Fault Detection and Isolation in Rotorcraft Systems

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Abstract: The problem of fault detection and isolation (FDI) is addressed for nonlinear dynamic systems modeled by polynomial differential-algebraic equations. Ritt's algorithm is used to obtain an input-output representation of monitored system by eliminating unknown variables. With introducing simplifying assumptions, the flight dynamics equations for the four rotor aircraft are considered. A trajectory tracking control structure based on a two layer non linear inverse approach is then proposed. A local approach to change detection then applied to the input-output representation for FDI residual generation and evaluation.

Keywords: Fault detection and isolation, Rotorcraft flight mechanics, nonlinear inverse control.

INTRODUCTION

In the last years a large interest has risen for the four rotor concept since it appears to present simultaneously hovering, orientation and trajectory tracking capabilities of interest in many practical applications.

The flight mechanics of rotorcraft are highly non linear and different control approaches (integral LQR techniques, integral sliding mode control, reinforcement learning) have been considered with little success to achieve not only autonomous hovering and orientation, but also trajectory tracking In this paper, with introducing some simplifying assumptions, the flight dynamics equations for a four rotor aircraft with fixed pitch blades are considered.

It appears that the flight dynamics of the considered rotorcraft present a two level input affine structure which is made apparent when a new set of equivalent inputs is defined. This allows to introduce a non linear inverse control approach with two time scales, one devoted to attitude control and one devoted to orientation and trajectory tracking.

The input-output representation is obtained through elimination of unknown variables. The local approach is a statistic tool allowing to transform very general FDI problems into an asymptotically equivalent simple problem, namely the detection of changes in the mean of a Gaussian random vector. It is based on the assumption that the faults are “small” and is thus particularly suited for the detection and isolation of incipient faults.

With the input-output representation and flatness differential, address the FDI problem in flatness nonlinear dynamic systems.

ANNEX: ROTORCRAFT FLIGHT DYNAMICS

The considered system is shown in figure 1 where rotors one and three are clockwise while rotors two and four are counter clockwise. Annex 1 describes the rotor dynamics.

The main simplifying assumptions adopted with respect to flight dynamics in this study are a rigid cross structure, no wind, negligible aerodynamic contributions resulting from translational speed, no ground effect as well as negligible air density effects and very small rotor response times. It is then possible to write simplified rotorcraft flight equations .

The moment equations can be written as:

$$\left.\begin{aligned} \dot{p} &= (a/I_{xx})\,(F_4 - F_2) + k_2\; q\; r \\ \dot{q} &= (a/I_{yy})\,(F_1 - F_3) + k_4 p\; r \\ \dot{r} &= (k/I_{zz})\,(F_2 - F_1 + F_4 - F_3) \end{aligned}\right\} \qquad (1)$$

where p, q, r are the components of the body angular

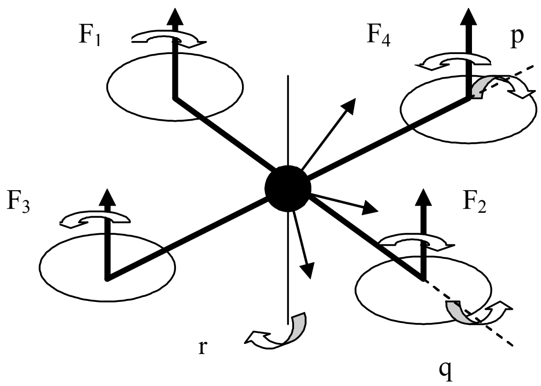

Figure 1- Four rotor aircraft

velocity, with $k_2(I_{zz} - I_{yy})/I_{xx}$ and $k_4 = (I_{xx} - I_{zz})/I_{yy}$, I_{xx}, I_{yy} and I_{zz} being the moments of inertia in body-axis and m the total mass of the rotorcraft.

The Euler equations are given by:

$$\left.\begin{aligned} \dot{\phi} &= p + \tan(\theta)\sin(\phi)\; q + \tan(\theta)\cos(\phi)\; r \\ \dot{\theta} &= \cos(\phi)\; q - \sin(\phi)\; r \\ \dot{\psi} &= ((\sin(\phi)/\cos(\theta))\; q + (\cos(\phi)/\cos(\theta))\; r \end{aligned}\right\} \qquad (2)$$

where θ, ϕ, and ψ are respectively the pitch, bank and heading angles.

The acceleration equations written directly in the local Earth reference system are such as:

$$\left.\begin{aligned}\ddot{x} &= (1/m)(\cos(\psi)\sin(\theta)\cos(\phi) + \sin(\psi)\sin(\phi))\,F \\ \ddot{y} &= (1/m)(\sin(\psi)\sin(\theta)\cos(\phi) - \cos(\psi)\sin(\phi))\,F \\ \ddot{z} &= -g + (1/M)\cos(\theta)\cos(\phi)\,F\end{aligned}\right\} \quad (3)$$

where x, y and z are the centre of gravity coordinates
and where :

$$F = F_1 + F_2 + F_3 + F_4 \quad (4)$$

and with the constraints:

$$0 \le F_{i_i} \le F_{\max} \quad i \in \{1,2,3,4\} \quad (5)$$