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Research Article

Variance Constrained Vibration Control of Morphing Tactical Unmanned Aerial Vehicles (TUAVs)

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Abstract

In this study, using dynamic model of passive and active morphing featured Tactical Unmanned Aerial Vehicle (TUAV) called which is produced in Erciyes University, Faculty of Aeronautics and Astronautics, Model Aircraft Laboratory, under the TUBITAK ARDEB 1001 program and designing Output Constrained Variance Controller for aircraft tracking the desired trajectory achieved with minimal vibration and minimum energy consumption. For this purpose, using MATLAB, in the simulation environment, studies have been performed and closed loop responses have been obtained. Longitudinal motion is in primary interest, desired output is pitching angle of TUAV, and desired input is elevator angle.

Keywords: TUAV, Flight Performance, Constrained Variance Controller.

1. Introduction

For the last around four and five decades *U*nmanned *A*ir *V*ehicles (UAVs) have been broadly benefited for both in military and also marketable operations. There were many casuses for expansive usage of UAVs. Some of these causes are listed next: Primarily, their manufacturing is cheap. Their operation is also cheap with respect to the old-fashioned manned vehicles. Second, their structure is flexible. It can be shaped with respect to the customer demand. Finally, in hazardous missions UAVs do not risk the pilot's life. There are many other advantages of UAVs with respect to the manned aerial vehicles not given here. Due to the this superiotities, UAVs are used in real life requests such as crop monitoring and spraying, photography, film and video, coast guarding etc. UAVs have been also applied for military tasks. For example, navy for decoying missiles by the emission of artificial signatures and shadowing enemy fleets, army for reconnaissance and surveillance of enemy activity and air force for radar system jamming and destruction and airfield base security.

The precise UAV observed in this article is Tactical UAVs (i.e. TUAVs). TUAVs are heavier class of UAVs (range from 50 kg to 1,500 kg) that fly at higher altitudes (range from 3000 m to 12000 m) and are presently applied principally to support military applications. The classification of Tactical UAVs is listed next: EN-TUAV (long endurance TUAV), LR-TUAV (long range TUAV), SR-TUAV (short range TUAV) and CR-TUAV (close range TUAV) [2]. Our TUAV called as ZANK III is in the class of CR-TUAV.

In this article output variance constrained controllers for vibration control of TUAVs is first time evaluated in TUAVs in the literature.

2. Our Tactical Unmanned Aerial Vehicle

Some of the technical properties of our produced TUAV are listed in Table 1. It is also illustrated in Fig 1.

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Table 1. Some Properties of TUAV

Property	**Magnitude**
Total Take-off Weight	50 kg
Total Payload	15 kg (5 kg of fuel)
Aircraft Length and Width	4 m wing span 2.188 m longitudinal length
Engine Horse Power (HP)	18 Hp
Maximum Flight Range	2550 km
Maximum Flight Endurance	28.7 h
Speed For Maximum Flight Endurance	88. 9 km/h
Flight Ceiling Altitude	12792 m

(a) (b)

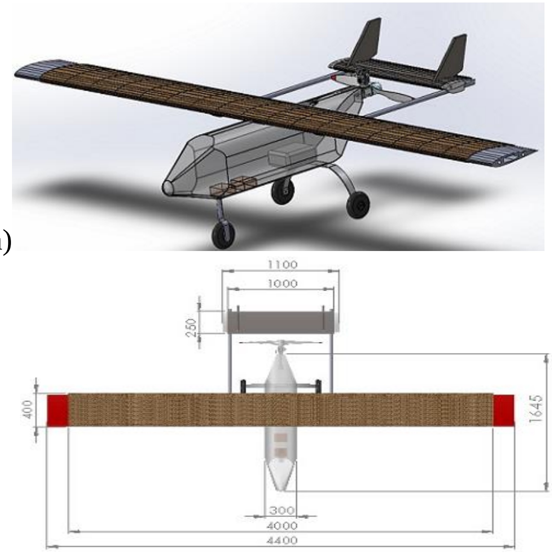


Figure 1. Drawings of TUAV

In Eq. 1 the longitudinal state-space model is given and it is used for flight control system design [3].

$$\begin{bmatrix}\Delta\dot{u}\\ \Delta\dot{w}\\ \Delta\dot{q}\\ \Delta\dot{\theta}\end{bmatrix}=\begin{bmatrix}X_u & X_w & 0 & -g\\ Z_u & Z_w & u_0 & 0\\ M_u+M_{\dot{w}}Z_w & M_w+M_{\dot{w}}Z_w & M_q+M_{\dot{w}}u_0 & 0\\ 0 & 0 & 1 & 0\end{bmatrix}\begin{bmatrix}\Delta u\\ \Delta w\\ \Delta q\\ \Delta\theta\end{bmatrix}+\begin{bmatrix}X_{\delta_T} & X_{\delta_e}\\ Z_{\delta_T} & Z_{\delta_e}\\ M_{\delta_T}+M_{\dot{w}}Z_{\delta_T} & M_{\delta_e}+M_{\dot{w}}Z_{\delta_e}\\ 0 & 0\end{bmatrix}\begin{bmatrix}\Delta\delta_T\\ \Delta\delta_e\end{bmatrix} \quad (1)$$

3. Variance Constrained Vibration Control

For a known continuous linear time invariant (LTI), stabilizable and detectable plant (see [4,5])

$$\dot{x}_p = A_p x_p + B_p u_p + w_p \,, y = C_p x_p \,, z = M_p x_p + v \quad (2)$$

and a positive definite input penalty matrix, $R > 0$, determine a full order dynamic controller

$$\dot{x}_c = A_c x_c + Fz \,, u_p = G\, x_c \quad (3)$$

to answer the problem

$$\min_{A_c,F,G} \; J = E_\infty\, u_p^T R u_p = tr(RGX_{c_j} G^T) \quad (4)$$

expose to variance constraints on the output or outputs

$$E_\infty\, y_i^2 \le \sigma_i^2, \qquad i = 1, ..., n_y \quad (5)$$

Above y and z characterize outputs of interest and sensor measurements, respectively, w_p and v are zero-mean uncorrelated Gaussian white noises with intensities of W and V, respectively, F and G are state estimator and controller gain matrices, respectively, x_c is the controller state vector, σ_i^2 is the upper limit imposed on the i-th output variance, n_y is the number of outputs, and furthermore $E_\infty \triangleq lim_{t\to\infty} E$, and E is the expectation operator. Finally, *tr* and ^{T} symbolize matrix trace and matrix transpose operators, respectively. The quantity of J commonly named as flight control system energy or flight control system cost and it is calculated using also the state covariance matrix, X_{c_j}. After the algorithm [4,5] converges and the output penalty matrix Q is determined, OVC parameters are

$$A_c = A_p + B_p G - FM_p, F = XM_p^T V^{-1}, G = -R^{-1} B_p^T K \tag{6}$$

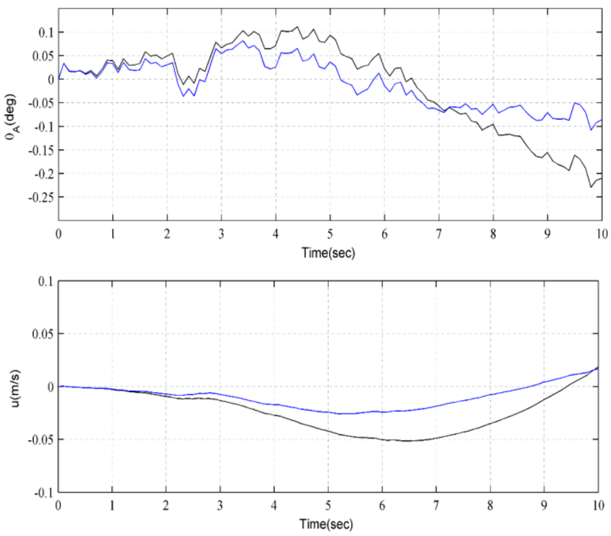
Above, X and K are solutions of solutions of two algebraic Riccati equations:

$$0 = XA_p^T + A_p X - XM_p^T V^{-1} M_p X + W \tag{7a}$$

$$0 = KA_p + A_p^T K - KB_p R^{-1} B_p^T K + C_p^T QC_p \tag{7b}$$

4. Results

In Fig. 2 closed loop responses after using soft and tight variance constraints are given. It can be seen that when tight output variance constrained used for aircraft pitch angle its peak values decreases. On the other hand, the peak values of control surface increases. In both cases OVC exponentially stabilizes closed loop systems.



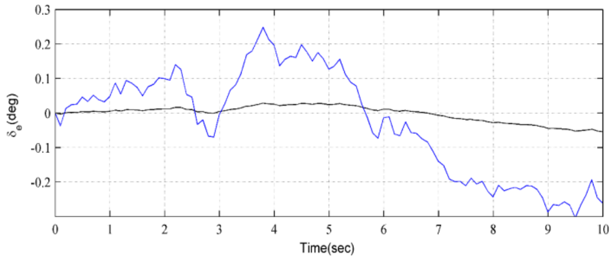


Figure 2. Longitudinal Autopilot Design and Closed Loop Responses (Blue: Tight OVC, Black: Soft OVC)

5. Conclusions

Effects of using variance constrained vibration control on Tactical Unmanned Aerial Vehicles are examined. For this purpose dynamic model of passive and active morphing featured Tactical Unmanned Aerial Vehicle (TUAV which is produced in Erciyes University, Faculty of Aeronautics and Astronautics, Model Aircraft Laboratory, under the TUBITAK ARDEB 1001 program is used. It is found that when tight constrained is used, the peak values of outputs of interest decreases. On the other hand, the peak values of inputs of interest increases.

Acknowledgement

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