theta \\ 0 & 1 & 0 \\ \sin\theta & 0 & \cos\theta \end{bmatrix} \quad (5)$$

$$R_z(\psi) = \begin{bmatrix} \cos\psi & \sin\psi & 0 \\ -\sin\psi & \cos\psi & 0 \\ 0 & 0 & 1 \end{bmatrix} \quad (6)$$

$$R_{zyx}(\varphi,\theta,\psi) = R_x(\varphi)R_y(\theta)R_z(\psi) = \begin{bmatrix} \cos\theta\cos\psi & \cos\theta\sin\psi & -\sin\theta \\ \sin\varphi\sin\theta\cos\psi - \cos\varphi\sin\psi & \sin\varphi\sin\theta\sin\psi + \cos\varphi\cos\psi & \sin\varphi\cos\theta \\ \cos\varphi\sin\theta\cos\psi + \sin\varphi\sin\psi & \cos\varphi\sin\theta\sin\psi - \sin\varphi\cos\psi & \cos\varphi\cos\theta \end{bmatrix} \quad (7)$$

This yields the following expression:

$$\begin{aligned} \dot{\phi} &= p + q\sin\phi\tan\theta + r\cos\phi\tan\theta \\ \dot{\theta} &= q\cos\phi - r\sin\phi \\ \dot{\varphi} &= \frac{1}{\cos\theta}(q\sin\phi + r\cos\phi) \end{aligned} \quad (8)$$

Another mathematical relation used when calculating the model is the relation between the velocities in the inertial reference frame and the velocities in the body fixed reference frame, given by

$$\begin{bmatrix} \frac{dx_i}{dt} \\ \frac{dy_i}{dt} \\ \frac{dz_i}{dt} \end{bmatrix} = R_{zyx}^{-1}(\varphi,\theta,\psi)\begin{bmatrix} u \\ v \\ w \end{bmatrix} \quad (9)$$

where x_i、 y_i and z_i represent the inertial reference frame position.

There are several kinds of forces acting on the UAV. The first one is the gravity, the second one is the lift, the third one is the forces generated by the control surface, and the final one is the forces generated by the fuselage and the duct when the noise wind acts on them. All the component forces and moments are discussed below.

A. Gravities

Since the roll attitude ϕ and pitch attitude θ are not zero, the gravity can be decomposed to three forces along X, Y and Z axis

$$\begin{aligned} F_{Gx} &= -mg\sin\theta \\ F_{Gy} &= -mg\cos\theta\cos\phi \\ F_{Gz} &= mg\cos\theta\sin\phi \end{aligned} \quad (10)$$

where g represents the local gravitational acceleration.

As the vehicle center of gravity is the reference frame origin,

$$M_{Gx} = M_{Gy} = M_{Gz} = 0 \quad (11)$$

B. Airfoil

This vehicle, like conventional helicopter spins airfoils to generate lift which is the main source of the power. For this type of aircraft, the airfoils create lift in the hovering flight or small ranges maneuvers in helicopter mode. When it flights forward at a high speed in the fixed-wing airplane mode, the duct works like an annular wing to create lift to balance the gravity. In this mode the lift created by the airfoils can be decomposed to two components: one component is used to balance the gravity, and the other is used to drive the vehicle to flight forward. Many factors must be considered before the vehicle is made, payload、 airframe and control system weight. The lift generated by the airfoil can be calculated as [3]:

$$\begin{aligned} F_{Ax} &= F_{Ay} = 0 \\ F_{Az} &= -T \end{aligned} \quad (12)$$

$$\begin{aligned} M_{ax} &= 0 \\ M_{ay} &= 0 \\ M_{az} &= -M_e \end{aligned} \quad (13)$$

$$T = \frac{1}{4}n_b(v_b - v_i)\omega_r r^2\rho_\infty a_0 b c_r \quad (14)$$

$$v_b = v_z + \frac{2}{3}\omega_r r(\frac{3}{4}K_{twist}) \quad (15)$$

$$M_e = N_b\int_0^r \frac{1}{2}\rho\omega_r r^3 C_D dr \quad (16)$$

where v_i represents the induced velocity through the rotor, a_0 represents the rotor lift curve slope, b represents the number of rotor blades, c_r represents the rotor blade chord, ρ represents air density, n_b

represents the number of the airfoil, r represents the radius of the rotor [4], v_z represents the airflow along the z axis in the body reference frame, ω_r represents the angular velocity of the rotor, and K_{twist} is the twist of the blades. The wind induced by the propeller, v_i can be calculated as [5] [6]:

$$v_i = \sqrt{\frac{T}{2\rho A}} \tag{17}$$

C. Control vanes

The basic sources of the vehicle that create the control forces and moments are the three pairs of control vanes, in which the roll and pitch vanes work synchronously and the yaw vanes work differentially. Some works are done to decrease the interaction coupling between the each pair of control vanes, such as installing the fixed vanes between them to separate the airflow in each channel, as seen in fig. 3. Assuming that there is no interaction between the vanes, the forces and moments generated by angle originating from a rotation about the z axis.

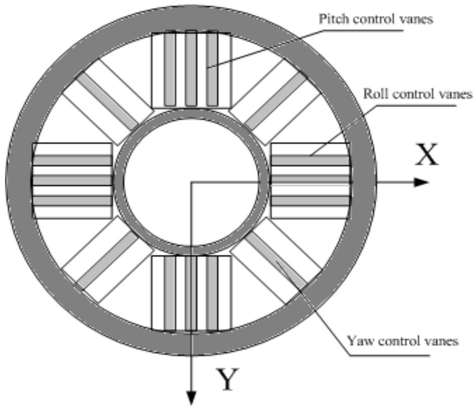

Figure3. Configuration of the control vanes

$$F_{Cx} = \frac{1}{2} N_{pitch} \rho v_i^2 S_c C_l(\delta_{pitch})$$

$$F_{Cy} = \frac{1}{2} N_{roll} \rho v_i^2 S_c C_l(\delta_{roll})$$

$$F_{Cz} = \frac{1}{2} N_{roll} \rho v_i^2 S_c C_d(\delta_{roll}) + \frac{1}{2} N_{pitch} \rho v_i^2 S_c C_d(\delta_{pitch}) + \frac{1}{2} N_{yaw} \rho v_i^2 S_c C_d(\delta_{yaw}) \tag{18}$$

$$M_{Cx} = \frac{1}{2} N_{roll} \rho v_i^2 S_c C_l(\delta_{roll}) l_{roll}$$

$$M_{Cy} = \frac{1}{2} N_{pitch} \rho v_i^2 S_c C_l(\delta_{pitch}) l_{pitch} \tag{19}$$

$$M_{Cz} = \frac{1}{2} N_{yaw} \rho v_i^2 S_c C_l(\delta_{yaw}) l_{yaw}$$

where S_c terms represent the area of the control vane. δ_{roll} , δ_{pitch} and δ_{yaw} are control vane deflection respectively, l_{roll} 、 l_{pitch} and l_{yaw} are the arms of forces produced by control surfaces:

D. Fuselage

The main component of the fuselage that generates lift and drag is duct. The forces and moments due to the duct aerodynamic drag can be written as:

$$F_{Fx} = -\frac{1}{2} \rho C_{D,x} V_x^2 S_x$$

$$F_{Fy} = \frac{1}{2} \rho C_{D,y} V_y^2 S_y \tag{20}$$

$$F_{Fz} = \frac{1}{2} \rho C_{D,z} V_z^2 S_z$$

$$M_x = F_{Fy} l_{ax}$$

$$M_y = F_{Fx} l_{ay} \tag{21}$$

$$M_z = 0$$

Where $C_{D,x}$, $C_{D,y}$ and $C_{D,z}$ are the lift coefficients along each axis, l_{ax} , l_{ay} are the arms of the forces. We can see that the duct produces any force and moment in the hovering mode, but when it flying forward the duct can produce lift on the vehicle which depends on the tilt angle

As seen in fig 4, when the saucer UAV flights in the crosswind or at a high forward speed, the vehicle is in the interaction of the airstream and the airflow along the axis of the vehicle. The airflow around the duct is asymmetric so that there must be pressure difference around the duct which is the moment drag which have to turn the airstream downward to flow along the axis of the vehicle. And the drag is [7][8] .

$$D = \rho (V_{wx} + V_x)(\pi r^2) V_i \cos(\alpha) \tag{22}$$

where V_{wx} represents the wind velocity, V_x is the velocity along the x axis of the inertial frame.

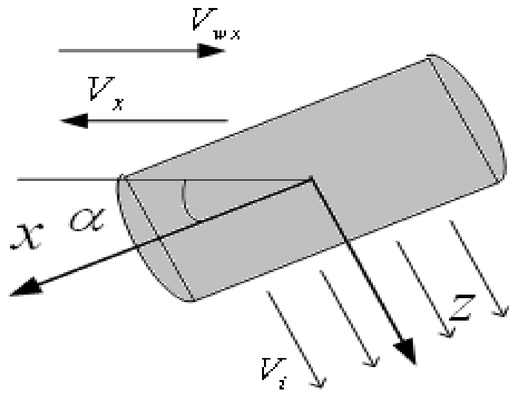

Figure4. Configuration of the fuselage

E. Gyroscopic Moment

The rotation of the rotor and airfoils create gyroscopic torques .

$$M_{gyro}=\frac{dH}{dt}+\Omega\times H=\frac{d(I\omega)}{dt}+\Omega\times I\omega$$
$$=\begin{bmatrix} I_{xprop} & 0 & 0 \\ 0 & I_{yprop} & 0 \\ 0 & 0 & I_{zprop}\end{bmatrix}\begin{bmatrix}\dot{p}\\ \dot{q}\\ \dot{r}+\dot{\omega}_p\end{bmatrix}+$$
$$\begin{bmatrix}p\\q\\r\end{bmatrix}\times\begin{bmatrix} I_{xprop} & 0 & 0 \\ 0 & I_{yprop} & 0 \\ 0 & 0 & I_{zprop}\end{bmatrix}\begin{bmatrix}p\\q\\r+\omega_p\end{bmatrix} \quad (23)$$
$$=\begin{bmatrix} I_{xprop}\dot{p}-I_{yprop}qr+I_{zprop}q(r+\omega_p) \\ I_{yprop}\dot{q}+I_{xprop}pr-I_{zprop}p(r+\omega_p) \\ I_{zprop}(\dot{r}+\dot{\omega}_p)\end{bmatrix}$$

so

$$\begin{aligned} M_{gyrox}&=I_{xprop}\dot{p}-I_{yprop}qr+I_{zprop}q(r+\omega_p)\\ M_{gyroy}&=I_{yprop}\dot{q}+I_{xprop}pr-I_{zprop}p(r+\omega_p)\\ M_{gyroz}&=I_{zprop}(\dot{r}+\dot{\omega}_p)\end{aligned} \quad (24)$$

As I_{xprop} □ 0 、 I_{yprop} □ 0, the gyroscopic torques can be expressed as follows

$$\begin{aligned} M_{gyrox}&=I_{zprop}q\omega_p\\ M_{gyroy}&=I_{zprop}p\omega_p\\ M_{gyroz}&=I_{zprop}(\dot{r}+\dot{\omega}_p)\end{aligned} \quad (25)$$

From the above analysis, the integration of the forces and the moments can be expressed as follows:

$$\begin{aligned} \Sigma F_x&=F_{Gx}+F_{Ax}+F_{Cx}+F_{Fx}+D_x\\ \Sigma F_y&=F_{Gy}+F_{Ay}+F_{Cy}+F_{Fy}+D_y\\ \Sigma F_z&=F_{Gz}+F_{Az}+F_{Cz}+F_{Fz}\end{aligned} \quad (26)$$

$$\begin{aligned} \Sigma M_x&=M_{Gx}+M_{Ax}+M_{Cx}+M_{Fx}+M_{gyrox}\\ \Sigma M_y&=M_{Gy}+M_{Ay}+M_{Cy}+M_{Fy}+M_{gyroy}\\ \Sigma M_z&=M_{Gz}+M_{Az}+M_{Cz}+M_{Fz}+M_{gyroz}\end{aligned} \quad (27)$$

IV. ROBUST MODEL FOR THE DESIGN AND SIMULATION OF CONTROLLER IN SAUCER UAV

System simulation technology is a comprehensive technology based on control theory, computer technology and similitude principle, with the tools of computer and various physical effect equipments and the help of system model to experiment and study the real or envisaged system. Flight simulation is a complex system-oriented simulation taking the movement of aircraft as the research object. First it establishes the related mathematical model in accordance with aircraft kinematics, aerodynamics and flight control theory and other relevant theories, and then relies on this model to conduct analog experiments and analytical investigation[9].

A. Integrated Framework and Design of Flight Control System Simulation of saucer UAV

According to the hierarchical relation of the system function realization, the hierarchical structure framework of the whole simulation system is shown in Figure 5, which is divided by the hierarchical design philosophy.

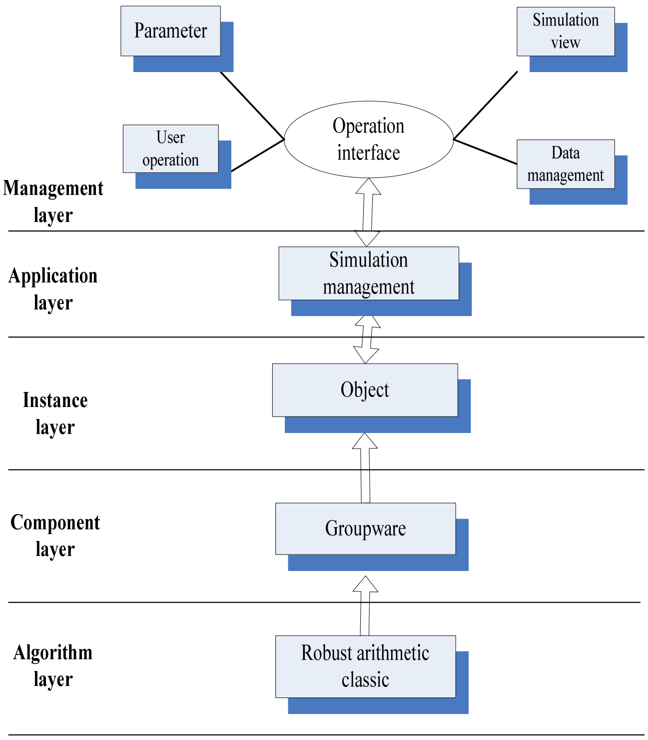

Figure5. Overall frame diagram of the simulation system

(1) Algorithm Layer

The basic work of digital simulation is to build mathematical models and their mathematical solution. Algorithm layer, as the most basic level, provides the necessary basic functions for establishing mathematical description for the upper model.

(2) Component Layer

Flight control system is composed of a series of different functional units, such as the rotor wings, the control rudders and so on. Each functional unit may also be composed of different components. These individual components can build up their respective simulation model, termed as component models. As in the flight control component modeling, each physical component decomposed by its function will correspond to a class. The pneumatic and control process within each component is varied. They solve the output parameters from the known parameters and input parameters, which are based on their respective component characteristics. The calculation of each component is confined to a single component and does not involve the impact of components, so that the individual components can be abstracted into a component control volume. And on the surface of the component control volume (inlet and outlet) there is data inflow or outflow, which forms the external input and output interfaces. While within the control body there is a single data analysis, different control volumes exchange data through objects. Component layer storing a variety of software models which constitute the component is the core of the entire simulation system. Through the simulation study of the component layer, the parameters information of the various components including input and output characteristics can be grasped.

(3) Instance layer

In the Instance layer, according to the specific system structure, each component of the system and their interrelation are defined, component connection sequence and direction of parameter passing are programmed, and the specific simulation object models of each component are connected.

(4) Application Layer

It is the primary operative part of the simulation task. It receives the input parameters and command of the management layer, obtains model characteristic parameters through the algorithm solving to the simulation object model by invoking the solving algorithm and completes the task of system simulation.

(5) Management Layer

It realizes the management function of the simulation process, completes the interaction between the users and the simulation software, passes a variety of system set-up parameters and commands of the users to the application layer, completes the simulation calculation, and displays, preserves and processes the simulation results.

In summary, through the analysis of simulation system, the hierarchical structure from the simple to the complex is formed, the function and data structure provided by the lower layer which is depended on by the high layer are optimized layer by layer, and the functions at all levels are clear. Not only does it increase the structure and intelligibility, but reduces the workload of the design and debugging, and improves the efficiency of the simulation study.

B. Implementation and Result Analysis of the Flight Control System Simulation

To complete the simulation study of the system, a mathematical model of each component must be established and the system simulation model is formed afterwards. The realization of the entire system simulation is carried out from the bottom upwards layer by layer. From the bottom to the top, layer by layer, accompany of debugging, until all the layers is perfect in function.

The flight control computer is switched in the simulation systems to test the real-time flight simulation. The system components are shown in Figure 6.

Before starting the simulation, the simulation systems and the autopilot are in the initialized state before take-off. By showing the "take-off" command launched by computer monitoring software, the system get into the autonomous navigation state. The simulation computer starts simulation, the monitoring software conduct data logging and real-time display automatically and the recorded data are analyzed by the software tools such as MATLAB ,etc..

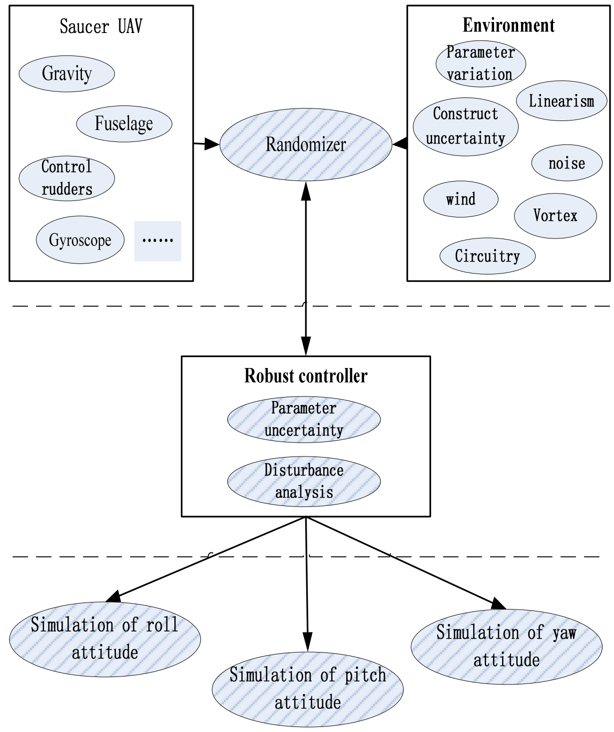

Figure6. Flight simulation composition diagram

C. Multi-objective H_2 / H_∞ Robust Flight Controller Design and Simulation

Use case analysis is the basis for system design and development, and a clear demand for the system. The principal agent includes the model builder, file system, database system and so on. The use case is expressed as an oval in the diagram, the exchange of information is expressed with straight lines with arrows.

"uses" on the arrow line expresses the usage relation and "extends" expresses the extension relation.

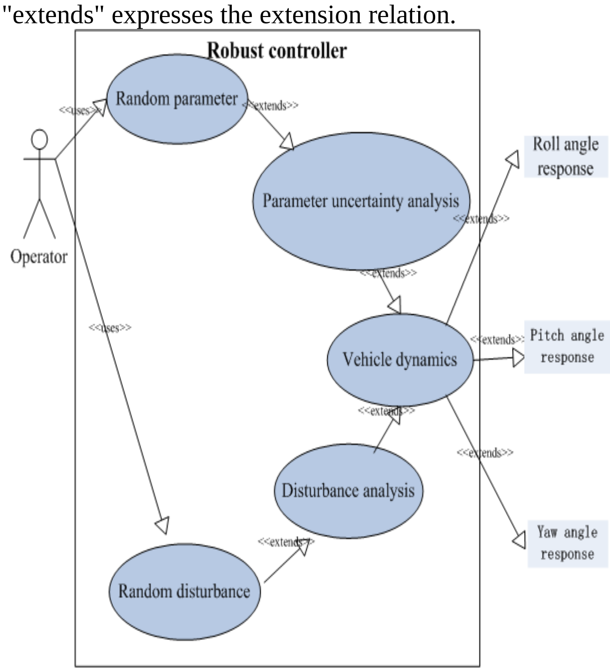

Figure7. Robust controller simulation use-case diagram

The attitude control system of the small saucer UAV is a classical MIMO system, which includes time varying parameters and all kinds of disturbances. It is necessary to develop an advanced control method to deal with the uncertainty and disturbances [10]. Many advanced controllers has been developed for some unconventional aircraft, such as adaptive control and dynamic inversion control [11] [12], but the model constructed only from theoretical analysis is not satisfied for enough accuracy. The robust model based on H_2/H_∞ control is very available in deal with that problem.

Theorem 1: Consider system (28)

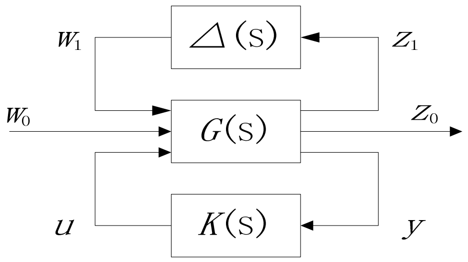

Figure8. The H_2/H_∞ control system

$$\begin{cases} \dot{x} = Ax + B_0 w_0 + B_1 w_1 + B_2 u \\ z_0 = C_0 x + D_{01} w_0 + D_{02} u \\ z_1 = C_1 x + D_{11} w_1 + D_{12} u \\ y = x \end{cases} \tag{28}$$

Where $\Delta(s)$ is the uncertainty of the model; $K(s)$ is the state-feedback controller; z_0 and z_1 are the evaluated outputs; Then the closed-loop system in (28) is asymptotically stable and satisfies.

$$\left\|T_{z_0 w_0}(s)\right\|_\infty < \gamma_1, \left\|T_{z_1 w_1}(s)\right\|_2 < \gamma_2, \gamma_1, \ \gamma_2 > 0 \tag{29}$$

and minimize the γ_2

There exists ,

$X = X_1 = X_2, W = W_1 = W_2 = KX$ and satisfying

$$\begin{bmatrix} (AX_1 + B_2W_1) + (AX_1 + B_2W_1)^T & B_1 & (C_1X_1 + D_{12}W_1)^T \\ B_1^T & -\gamma_1 I & D_{11}^T \\ C_1X_1 + D_{12}W_1 & D_{11} & -\gamma_1 I \end{bmatrix} < 0$$

$$\begin{cases} AX_2 + B_2W_2 + (AX_2 + B_2W_2)^T + B_0B_0^T < 0 \\ \begin{bmatrix} -Z & C_0X_2 + D_{02}W_2 \\ (C_0X_2 + D_{02}W)^T & -X_2 \end{bmatrix} < 0 \\ Trace(Z) < \gamma_2^2 \end{cases} \tag{30}$$

and minimized the γ_2 simultaneously, and the state-feedback controller is given by

$$u = WX^{-1}x = Kx \tag{31}$$

That is, the controller design problem has been transformed into a set of LMI conditions. It can be solved by the use of the LMI toolbox in MATLAB [13].The result is as follows:

$$K = \begin{bmatrix} 0.28 & 0.19 & -51.18 & 31.55 & 12.67 & 0.74 & 0.31 & 1.83 \\ 0.31 & 0.22 & -55.08 & 31.28 & -12.62 & 0.77 & 0.36 & 1.82 \\ -0.24 & 0.24 & -21.09 & -37.09 & -0.20 & -0.22 & 0.68 & -1.83 \end{bmatrix} \tag{32}$$

The complete nonlinear model of the UAV is utilized in the simulation.

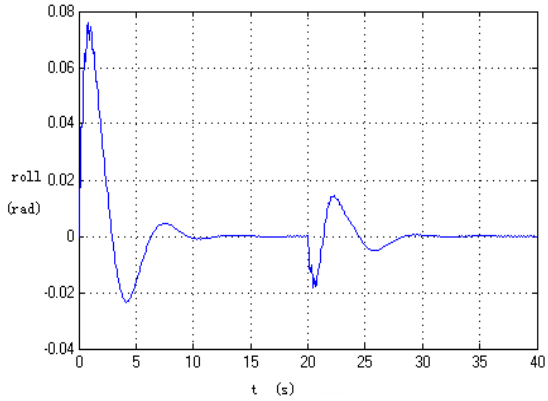

Figure9. The roll attitude

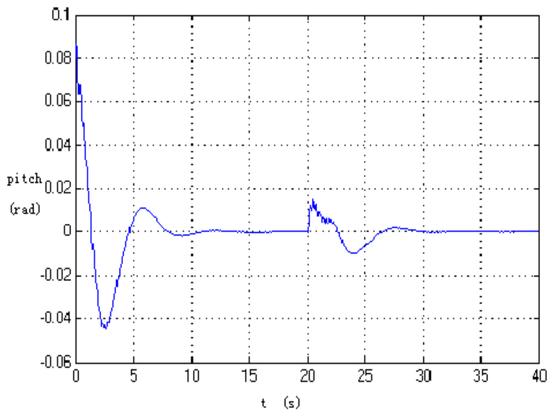

Figure10. The Pitch Attitude

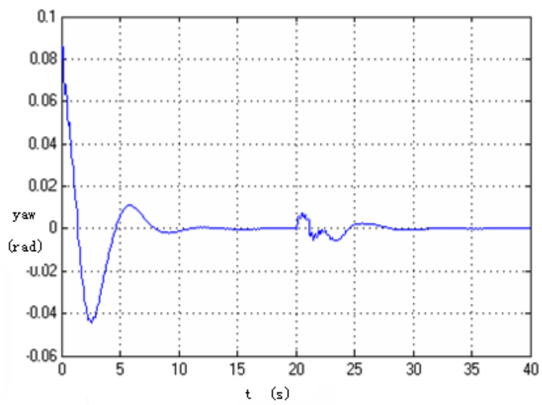

Figure11. The Yaw Attitude

Figure 9、10、11 shows the simulation responses of the system. In order to validate the robust stability and the disturbance rejection of the controller, the wind disturbance at 20s and inertial error +20% were introduced into the simulation. The simulation results show the controller has a good performance to deal with the distribution and parameter uncertainty.

V . CONCLUSION

The saucer UAV, with compact structure and light weight, can take-off and land vertically. Due to the special aerodynamic structure, the aerodynamic characters of the aircraft is very complex, the controller must be very robust to deal with the unpredictable conditions such as crosswind and parameter uncertainty. In this paper, a robust controller based on H_2/H_∞ control theory was designed to decrease the influence that the disturbance generates and minimize the influence that the parameter variety generates. The simulation results indicate that, this method which has been used successfully on other vehicle was found to be suit for the saucer UAV. The controller can improve the disturbance rejection and advance the yarage for the pilot.

The prototype of the saucer UAV has been done, and indoor experiments with an application of PID controller show that it is very maneuverable with no crosswind. The extraventricular flight test with crosswind will be done later to verify the availability of the controller in this paper.

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