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Model Predictive Control with Laguerre Functions for a Buoyancy-Driven Airship

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Abstract

The high altitude platform such as a buoyancy-driven airship has been receiving much attraction recently. However, to control the airship is challenging because of its complicated model. This paper applies model predictive control with Laguerre functions to the airship. The simulation results are given in this paper and show satisfaction regarding the proposed control method.

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Keywords: Model Predictive Control; Laguerre Function; Buoyancy-Driven Airship

1. Introduction

There has been increasing interest in using high altitude unmanned airship which keeps distance about 17-22 km above the ground. Such unmanned airship is capable of serving as an observing station and a wireless communication relay station[1]. The unmanned airship has many advantages such as: it can be driven by solar power to make it long-time service and it can carry 1000 kg to 3000 kg loads. A conventional airship is illustrated in Fig. 1.

The airship works as follows. When air is released from ballonets, the mass of the airship decreases, the lift becomes positive. Together the ballast moves to the tail of airship, the pitch angle θ becomes positive, and the airship moves forward and upward. The airship moves forward and downward by reversing the above mechanism.

A challenging research for this problem is to control the airship to locate and stabilise at a desired position. Only has the standard linear quadratic regulator (LQR) method been applied to control the airship so far[2]. Since recently

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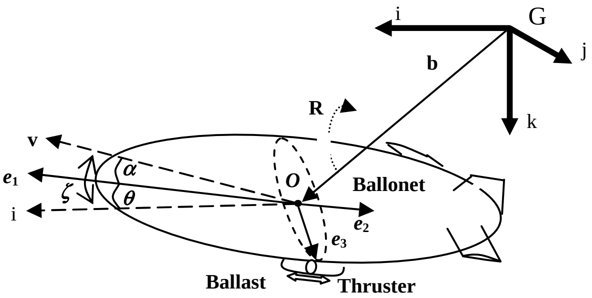

Fig. 1. Structure of Unmanned Airship.

model predictive control (MPC) has become an attractive and successful control technique and MPC has not been investigated in controlling the airship, the main contribution of this article is to deploy a model predictive control to the airship. The major issues in MPC are length of prediction horizon, control horizon, closed loop performance, computational efficiency. The use of Laguerre functions with MPC is considered in this paper because using Laguerre functions can reduce the load of computation without deteriorating the dynamic performance[3].

2. Model of a buoyancy-driven airship

Let $\{O, e_1, e_2, e_3\}$ be the body frame with reference point O at the center of the airship and $\{O, \mathrm{i}, \mathrm{j}, \mathrm{k}\}$ be the inertial frame fixing to the earth. The direction of gravity is in the axis k. The dynamic model of the airship is fully derived by Wu *et al.*[2] and given by the following equation:

$$\left[\dot{\mathbf{R}}_\mathbf{1} \quad \dot{\mathbf{b}} \quad \dot{\mathbf{v}} \quad \dot{\boldsymbol{\Omega}} \quad \dot{\mathbf{r}}_\mathbf{p} \quad \dot{\mathbf{B}}_\mathbf{p} \quad \dot{m}_b\right]^T = \left[\mathbf{R}_\mathbf{1}\hat{\boldsymbol{\Omega}} \quad \mathbf{R}_\mathbf{1}\mathbf{v} \quad \mathbf{M}^{-1}\mathbf{F} \quad \mathbf{J}^{-1}\mathbf{M} \quad \tfrac{1}{\bar{m}}\mathbf{B}_\mathbf{p} - \mathbf{v} - \boldsymbol{\Omega}\times\mathbf{r}_\mathbf{p} \quad \mathbf{u} \quad u_4\right]^T \qquad (1)$$

where $\mathbf{v} = (v_1, v_2, v_3)$ is the velocity, $\boldsymbol{\Omega} = (\Omega_1, \Omega_2, \Omega_3)$ is the angular velocity, $\hat{\boldsymbol{\Omega}} \in$ *so*(3), where *so*(3) is the Lie algebra of *SO*(3), $\mathbf{r}_\mathbf{p} = (r_{p1}, r_{p2}, r_{p3})$ is the vector from the centre of buoyancy to the mass points of the ballast, $\mathbf{b} = (x, y, z)$ is the position of the airship, $\mathbf{B}_\mathbf{p} = (B_{p1}, B_{p2}, B_{p3})$ is the momentum of the ballast, $\mathbf{u} = (u_1, u_2, u_3)$ is the total external force acting on the ballast, $\mathbf{R_1}$ is the rotation matrix, **M** is the moment matrix, **F** is the force matrix, **J** is the matrix of the moment of inertia, $\bar{m}$ is the mass of the inside movable ballast, m_b is the variable mass of the ballonets, and u_4 is the input to control the mass of the ballonets.

As can be seen from (1), complete controlling of the airship is hard to achieve and quite complicated. For the sake of simplicity, we assume that the airship is moving only in the vertical direction. Thus, (1) can be reduced to (2).

$$\left[\dot{\theta} \quad \dot{\Omega}_2 \quad \dot{v}_3 \quad \dot{r}_{p3} \quad \dot{B}_{p3}\right]^T = \left[\Omega_2 \quad (-r_{p3}B_{p3}\Omega_2 - \bar{m}gr_{p3}\sin\theta) \quad \tfrac{1}{m_3}(B_{p3} - u_3) \quad (\tfrac{1}{\bar{m}}B_{p3} - v_3) \quad u_3\right]^T \qquad (2)$$

where $m_3 = m_s + m_h$; m_h denotes the uniformly distributed hull mass, and m_s denotes the total stationary mass of the airship.

3. Model predictive control with Laguerre functions[4]

3.1. Laguerre functions

The discrete Laguerre function, donoted by $l_n(k)$, is defined by taking the inverse z-transform of

$$\Gamma_n(z) = \frac{\sqrt{1-a^2}}{1-az^{-1}}\left(\frac{z^{-1}-a}{1-az^{-1}}\right)^{n-1} \qquad (3)$$