Research on Balance of Unmanned Aerial Vehicle with Intelligent Algorithms for Optimizing Four-Rotor Differential Control

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Abstract: The UAV without control surface (UAV) proposed in this paper uses the propeller driven by four electric motors as propulsion and attitude control. The UAV can take off and land vertically (VTOL), but the control of propeller is a particularly complex problem from hovering to cruise flight. A novel control algorithm using optimal estimates similar to multipurpose linear quadratic regulator (LQR) is suitable for the latest developments. One of the technologies can generate the transformation control input available for a time-varying system model, which will be used by aircraft pilots to provide the necessary control signals for UAV propellers. As a result, traditional trained pilots can control this novel UAV without additional training. In addition, it can be predicted that the general control algorithm can be used for autonomous control of UAVs in the future, allowing the autonomous development of novel control strategies to control the required UAVs.

1. Introduction

This paper describes a novel method of UAV control, but it will also be applicable to many existing and proposed aircraft. The development of this method is motivated by the challenges associated with specific conceptual aircraft. Figure 1 shows the position of the four rotors used to provide thrust and control the new biplane attitude. In horizontal cruise flight, each rotor provides equal thrust and generates equal angular momentum. Therefore, the aircraft is a zero angular momentum (ZAM) UAV. ZAM UAV, through the specification, has no other flight control mechanism. To adjust the attitude, it is necessary to complement the control of the rotor in order to maintain the ZAM conditions while generating the required changes. For example, in order to control pitch, the angular velocities of rotor 3 and rotor 4 can be increased equivalently. The net angular momentum of the rotor remains zero, and the pitch moment is caused by the difference of thrust between the rotors. The angular velocities of rotor 2 and rotor 4 can be modified equivalently when yawing is controlled. The total angular momentum of the ZAM UAV remains zero, except that the net angular momentum rotor near the axis of the ZAM is the pitch and yaw moment caused by the deliberate asymmetric thrust required in the same order of magnitude.

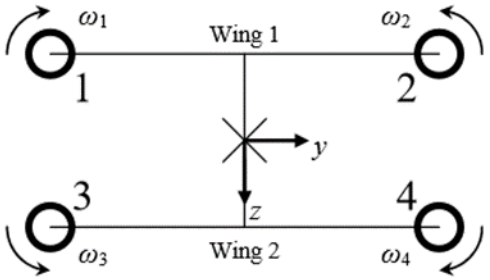

Figure 1. Rear view of Four-rotor structure

2. Balance control

Kalman filter is used in this paper. Its optimal estimation is a model-based least square error state observer. The optimal controller is a linear quadratic regulator (LQR) based on a model. The basic theory is that observer theory is equivalent to progressive control theory. In order to develop the

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translation of control, the author has recently applied the optimal estimation to the dynamic model of one of the aircraft, which is embodied in the state transition matrix of Kalman filter for real-time modification. The same method can be applied to the development of LQR for rotor control in ZAM UAV. Note, however, that this method will also apply to any aircraft or process. Through a novel system, the traditional control of input response is adopted. In a Kalman filter, the state and time of the process are taken as the linear weighted sum of the state variables, and the random process vector called state noise changes. The weighted sum is embodied in the state transition matrix, which involves state variables from one time step to the next. Traditionally, the state transition matrix is constant. In a LQR, the dynamics of the control process is similarly represented in a traditional constant state transition matrix. With a time-varying state transition matrix, the LQR is no longer a linear controller, but a linear combination of the variables of the current state as the control input, but the coefficients are an unsteady non-linear combination of the state variables. The complex dynamics of ZAM UAV and this versatility are easy to model in control algorithm.

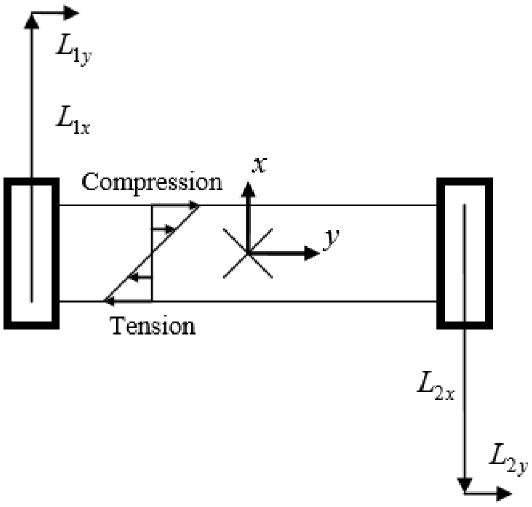

Fig. 2 Over the wing, top view, frontal view

3. Intelligent Algorithms

Considering the case of constant positive pitch velocity for aircraft, referring to Fig. 3, it is necessary to maintain a constant pitch velocity because there is no differential thrust, and the angular momentum is constant in the scalar value of each rotor, but the direction of the angular momentum vector is constantly changing. Therefore, each individual rotor is subject to rotational acceleration, and the angular momentum of the rotor transfers stress to the other through the fuselage.

$$\vec{M}_n = \frac{d\vec{L}_n}{dt} = \vec{\omega}_{FRAME} \times \vec{L}_n = -\omega_{FRAME\_y} L_{nx} \hat{k} = \frac{\omega_{FRAME\_y} L_n}{(-1)^{m+n+1}} \hat{k} \tag{1}$$

Note that this stress is in the normal direction, due to the simple bending of the upper part of the wing while hovering, but not at the bottom of the wing. The stress produces a small strain.

$$\varepsilon_{WING\_m\_y} = \frac{\sigma_{WING\_m\_y}}{E} = \frac{(-1)^{n+1} M_{nz} x}{EJ_{WING\_x}} = \frac{\omega_{FRAME} L_n x}{(-1)^m EJ_{WING\_x}} \tag{2}$$

This results in a small deviation in the direction of the angular momentum vector for each rotor,

$$
\begin{aligned}
\vec{L}_n &= L_{nx}\left(\hat{i} + \frac{\varepsilon_{WING\_m\_y}}{(-1)^n x}\frac{D_{SPAN}}{2}\hat{j}\right) \\
&= L_{nx}\left(\hat{i} - \frac{M_{nz}x}{EJ_{WING\_x}x}\frac{D_{SPAN}}{2}\hat{j}\right) \\
&= L_{nx}\left(\hat{i} - \frac{M_{nz}D_{SPAN}}{2EJ_{WING\_x}}\hat{j}\right) \\
&= L_{nx}\left(\hat{i} + \frac{\omega_{FRAME\_y}L_{nx}D_{SPAN}}{2EJ_{WING\_x}}\hat{j}\right) \\
&= (-1)^{m+n}L_n\hat{i} + \frac{\omega_{FRAME\_y}D_{SPAN}L_n^2}{2EJ_{WING\_x}}\hat{j}
\end{aligned}
\tag{3}
$$

$$
\vec{L}_{VEHICLE} = \vec{L}_{FRAME} + \sum_{n=1}^{4}\vec{L}_n = \omega_{FRAME\_y}\left(I_{FRAME\_yy} + \frac{\left(L_1^2 + L_2^2 + L_3^2 + L_4^2\right)D_{SPAN}}{2EJ_{WING\_x}}\right)\hat{j}\,. \tag{4}
$$

In particular, small deviations cause a small fraction of the angular momentum of each rotor to affect the pitch rate in the same direction. We define the origin of Figure 3 at the structural centroid of each wing. The magnifications of L_1Y and L_2Y are enlarged in Fig. 3 to illustrate that the combination of small deviations in the direction of each rotor causes additional angular momentum in the direction of the body angular velocity throughout the aircraft, so the angular momentum of the aircraft,

It should be noted that the effect of the rotor is to simply increase the inertia of the aircraft. The angular momentum of the motor and propeller is determined by the wingspan and the material and geometry of the wing.

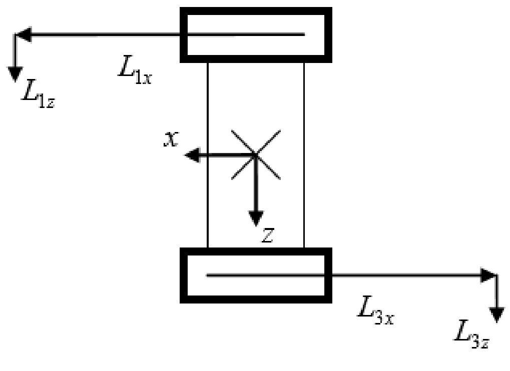

Figure 3 Left view, yaw rate

Considering the constant positive yaw speed, for aircraft, referring to Fig. 3, because there is no differential thrust, it is necessary to maintain a constant yaw rate, while ignoring the current aerodynamic effects, the scalar value of angular momentum of each rotor remains constant. However, the direction of angular momentum vector is constantly changing. Therefore, each individual rotor is subject to rotational acceleration.

$$
\vec{M}_n = \frac{d\vec{L}_n}{dt} = \vec{\omega}_{FRAME} \times \vec{L}_n = \omega_{FRAME\_z}L_{nx}\hat{k} = \frac{\omega_{FRAME\_z}L_n}{(-1)^{m+n}}\hat{j} \tag{5}
$$

Rotor angular momentum transfers stress to another through the fuselage. Note that this stress produces torque on each rotor. The wing shear stress produces a small shear strain.

$$\varepsilon_{WING\_m\_xz} = \frac{\sigma_{WING\_m\_xz}}{G} = \frac{(-1)^{n-1} M_{ny} r}{GJ_{WING\_yy}} = \frac{\omega_{FRAME\_z} L_n r}{(-1)^{m+1} GJ_{WING\_yy}} \tag{6}$$

This results in a small deviation in the direction of the angular momentum vector for each rotor.

$$\begin{aligned} \vec{L}_n &= L_{nx}\left(\hat{i} + \frac{\varepsilon_{WING\_m\_xz}}{(-1)^{n-1} r}\frac{D_{SPAN}}{2}\hat{k}\right) \\ &= L_{nx}\left(\hat{i} + \frac{M_{ny} r}{GJ_{WING\_yy} r}\frac{D_{SPAN}}{2}\hat{k}\right) \\ &= L_{nx}\left(\hat{i} + \frac{M_{ny} D_{SPAN}}{2GJ_{WING\_yy}}\hat{k}\right) \\ &= L_{nx}\left(\hat{i} + \frac{\omega_{FRAME\_z} L_{nx} D_{SPAN}}{2GJ_{WING\_yy}}\hat{k}\right) \\ &= (-1)^{m+n} L_n \hat{i} + \frac{\omega_{FRAME\_z} D_{SPAN} L_n^2}{2GJ_{WING\_yy}}\hat{k} \end{aligned} \tag{7}$$

It should be noted that small deviations cause a small fraction of the angular momentum of each rotor to affect yaw rates in the same direction. The magnification of L_1z and L_3z illustrates in Figure 3 that small deviations in the direction of each rotor combine to cause additional angular momentum of the whole aircraft to change the direction of the body angular velocity, so the angular momentum of the aircraft is,

$$\vec{L}_{VEHICLE} = \vec{L}_{FRAME} + \sum_{n=1}^{4} \vec{L}_n = \omega_{FRAME\_y}\left(I_{FRAME\_zz} + \frac{\left(L_1^2 + L_2^2 + L_3^2 + L_4^2\right) D_{SPAN}}{2GJ_{WING\_yy}}\right)\hat{k}\,. \tag{8}$$

4. Conclusion

Experiments are currently validating the two-stage and three-stage effects proposed in this paper, as well as describing the control method of a dual-engine aircraft model that does not use control surfaces on the market. The experiment is controlled by pilots without ZAM UAV experience. The results of this study will be widely applicable to new UAVs, especially those with unconventional control requirements. This will give new dynamics and autonomous control strategies to processes developed for conventional flying vehicles, ZAM UAVs or any aircraft.

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