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Research on Motor Control System of UVA Based on Sliding Film Variable Structure Principle

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Abstract: *The motor control system of unmanned aerial vehicle (UAV) will be affected by the environment during its operation, which has certain nonlinear characteristics. The sliding mode variable structure control method is proposed in this paper. Through the pre design of its parameters and sliding modes, the influence of interference, parameter changes, temperature and other factors on the system is reduced, the power factor, precision and working efficiency of the system are improved, and the robustness of the motor is improved; In view of the chattering phenomenon generated by the system, the causes and elimination methods are discussed, with a view to making the system intelligent, autonomous and portal collaborative in the future, combined with modern AI technology.*

Keywords: *UAV; Electric Machinery; Synovial Control*

1. Introduction

UAV, also known as unmanned aerial vehicle (UAV), started early abroad, especially since the 1990s, due to the continuous progress of science and technology and theoretical level, UAV technology has become relatively mature, and gradually achieved more stable control of UAV. In China, UAV system technology mainly relies on traditional methods such as operators and established procedures to complete remote operation and control, and the technology developed is still in a relatively basic state. Therefore, the autonomous level and intelligence of the UAV system are not high, which limits the application efficiency of the system and affects the further performance of the UAV. At present, it is an era of rapid development of information technology, which is conducive to the research and development of corresponding technologies of UAV system, better realization of information collection and system monitoring, improvement of information transmission efficiency, and more flexibility and autonomy of relevant information. At the same time, it also poses new challenges to UAV technology. Therefore, in order to achieve better self-control of UAV information system, it is necessary to focus on the research on the control type and control mode of UAV motor system, fundamentally and continuously improve the level of automation and intelligence of the system, and enhance the working ability of UAV system.

2. Research status of UAV system control

With the continuous development of society, driven by information technology, UAV technology has achieved effective application and promotion at home and abroad. Especially in the military field, he has been used earlier. In the war, he can carry lighter weapons, collect enemy information, deliver rescue materials, and convey operational instructions, playing an irreplaceable role. In recent years, UAV technology has begun to develop in the civil field. Due to the increasing demand for applications and the increasingly complex working environment, UAVs are required to put forward higher requirements in control mode, intelligent perception system, ground reception and other aspects.

In recent years, with the continuous progress of autonomous control technology, UAV system control technology has gradually developed. It is mainly to develop a more optimized control scheme through the reception and processing of environmental information under the condition of unmanned control, which will be applied to the actual work process and help the implementation and completion of various work tasks.[1] At present, in the process of practical application of UAV, its control technology is still in a relatively basic descriptive type. In the process of development, more scientific theories need to be added as a basis to provide more accurate qualitative measurement indicators, and further explore and prove the relevant technologies of autonomous control. Therefore, under the influence of AI fusion in the future, the control technology of UAV will be developed rapidly, and its work efficiency in various fields can be well realized[2].

3. Permanent magnet synchronous motor

The motor is one of the important components of the UAV power system, and its main function is to complete the mutual conversion of electrical energy and mechanical energy. Most UAVs mainly use permanent magnet synchronous motor in brushless motor. This type of motor mainly uses semiconductor switching devices to achieve electronic commutation, so as to achieve high reliability and avoid spark, noise, etc.

3.1 Mathematical principle of permanent magnet synchronous motor

Permanent magnet synchronous motor generally consists of stator, rotor and end cover. The stator, also called armature, is generally equipped with three-phase AC windings, which can reduce iron loss when the motor is running; The rotor is mainly equipped with permanent magnet materials, which can be pressed by lamination or made into solid. In the three-phase symmetrical winding of the motor, the current will produce a circular rotating magnetomotive force with constant amplitude. The relationship between its magnitude and single-phase magnetomotive force is as follows:

$$F = \frac{3}{2}F_{\varphi l} = \frac{3}{2}\times 0.9k\times\frac{NI}{P}$$

Since the speed of the motor is always synchronous, the magnetic field generated between the rotor and the stator will remain relatively static. Due to the interaction between the magnetic fields, a new magnetic field will be formed between the stator and the rotor. The magnetic field will interact with the rotor to produce an electromagnetic torque that hinders the rotation of the motor:

$$T_e = kB_R B_{net}\sin\theta$$

It can be seen from the above formula that the position relationship of the resultant magnetic field formed in the air gap between the stator and the rotor is different from that of the main magnetic field. Therefore, the permanent magnet synchronous motor will be in the power generation state when the resultant magnetic field of the air gap lags behind the main magnetic field, and will be in the electric state when the resultant magnetic field of the air gap leads the main magnetic field.

The stator voltage equation of synchronous motor in two-phase rotating coordinate system is as follows:

$$u_d = R_s i_d + L_d\frac{d}{d_t}i_d - \omega L_q i_q$$

$$u_q = R_s i_q + L_d\frac{d}{d_t}i_q + \omega L_d i_d + \omega\varphi f$$

3.2 Classification and characteristics

Permanent magnet synchronous motors are generally divided into three categories according to the different positions where permanent magnet materials are installed on the rotor. One is convex type, which has the characteristics of simple structure, low cost, easy design, small rotor inertia, and basically equal inductance; The other is the embedded type with permanent magnet materials embedded in the rotor, which is characterized by high power density, high permeability, strong dynamic performance and relatively simple manufacturing process; The third type is the embedded type with magnetic materials inside the rotor. Its main feature is that the ferromagnet is protected by the pole shoe formed between its surface and the stator core. The reluctance torque generated is helpful to improve the overload capacity and power density of the motor.

There are many kinds of permanent magnet synchronous motors, but most of them have certain common characteristics. As the motor system adopts a fully enclosed structure, it does not produce gear wear, which can reduce noise and achieve no lubrication and maintenance; Its allowable overload

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current is relatively large, which can significantly improve its power factor and reliability; Because the permanent magnet material is used as the magnetic pole, it can achieve high air gap flux density, so the motor has the characteristics of small size, light weight, small heating, etc; Its moment of inertia is also small, the allowable pulse torque is large, and it can obtain larger motion acceleration, achieving good dynamic performance and reliable operation.

3.3 Motor control strategy

In order to achieve the effect of high precision, fast response, high power factor, high system power and small pulsating torque, vector control and sliding mode variable structure control are currently used in the AC speed regulation system of motor. First, it is applied to the $i_d = 0$ control of a small capacity system. The stator current of this method is proportional to the output torque, and there is no magnetic effect. It is a simple current control mode; The other is the constant flux linkage control method, which can improve the output torque of the motor and obtain a higher power factor. Its disadvantage is that the demagnetization component is large; Another method is to control the power factor of the motor to be equal to 1, that is, cos φ= 1, which can make the upper limit of output torque smaller, but the control is relatively complex; The maximum control torque current is to minimize the electronic current and reduce the copper loss under the condition of meeting the output torque, which can reduce the cost of the system. At the same time, the performance of the motor at high speed can be changed by using appropriate field weakening control. This method and $i_d = 0$ control are more suitable for the control mode of permanent magnet synchronous motor.

According to the following formula:

$$T_e = \frac{3}{3} P_P (\varphi_d i_q - \varphi_q i_d) = \frac{3}{2} P_p [\varphi_f i_q + (L_d - L_q) i_d i_q]$$

Then $i_d = 0$ ’ the torque of the permanent magnet synchronous motor can be expressed as:

$$T_e = \frac{3}{2} P_p \varphi_f i_q$$

Therefore, when $i_d = 0$, electromagnetic torque can be well controlled through control i_q.

Sliding mode variable structure control is a nonlinear integrated control method developed in recent years. Because UAV will face the influence of many environmental factors in the flight process, the UAV system is often in a discontinuous state of control, and the structure changes with time. This control method can design its sliding mode to avoid the disturbance of system parameters and state as much as possible, which can make the system have good robustness.

4. Sliding mode variable structure control

Sliding mode variable structure control began in the last century. After years of development and accumulation, it has formed an independent research field and has a wide range of applications. This control method is aimed at the state instability of the system in the dynamic process. By setting a certain switching function, the control system can achieve from one sliding mode to another sliding mode. This control can be free from the influence of parameters and other disturbances, and can ignore online identification, which is easy to achieve. The disadvantage of this method is that when the modes change, the system moves along the sliding surface, which will cause chattering.

4.1 Mathematical model

Sliding mode variable structure control is essentially a kind of nonlinear control, which is different from other control mainly reflected in the instability of the system state. The control system mainly sets one or more switching functions S=S (x) in the state space of the system, sets a switching surface S (x)=0 between switching functions in the state space, and sets corresponding switching switches to realize the movement of sliding mode in different areas according to the control strategy, i.e. the law of switch switching. Specifically, when the system moves near the switching surface, it will be attracted by it, making the system slide to another state space caused by the switching surface. This motion has certain advantages, and is not affected by its parameters and disturbances.

There is a system, the state function of which is x, and the input and output variables are represented by u and y respectively,

Therefore,

$$\dot{x} = f(x,u,t) + g(x)u, x \in R^n, u \in R^m, t \in R$$

$$y = g(x), y \in R^l, l \le m \le n$$

In the formula, n, l and m respectively represent the dimensions of the system's state variables, output variables and input variables, R represents the real domain, and the control quantity is

$$U(x) = \{u^+(x), s_i(x) \succ 0; u^-(x), s_i(x) \prec 0\}$$

The variable structure here is embodied in $u^+(x) \neq u^-(x)$ that the control that makes it meet the following conditions is called sliding mode variable structure control:

(1) Basic condition: there $s \cdot \dot{s} \le 0$ must be corresponding modes.

(2) Arrival condition: the state points outside the switching surface $s_i(x) = 0$ will arrive at the switching surface in a limited time.

(3) The switching surface should be in the sliding mode area, with good dynamic performance and relatively stable movement.

4.2 Buffeting

The sliding mode variable structure control method is to design the system in advance by setting the mathematical model and parameters, so that the system has a discontinuous switching characteristics. Therefore, the system will be affected by the measurement accuracy and control variable changes, making the sliding mode impossible to be in an ideal state all the time. In actual operation, the system will be affected by chattering.

The causes of buffeting mainly include:

(1) Lagging factors. In the state space of the motor system, because the accuracy of the state change will be delayed due to the influence of time, the time lag of the switch will occur near the switching surface, and there will also be a certain state change lag area in the state space, namely "dead zone". Therefore, the time and space lag of the switch will cause the sliding mode to generate additional attenuation triangle wave and equal amplitude waveform.

(2) Inertia factor. In the real control system, because the energy of the system is limited, the control ability of the system is limited, and the acceleration of the system will be limited to a certain extent, which will lead to a certain inertia of the system. Therefore, in the process of switching, there must be a hysteresis phenomenon, which is similar to the chattering phenomenon of the hysteresis switch. When the switch space lag meets the system inertia, if the former is less than the latter, the chattering will appear in the form of attenuation triangle wave; if the former is greater than the latter, the chattering will appear in the form of equal amplitude oscillation.

(3) Time dispersion factor. In addition to the normal sliding mode, there is another "quasi sliding mode" state inside the system. The action of the switch cannot act on the switching surface exactly, but acts on the surface of a conical geometry with the origin as the vertex.[3] The size of the geometry is affected by the sampling period, which is also a factor of time lag in essence. The larger the volume is, the stronger the chattering amplitude will be.

(4) Error factors. The switching surface of the system will also be affected by the state measurement error, and has uncertainty. Therefore, the amplitude of buffeting will increase with the increase of

measurement error.

Buffeting reduction methods include:

(1) Eliminate interference. In view of the negative impact of the external environment and variable disturbances on the system, it is necessary to accurately estimate and filter it. A new sliding mode disturbance observer is applied. This observer can be well combined with the sliding film governor, and its disturbance parameters are taken as the input parameters of the governor, so as to improve the anti-interference ability of the system.

(2) Approach rate adjustment. Based on the sliding mode control model of permanent magnet synchronous motor, a new approach is adopted to improve the state variable and speed error control in time to reduce the inherent chattering of the system.

(3) Algorithm optimization. For high frequency switching in sliding mode control, high-order sliding mode spiral algorithm can be used to reduce chattering caused by external and internal parameters without affecting its original fault tolerance and response speed.

Permanent magnet synchronous motor (PMSM) is a very typical nonlinear system. In reality, because it is often in the natural environment and is affected by the environment, the load of the system is disturbed. However, the sliding mode variable structure control method can make the motor adapt to the environment well, control its parameters, make the system achieve discontinuous changes between sliding modes, and reduce the disturbances caused by load disturbances, parameter changes, temperature changes and other factors, To improve the robustness of the motor, it has high power factor, high precision, high work efficiency and excellent stability performance. At the same time, due to the characteristics of sliding mode variable structure, the system has chattering phenomenon, which makes it subject to certain resistance in practical applications. Therefore, how to better weaken the buffeting effect in application requires continuous optimization of the system.

5. Conclusion

At present, there are some technical bottlenecks and key technology deficiencies in the development of autonomous control technology of UAV system, which are facing certain challenges. The focus of future development will be on the autonomous research and development of the system. In recent years, with the rapid development of artificial intelligence technology, the control system of UAV can be scientifically guided to achieve the effective application of intelligent technology and improve the working efficiency of its system and the utilization rate of its comprehensive efficiency. Through information interaction, the UAV can have higher autonomy, mitigate the impact of human factors on the system's autonomous control, make the controller and program easier to interface, and improve the compatibility stability and autonomy level. In the future, we will focus on the development from single machine operation to multi UAV cooperative operation, and realize the portal collaboration of UAV system.

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