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H_∞ Structured Controller Synthesis Applied to Flight Controller of QTW-UAV Using Meta-Heuristic Particle Swarm Optimization

Chiramathe Nami* Akinori Harada Koichi Oka*****

,,*** Department of Intelligent mechanics, Kochi University of Technology (KUT), Kochi, Japan*
(E-mails: 188003y@kochi-tech.ac.jp, harada.akinori@kochi-tech.ac.jp**, oka.koichi@kochi-tech.ac.jp***)*

Abstract: Structured H_∞ controller synthesis using particle swarm optimization has been designed in in control augmentation system of quad tilt wing unmanned aerial vehicle. It has been aimed to search for the existence of the optimal and practical controller feedback gains within the variations of the relaxation of H_∞ constraints for longitudinal motions. The optimization results were achieved in both minimize the maximum real parts of closed-loop eigenvalues and performance indexes in order to verify the validity of the proposed method.

Keywords: Control Augmentation System (CAS), Structured H∞ controller, robust control, Particle Swarm Optimization (PSO), Quad Tilt Wing Unmanned Aerial Vehicle (QTW-UAV).

1. INTRODUCTION

Unmanned Aerial Vehicles (UAVs) have been raised for various missions. i.e., surveillance, exploration of disasters. Airplanes with long flight ranges and hovering capabilities constitute to the major mobile platforms have been the subject of a growing research of interest during the last decade in UAV research perspective. Various tilt wings and tilt rotors UAVs have been developed. i.e., Bell Eagle Eye (Stephen et al., 2005), the Israel Aerospace Industries Panther (Daly et al., 2011) and others (Ahn et al., 2010). In particular, tilt wings UAVs have higher advantages over tilt rotors UAVs with respect to aerodynamic characteristics in hover as well as in cruise speed since there is no disturbance in propeller slipstream and consequently generate large lift (Rutherford, 1992). This paper utilized one of the QTW-UAV models developed by Japan Aerospace Exploration Agency (JAXA) named as McART3. Fig. 1 shows McART3 prototype (Sato and Muraoka, 2006). The model comprises of four propellers mounted at the middle of each wingspan. By rotating its tilt wings, McART3 can smoothly shift between vertical takeoff and landing mode while the aircraft retain flight attitude. The preset tilt angles are commanded through a radio control transmission operated by ground pilot. Flight control and sensor measure the current flight state and generate command to operate the flying mechanisms including speed controller, tilt servo, flap servo, rudder control and nose gear servo in order to obtain the required trim speed. The aircraft closed-loop dynamics (Sato and Muraoka, 2014) are consisted of two feedback systems, Stability Augmentation System (SAS) and Control Augmentation System (CAS). This paper focuses on noncomplex optimization problem of the particular CAS Proportional-Integral (PI) feedback gains. The controllers are optimized by structured H_∞ synthesis using Particle

Fig. 1. McART3 QTW VTOL prototype (Sato and Muraoka, 2014).

Swarm Optimization (PSO). Although there are efficient tools exist in order to solve structured H_∞ control problem. i.e., 'hinfstruct' command from Matlab® (Gahinet and Apkarian, 2011) Nonetheless, the algorithm searches for an existence of optimal controller gain which strictly enforce the closed-loop H_∞ norm less than unity. In addition, the relaxation of closed-loop H_∞ norm constraints cannot be modified due to the algorithm limited. Therefore, the algorithm returns the optimal value of the structured H_∞ synthesis by defaults. Due to the simplicity algorithm leading to practical application, PSO requires no gradient information to search for the extremum value of the design cost function (Maruta et al., 2009) In addition, PSO algorithm can be modified in order to relax the problem constraints. The optimized feedback gains are achieved the stability and performance criteria in nominal longitudinal motion of each scheduling tilt angles. This paper is organized as follow; Section 2 presents McART3 QTW-UAV configuration in longitudinal motion dynamics. Section 3 provides the derivation of PSO algorithm corresponding to basic structured controller framework. Section 4 demonstrates the optimization of structured H_∞ controllers using PSO which given as a promising solution to CAS controller PI gains. Last, conclusion and are given in order to verify the proposed techniques.

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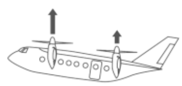
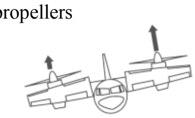
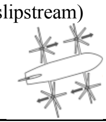
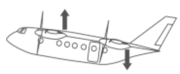
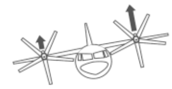
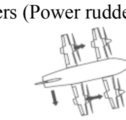
Table 1. Flight control method

	Pitch control	Roll control	Yaw control
Helicopter mode (vertical take off and landing mode)	Differential thrust between fore/aft propellers 	Differential thrust between left/right propellers 	Flaperons (Propeller slipstream) 
Conversion mode	Combination of helicopter and airplane modes		
Airplane mode (level flight)	Flaperons 	Flaperons 	Differential thrust between left/right Propellers (Power rudder) 

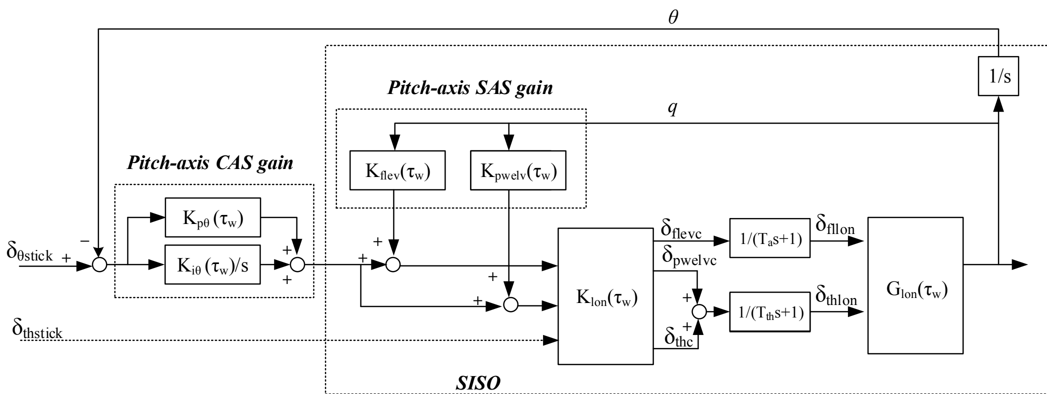


Fig. 2. Block diagram of longitudinal motion control (Sato and Muraoka, 2014)

2. MCART3 QTW-UAV CONFIGURATIONS

McART3 longitudinal motion dynamics are given as follows (Sato and Muraoka, 2016):

$$\dot{x} = A(\tau_w)_{\text{nominal}} x + B(\tau_w)u,$$
$$y = Cx + Du,$$

where

$$x = \left[u,\ w,\ q,\ \theta,\ \delta_{flev},\delta_{pwelv},\delta_{th}\right]^T, \quad (1)$$
$$u = [\delta_{flev_c},\delta_{pwelv_c},\delta_{th_c}]^T.$$

Table 1 (Sato and Muraoka, 2015) shows flight control method. The tilt wings configurations are consisted of three major modes including helicopter, conversion and airplane modes. This paper focuses on only pitch control in longitudinal motion using CAS controller. In helicopter mode, pitching moment is generated by differential thrust between forward and aft propellers. In airplane mode, pitching moment is generated by deflections of forward and aft Flaperons. During conversion between helicopter and airplane modes, interpolation between the helicopter and airplane control schemes is used. The usage of longitudinal SAS gains are shown in Table 2 (Sato and Muraoka, 2016). k_{flelv} and k_{pwelv} are engaged in longitudinal nominal plant state space matrix. Therefore, McART3 closed-loop dynamics are represented as SISO models in each tilt angle configurations. The optimized SAS gains are investigated by JAXA for longitudinal motions models are shown in Table 2. Table 3 (Sato and Muraoka, 2016) shows McART3 longitudinal motion flight parameters.

3. PARTICLE SWARM OPTIMIZATION

A general form of an optimization problem is described as:

$$\underset{x\in\Re^n}{\text{minimize}} \quad f(x) \quad (2)$$

where $f(x)$ is an objective function. The desired design parameters are $x_i (i = 1,2,\ldots,n)$. n is the number of parameters to be optimized. PSO algorithm utilizes swarm size of n_p particles i.e., $x_i = \{x_1, x_2, \ldots, x_{n_p}\}$, search for the solution of $x^* \in \mathbb{R}^n$ in (3).The position of the i^{th} particle and its velocity are denoted as $x_i = (x_1, x_2, \ldots, x_{n_p})^T \in \mathbb{R}^n$ and $v_i = (v_1, v_2, \ldots, v_{i,n_p})^T \in \mathbb{R}^n$ .The position and velocity update in each iteration of each i^{th} particle using an update law which describe in Eqs. (3-4) as follows :

$$x_i^{k+1} = x_i^k + v_i^{k+1}, \quad (3)$$
$$v_i^{k+1} = C_0 v_i^k + C_1 r_{1,i}^k (x_i^{best,k} - x_i^k) + C_2 r_{2,i}^k (x_{swarm}^{best,k} - x_i^k), \quad (4)$$

where C_0 is the inertia factor effect to each particle, C_1 is the particle cognitive scaling factor ,C_2 is the social scaling factor. $r_{1,i}^k$,$r_{2,i}^k$ are the random numbers which uniformly distributed within [0,1] ranges. $x_i^{best,k}$ is the best previously obtained position of the i^{th} particle. $x_{swarm}^{best,k}$