Safe and Robust Robot Maneuvers Based on Reach Control

Marijan Vukosavljev, Ivo Jansen, Mireille E. Broucke, Angela P. Schoellig

DYNAMIC SYSTEMS LAB

1 Overview

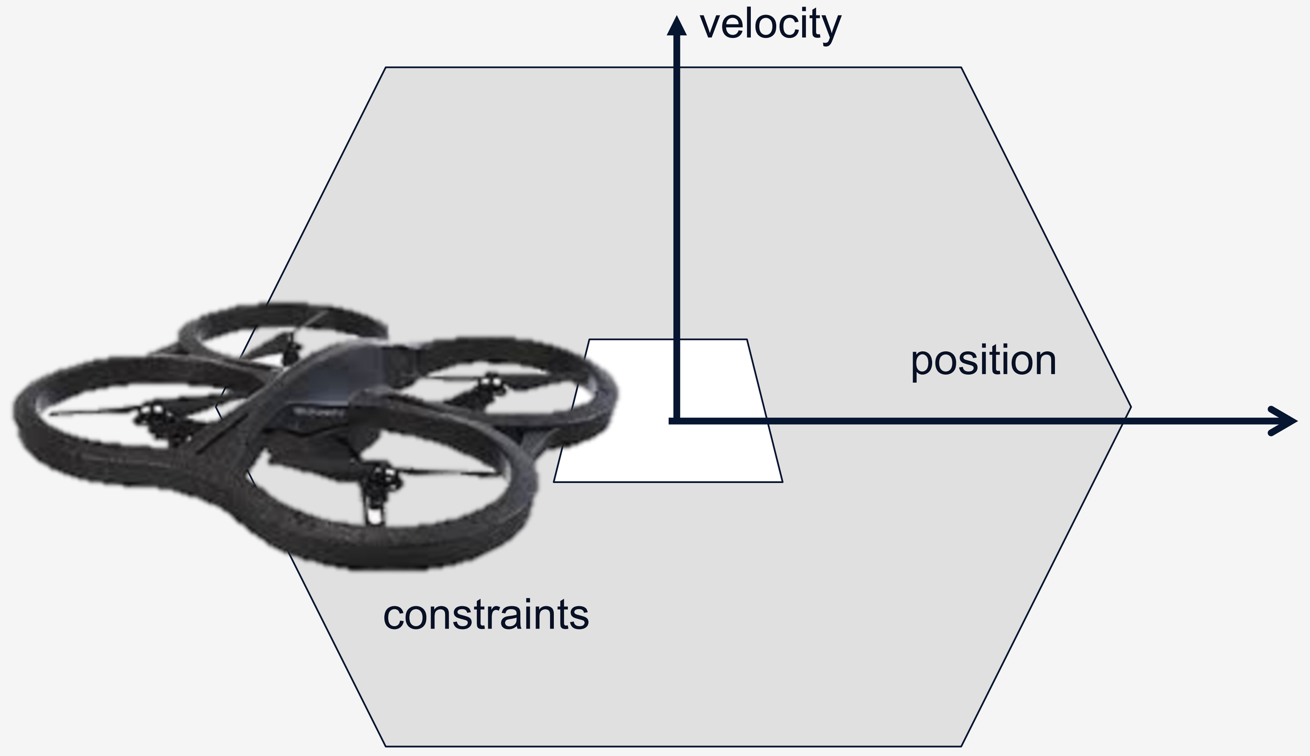
Novel **hybrid control** framework that achieves specifications involving **safety** and **sequence of events**

Demonstrated for side-to-side motion on indoor quadrocopter

2 Control Specifications

Safety constraints form an allowable polytopic region in the state space

Temporal logic specifications induce allowable directions to flow within the polytopic region



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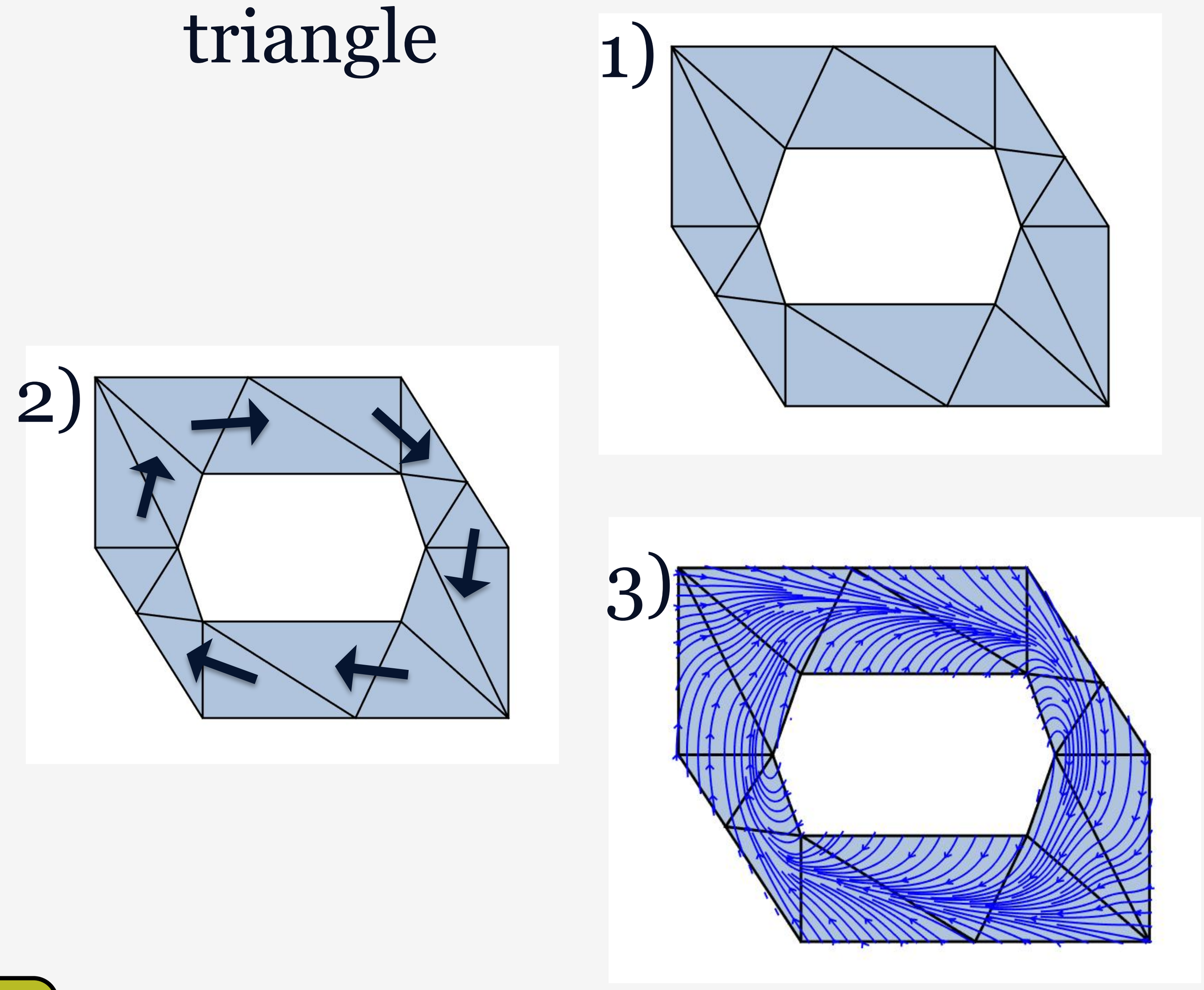
3 Hybrid Control Methodology

1) The allowable region is triangulated
2) A sequence of triangles, satisfying the temporal logic specifications, is determined
3) The sequence is implemented by low level affine feedback controllers defined for each triangle



4 Results

A demonstration on an indoor quadrocopter shows that the proposed methodology can meet the safety and strict sequencing specifications, even under severe unmodeled disturbances

4 Results

Future Work

We are currently working towards temporal logic specifications in 2D and 3D for single and multiple quadrocopters in the presence of obstacles. Our approach reuses this 1D result in each direction to reduce complexity

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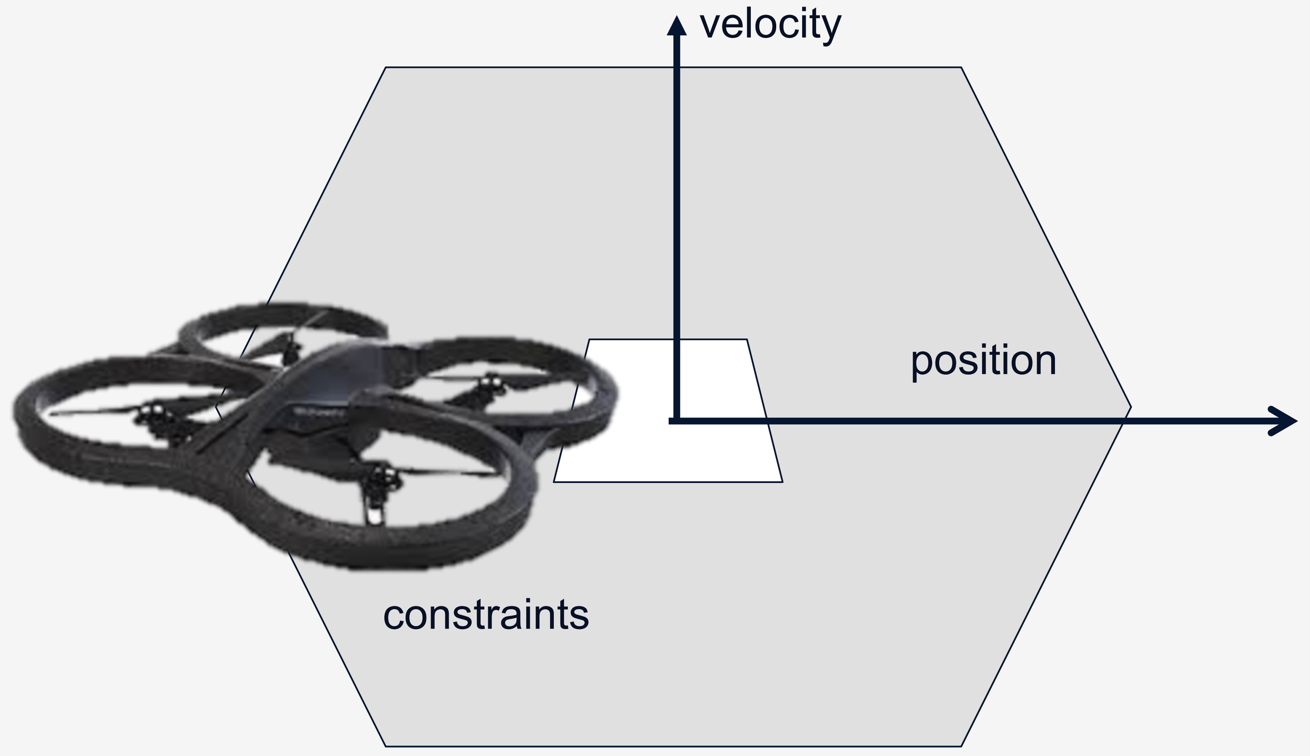

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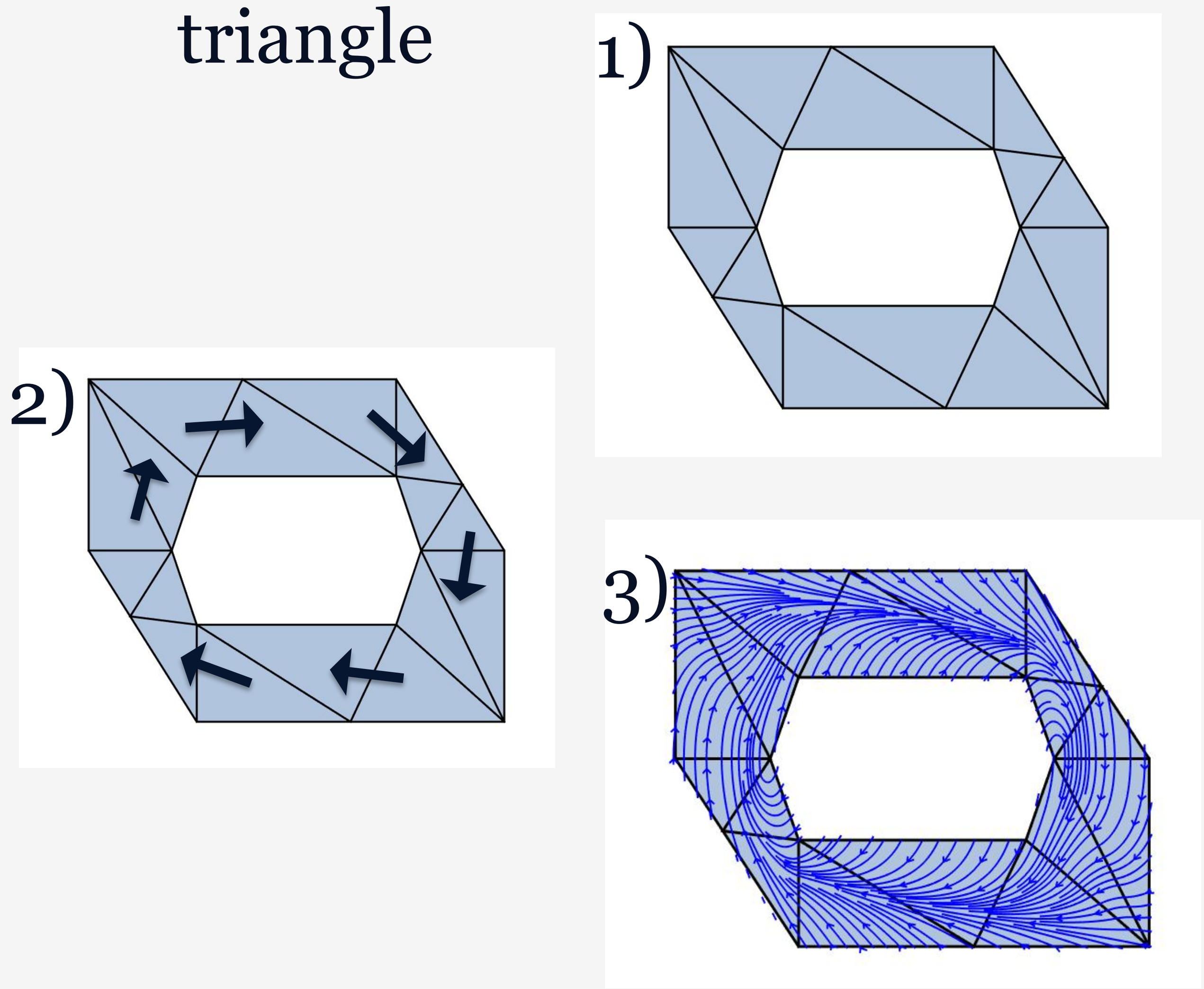

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2 Control Specifications - Application

Objective: transport the quadrocopter back and forth along the *x*-direction

Safety:
- (S1) room wall boundaries
- (S2) speed limit
- (S3) deceleration towards walls

Liveness:
- (L1) minimum cruise speed
- (L2) and (L3) turnaround acceleration

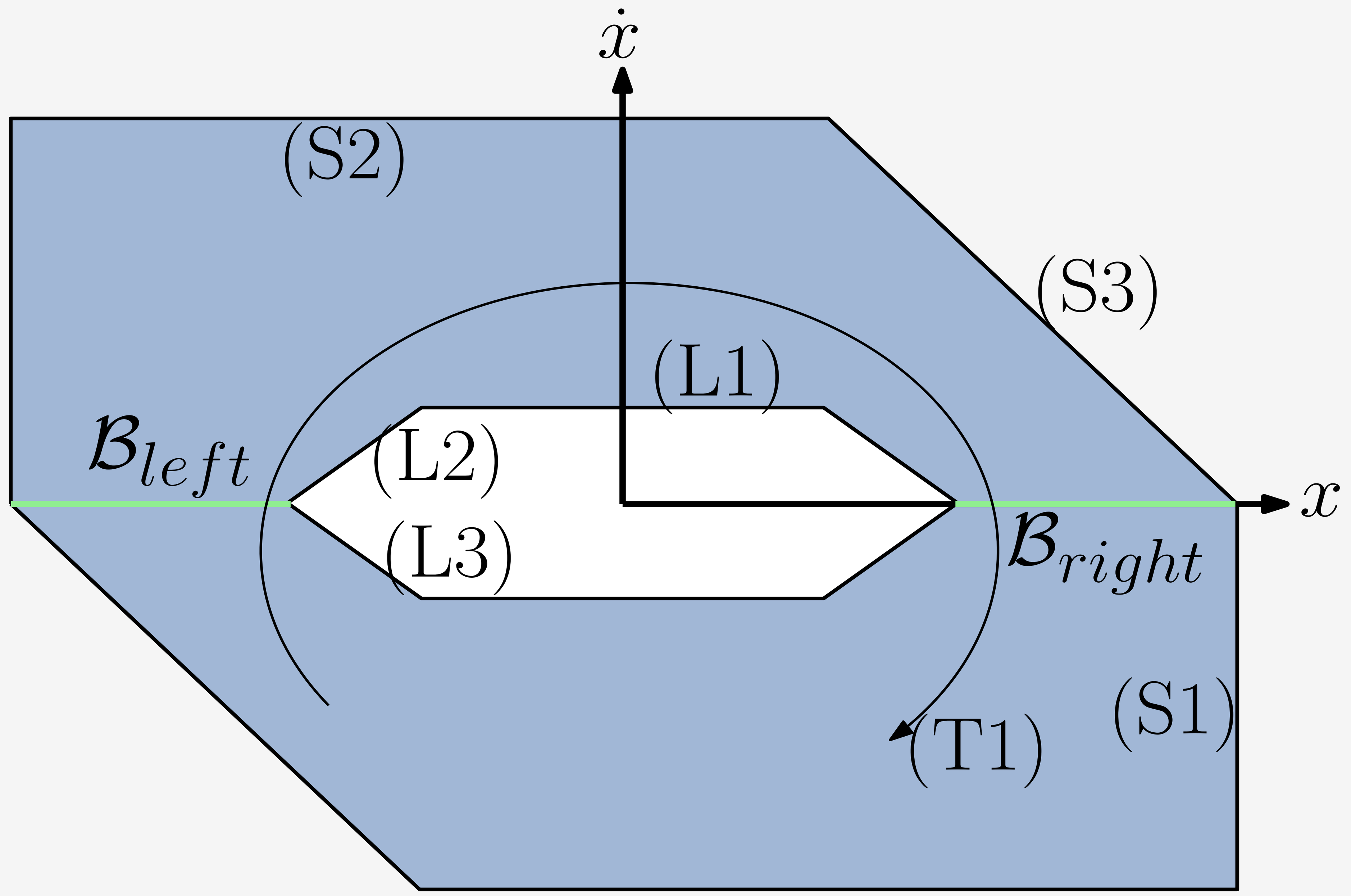
Desired Temporal Sequence:
- (T1) pass through B_{right} and B_{left} alternatingly

Modeling:
Reduced dynamics in *x*-direction are

$$\ddot{x} = g \tan\theta := u,$$

where the input to design is the pitch angle, θ

The other directions are stabilized in a standard way



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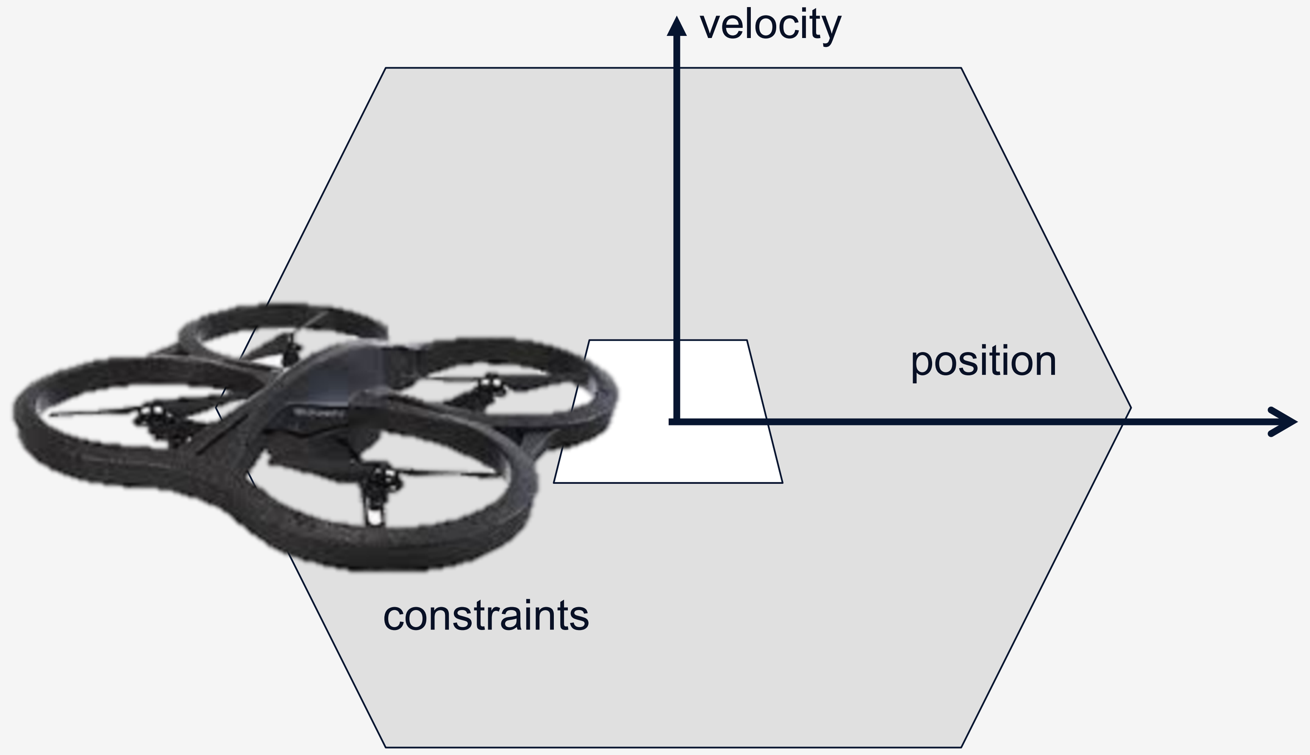

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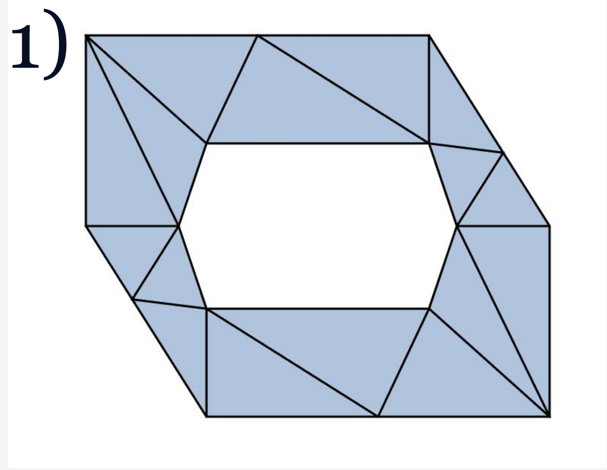

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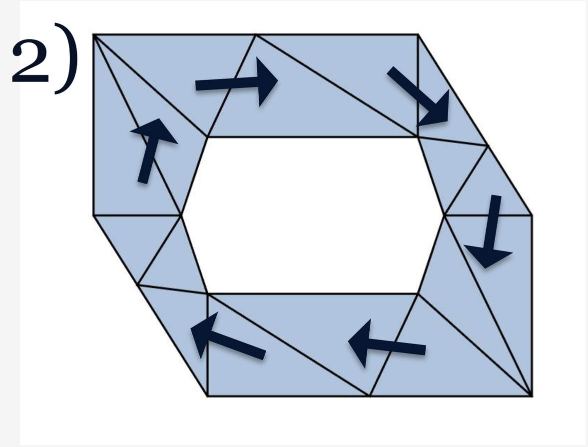

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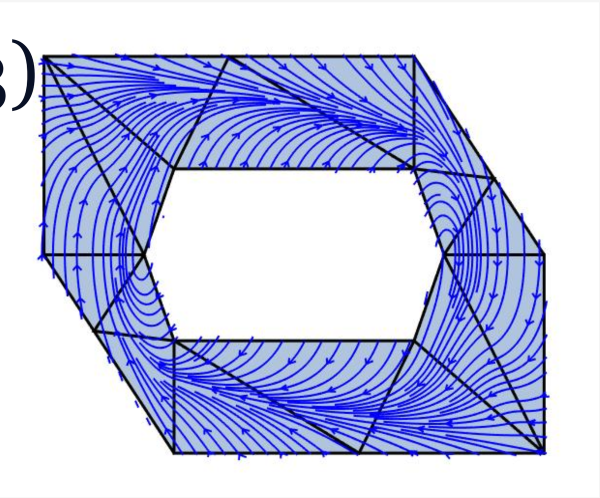

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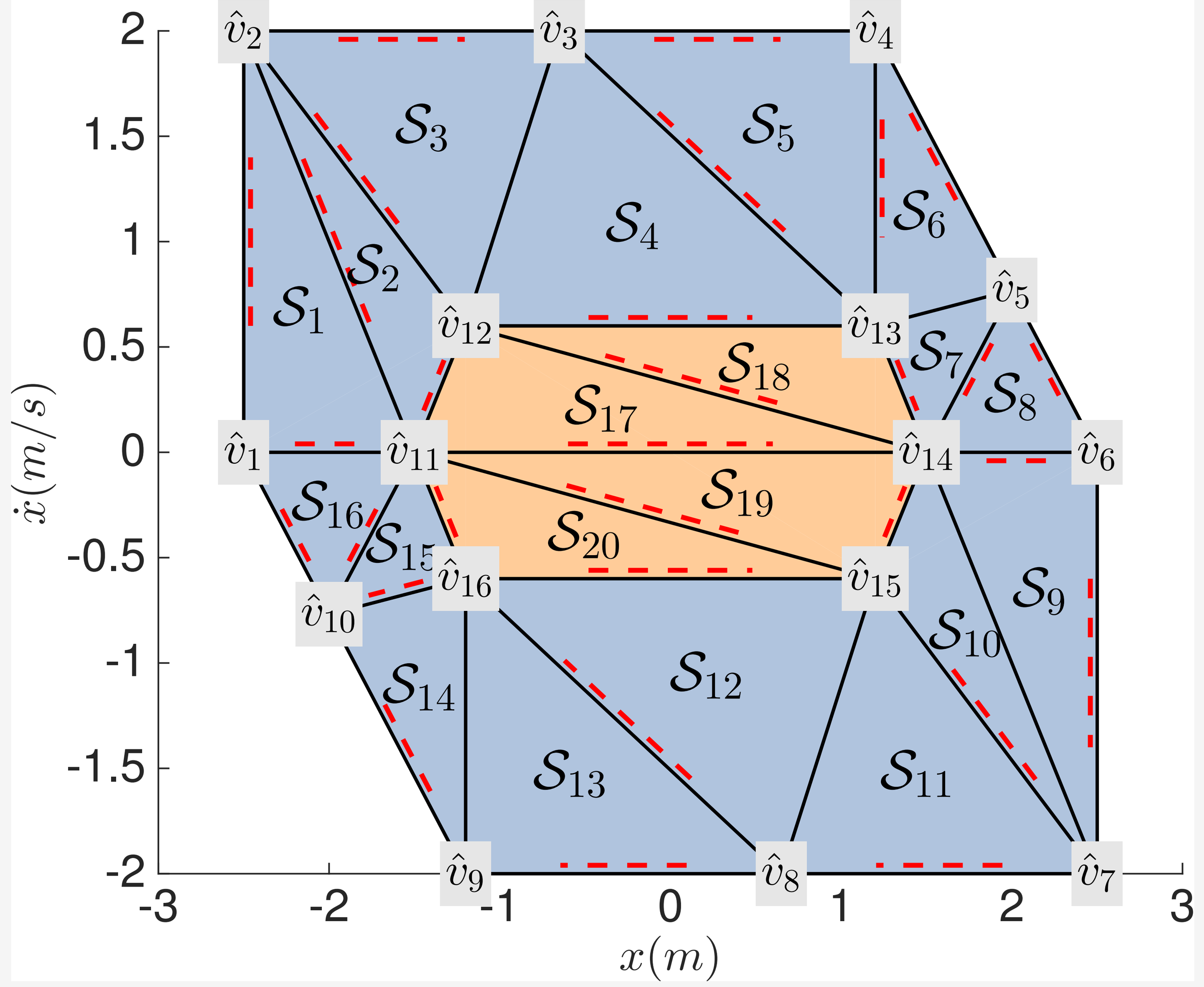
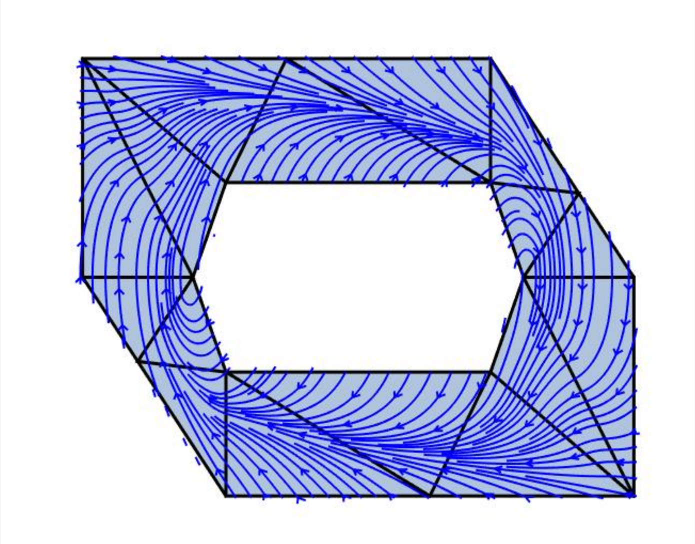
3 Hybrid Control Methodology - Application

1) Triangulation into 20 triangles

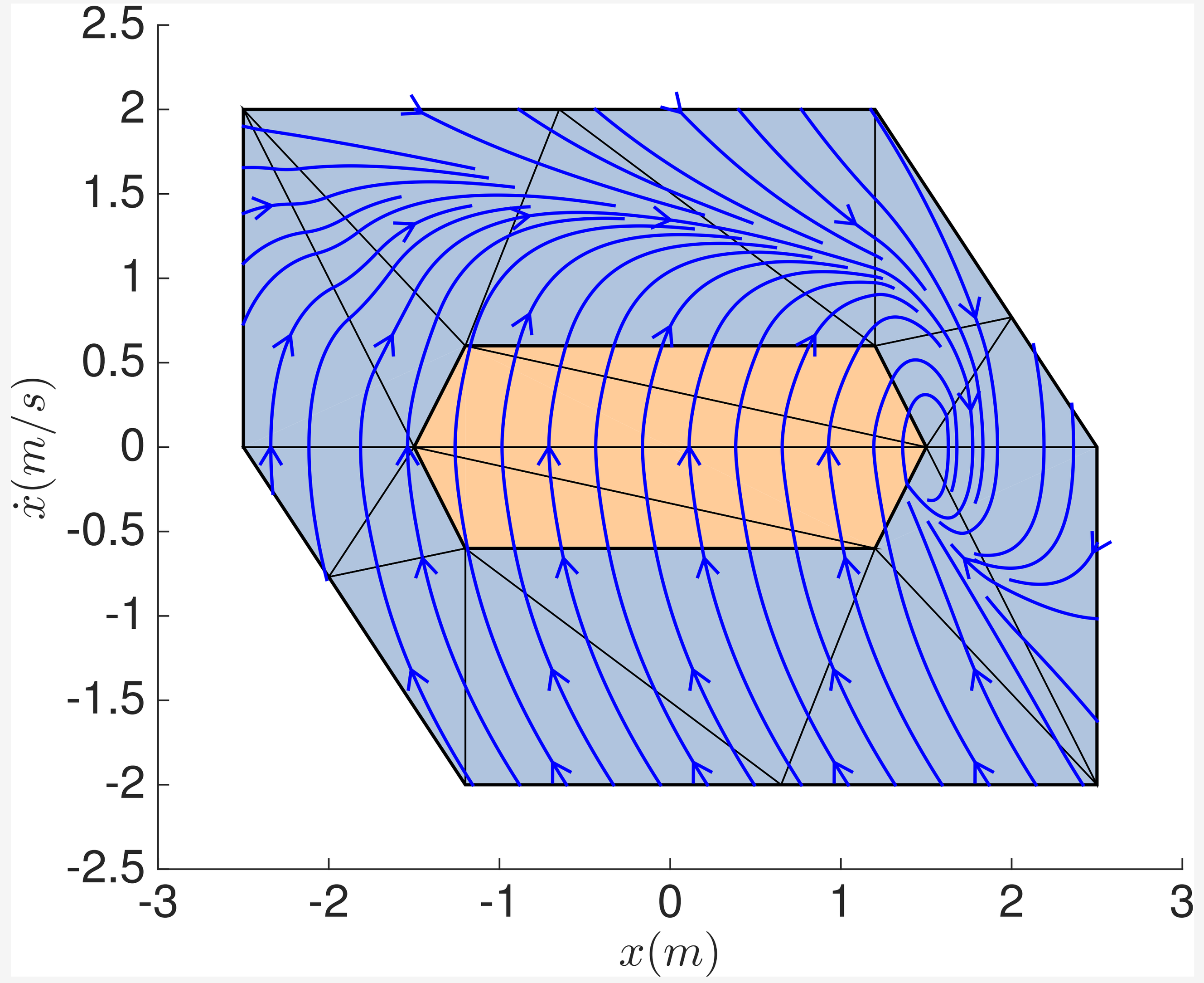
2) A sequence of triangles to reach the right side. Symmetry is used to implement moving to the left. Automation of this procedure is formalized in [1]

3) Affine feedback controllers constructed on each triangle. Overall results in a closed-loop behavior satisfying the safety and temporal specifications





Nominal closed-loop response



Left-to-right closed-loop response

[1] M. Kloetzer and C. Belta, “A fully automated framework for control of linear systems from temporal logic specifications,” IEEE Transactions on Automatic Control, vol. 53, no. 1, pp. 287-297, 2008.

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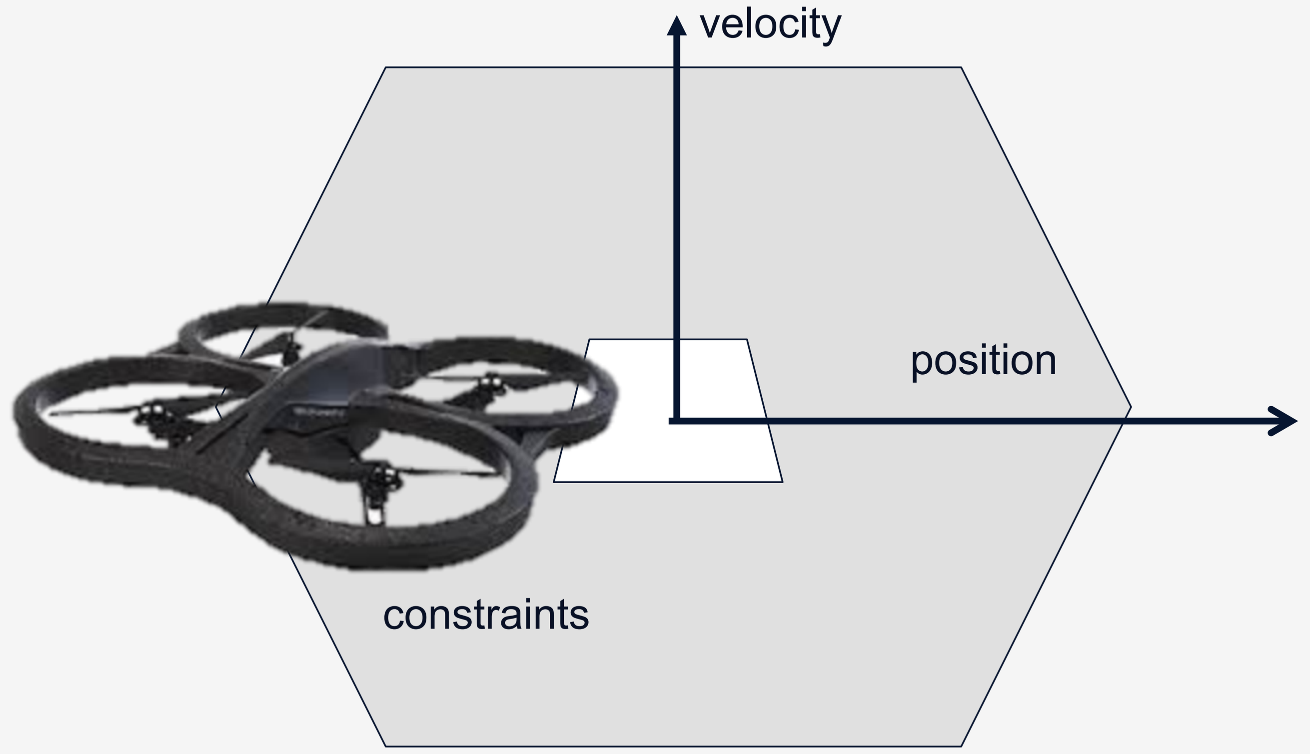

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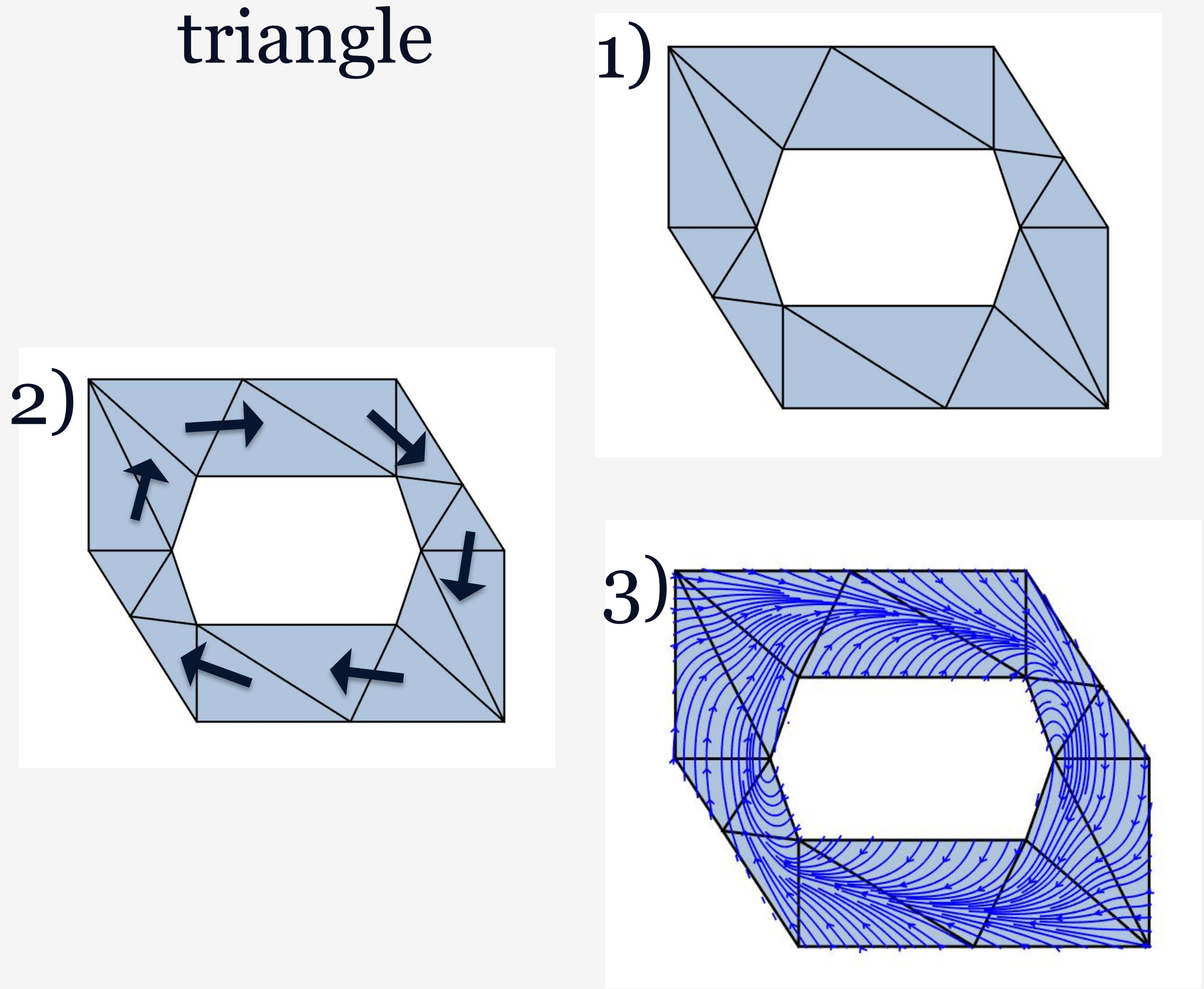

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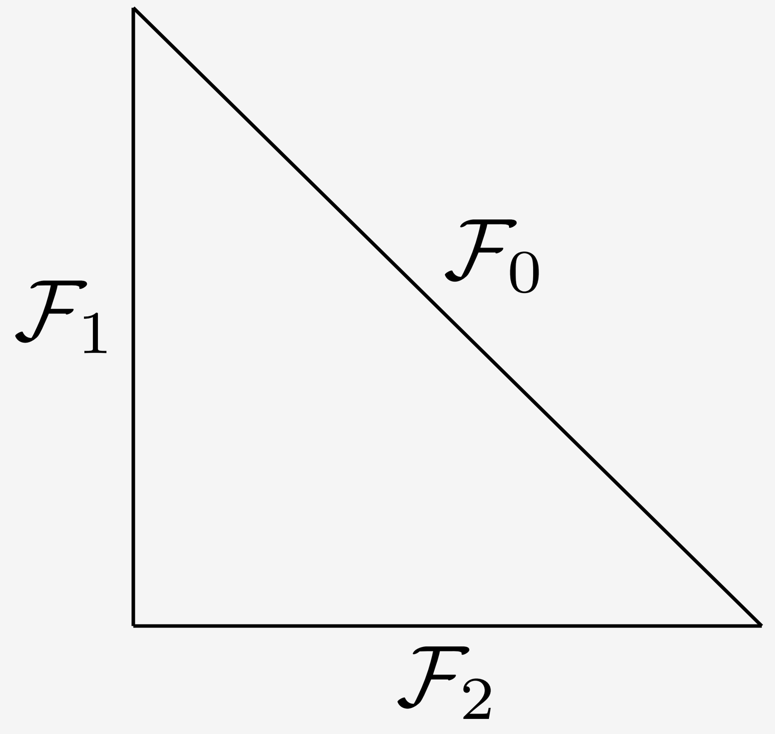
3 Hybrid Control Methodology – Reach Control Problem

The Reach Control Problem (RCP)

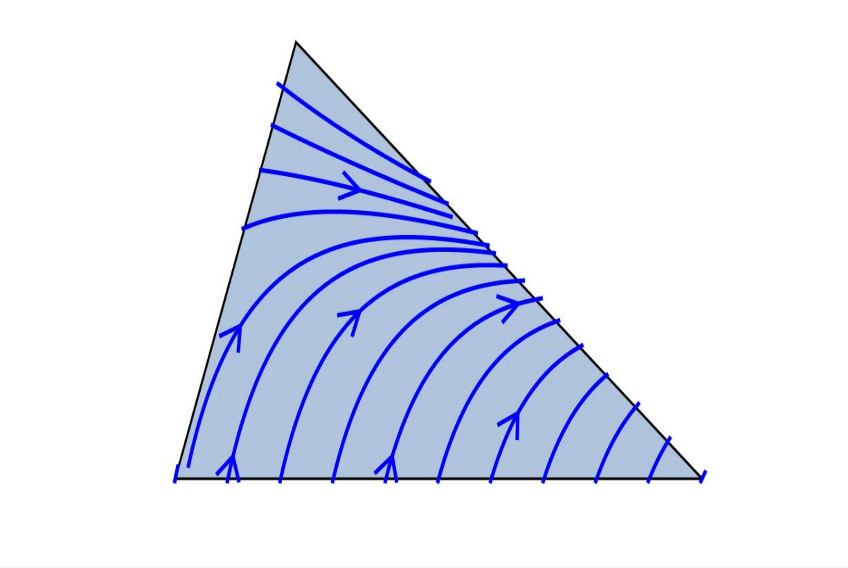
Given a simplex with a specified exit facet (e.g. F_0) and restricted facets (e.g. F_1 and F_2), solving the RCP determines an affine feedback controller such that trajectories starting in the simplex only leave through the exit facet



Quadropter Application

Affine feedback control law in terms of position and velocity:

$$u = k_1 x + k_2 \dot{x} + k_3 .$$



Gains determined by interpolating feasible control values selected at simplex vertices

L.C.G.J.M. Habets and J.H. van Schuppen, “A control problem for affine dynamical systems on a full-dimensional polytope,” Automatica, vol. 40, no. 1, pp. 21-35, 2004.

B. Roszak and M. E. Broucke, “Necessary and sufficient conditions for reachability on a simplex,” Automatica, vol. 42, no. 11, pp. 1913-1918, 2006.

M.E. Broucke and M. Ganness, “Reach control on simplices by piecewise affine feedback,” SIAM Journal on Control and Optimization, vol. 52, no. 5, pp. 3261 - 3286, 2014.

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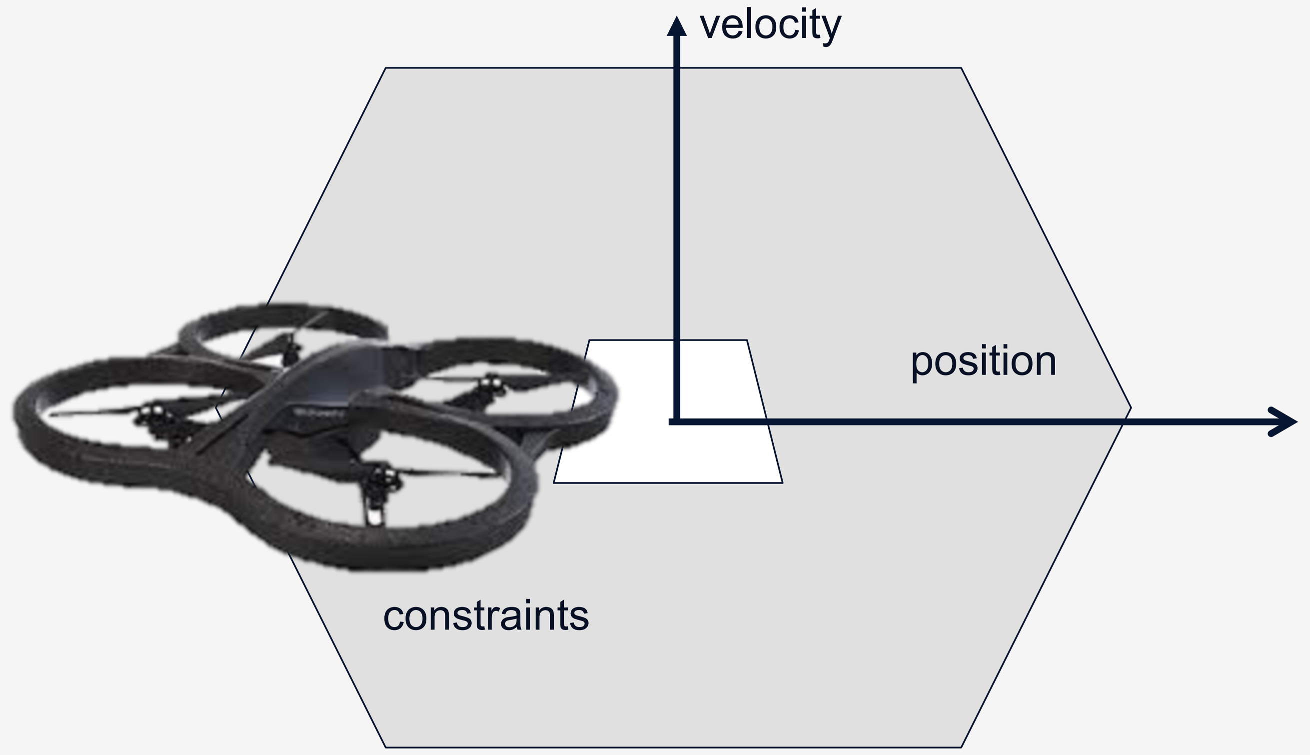

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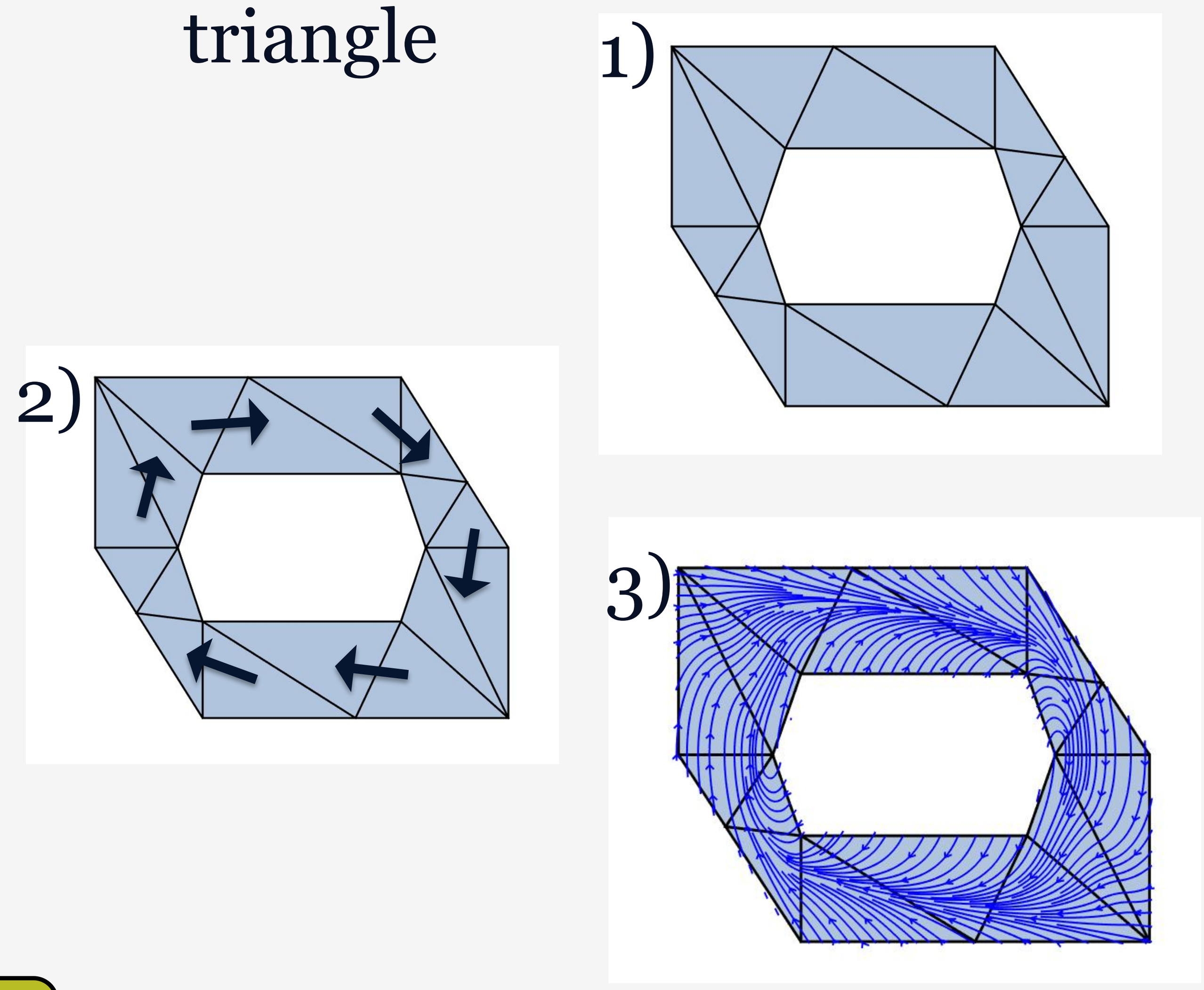

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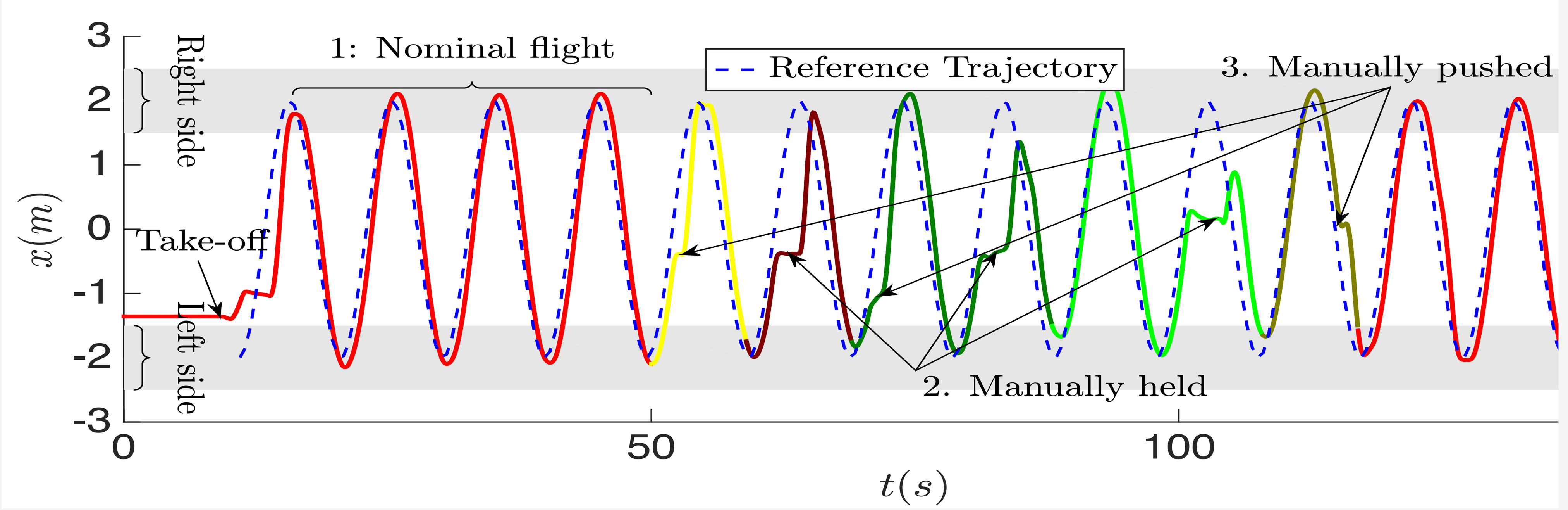
Standard Tracking Aproach



Hybrid Control Approach