Safe Flight Envelope of Closed-loop Quadcopters

G. Delansnay[1], H. G. Harno[2], Y. Kim[2], A. Vande Wouwer[1]
[1] System, Estimation, Control and Estimation (SECO), University of Mons, Belgium
[2] Department of Aerospace and Software Engineering, Gyeongsang National University, Republic of Korea
Email: `gilles.delansnay@umons.ac.be`

1 Introduction

In past years, quadcopters have experienced an ever increasing success due to the myriad of possible applications in transportation, photography and filming, structure inspection, farming, etc. Unfortunately, aerial vehicles are subject to perturbations or loss of control which can lead to important material damage or injuries. In order to secure aerial flight, safety tools should be developed. One of them is the Safe Flight Envelope (SFE) which determines the possible safe positions of the vehicle and allows establishing a safe strategy. It is defined as *a region within which the vehicle possesses the ability to leave, and then, return the trim condition in a finite time horizon* [1]. This study proposes an original procedure to compute the SFE by a forward-backward reachability analysis (see figure 1) based on zonotopes [2], and applied to a Parrot Mambo quadcopter.

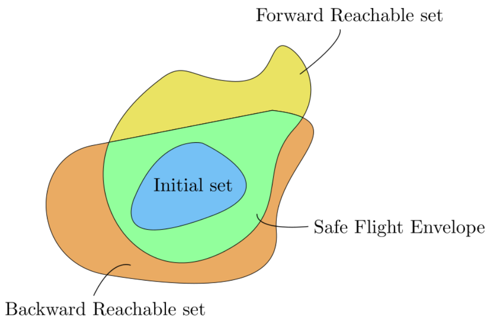

Figure 1: Safe Flight Envelope through Forward and Backward Reachability.

2 Closed-loop model identification

Quadcopters use complex control structures in order to achieve performance and robustness. The closed-loop structure has the decisive advantage of providing a partial linearization of the system, and the underlying idea of our analysis in order to develop an approximate linear state space representation of the system by resorting to input-ouput data sets and subspace identification. This model is at the core of the zonotopic reachability analysis.

3 Zonotopic Forward and Backward Reachability

Consider a set of initial conditions $\mathscr{X}_0$, a reference trajectory $u(.)$ with $\mathscr{X}_f(t_f, x_0, u(.)$ the set of solutions of our identified model and $\mathscr{X}_b(t_f, x_0, u(.))$ the set of solutions from the backward model. The forward and backward reachable set are given by:

$$R_f(t_f) = \{\mathscr{X}_f(t_f, x_0, u(.)) \in \mathbb{R}^n | x_0 \in \mathscr{X}_0, \forall t : u(t) \in \mathscr{U}(t)\}$$
$$R_b(t_f) = \{\mathscr{X}_b(t_f, x_0, u(.)) \in \mathbb{R}^n | x_0 \in \mathscr{X}_0, \forall t : u(t) \in \mathscr{U}(t)\}$$

Both sets are computed using the CORA toolbox [3]. The Safe flight Envelope corresponds to the intersection of the two sets.

4 Results

Figure 2 shows a safe Flight envelope using the approach described above.

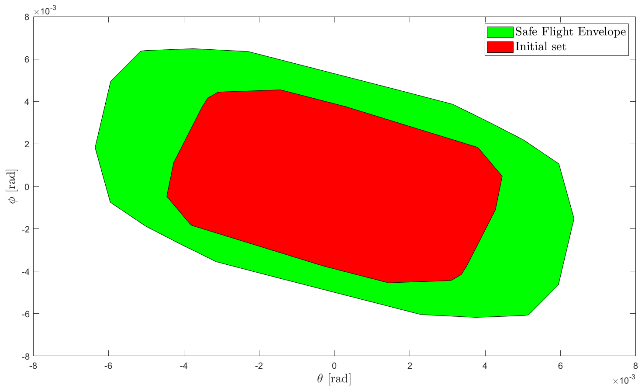

Figure 2: Safe Flight Envelope (green) for pitch and roll angles after 0.005 s from given initial set (red) and under an unitary step altitude reference.

References

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