Feasibility of Motion Primitives for Choreographed Quadrocopter Flight

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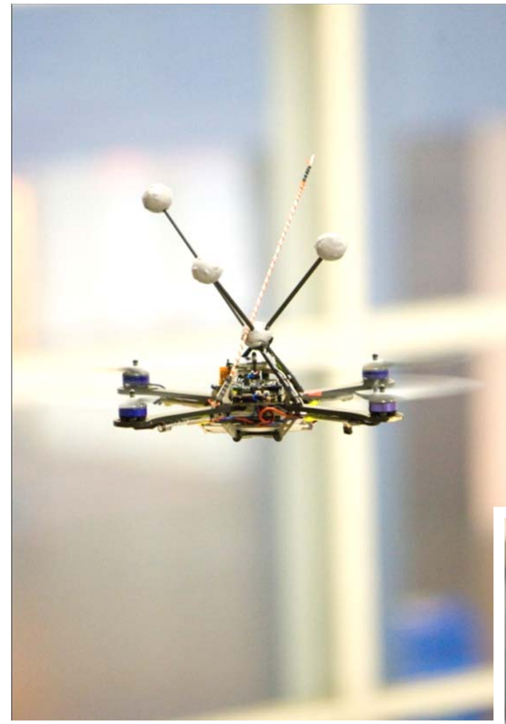
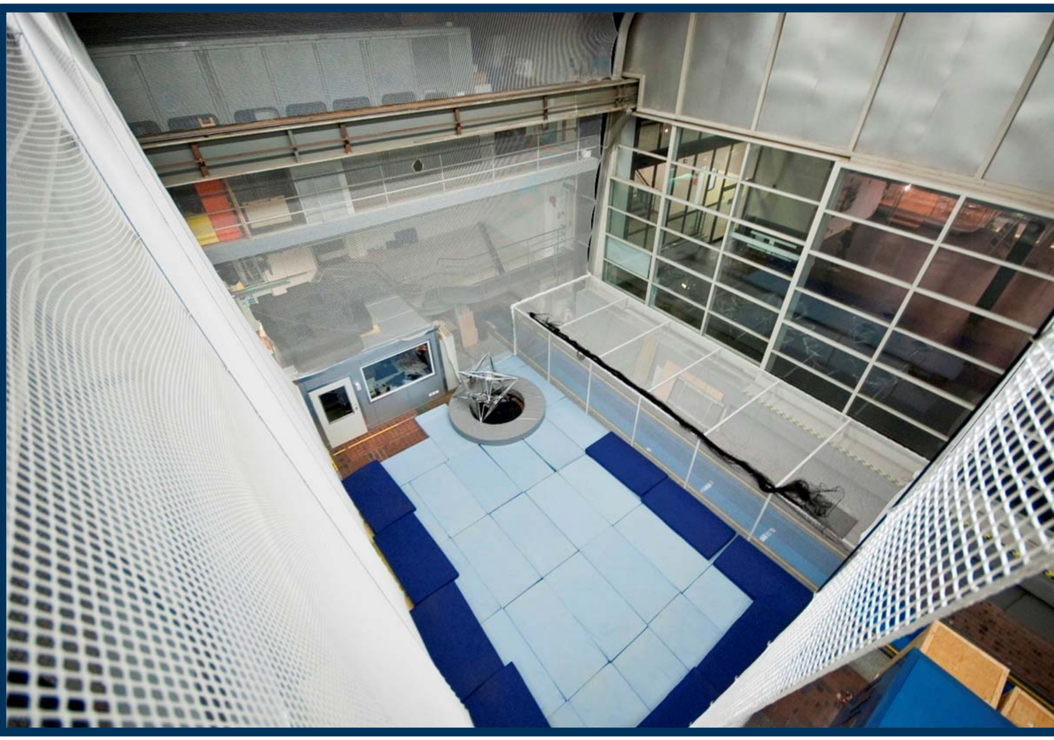
LET'S DANCE

… DANCE IN THE AIR

VISION Dance performance of multiple aerial robots





ACTORS

Type: **Quadrocopter**

Size: **Ø 3 feet**

Weight: **1 pound**

Flight time: **15 minutes**

STAGE

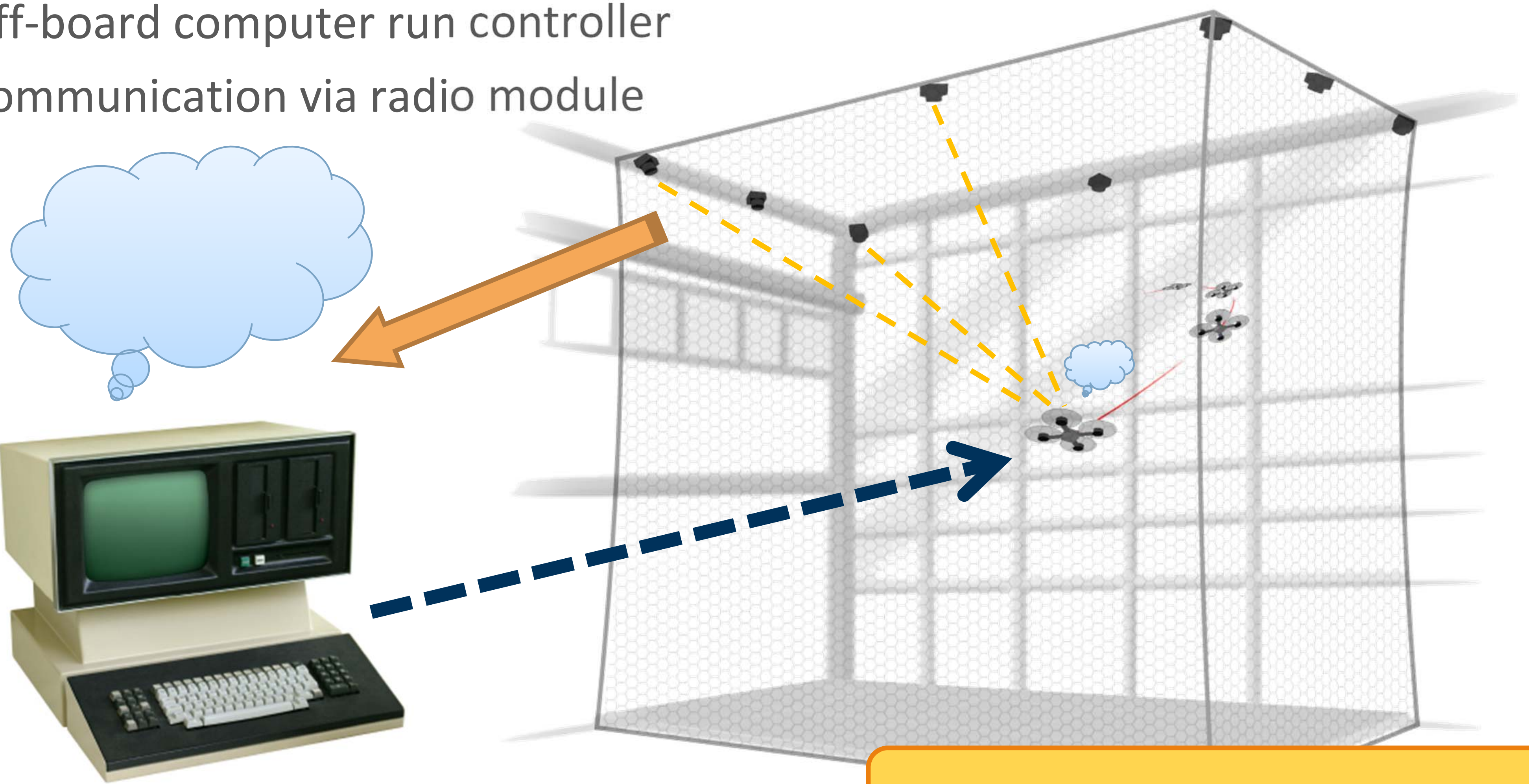
Name: **Flying Machine Arena**

Size: **33 x 33 x 33 feet**

Protection: **Nets, Padded floor**

TESTBED

- cameras provide position and attitude
- off-board computer run controller
- communication via radio module



Autonomous flight.

VIDEO: https://youtu.be/DrHlgxf0oQw?list=PLD6AAACCBFFE64AC5

OBJECTIVE & FOCUS

GOAL An *intuitive* interface for creating meaningful and feasible quadrocopter choreography.

… use controls and system dynamics.

MOTION DESIGN

FEASIBILITY

Parameterized motion primitives.

Based on model.

PREPROGRAMMED.
DONE AHEAD OF TIME.

FOCUS

CONTROL

SYNCHRONIZATION

[Schoellig, Augugliaro and D'Andrea, ICRA 2010 & IROS 2010]

MOTION DESIGN – idea

CHOREOGRAPHY – concatenation of basic motion elements

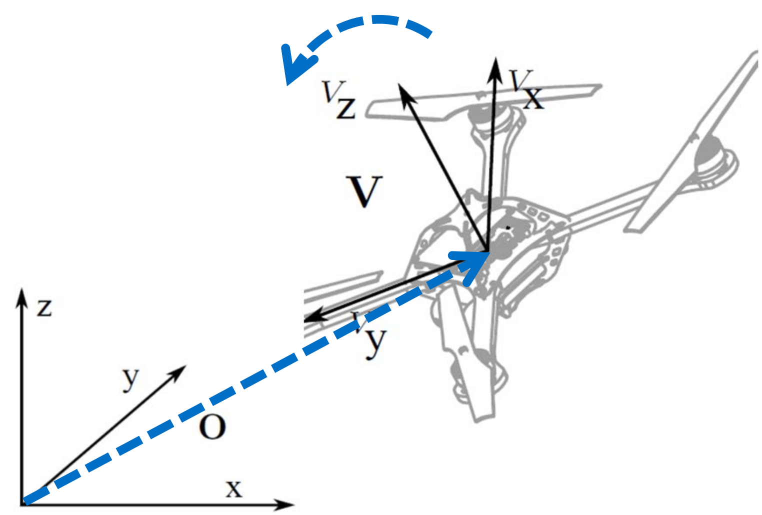
MOTION PRIMITIVE A | MOTION PRIMITIVE B | .... | MOTION PRIMITIVE D

Specify motion through
position and **yaw** (4DOF):

$$\begin{cases} s(t) = (x(t), y(t), z(t)) \\ \alpha(t) \end{cases}$$

Introduce parametrized motion primitives:

$$\begin{cases} s_d(t) &= s_d(p,t), \qquad t \in [t_0, t_f] \\ \alpha_d(t) &= \alpha_d(p,t) \end{cases}$$



DESIGN PARADIGM. **space – time – energy – structure**

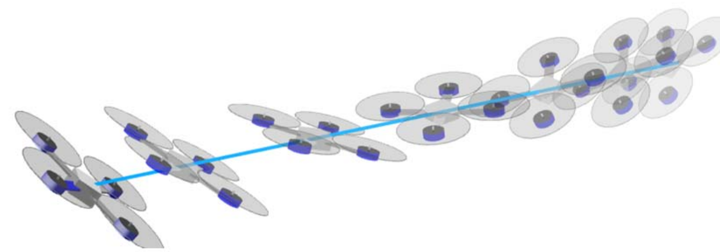
MOTION DESIGN – example

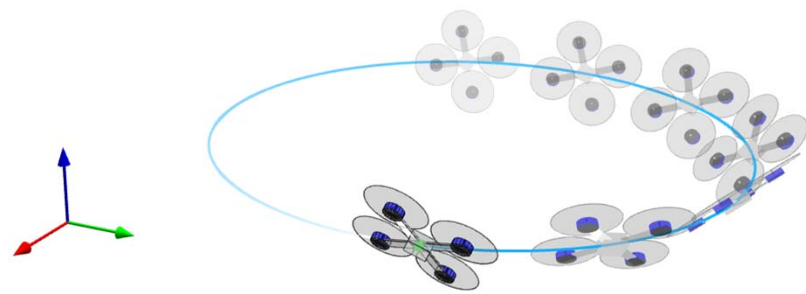
Periodic motion primitive.

$$s_d(t) = a_0 + \sum_{k=1}^{N} a_k \cos\left(k\,\Omega t\right) + b_k \sin\left(k\,\Omega t\right), \qquad \Omega = 2\pi/T.$$

includes

- side-to-side motions
- circles
- spirals
- ....





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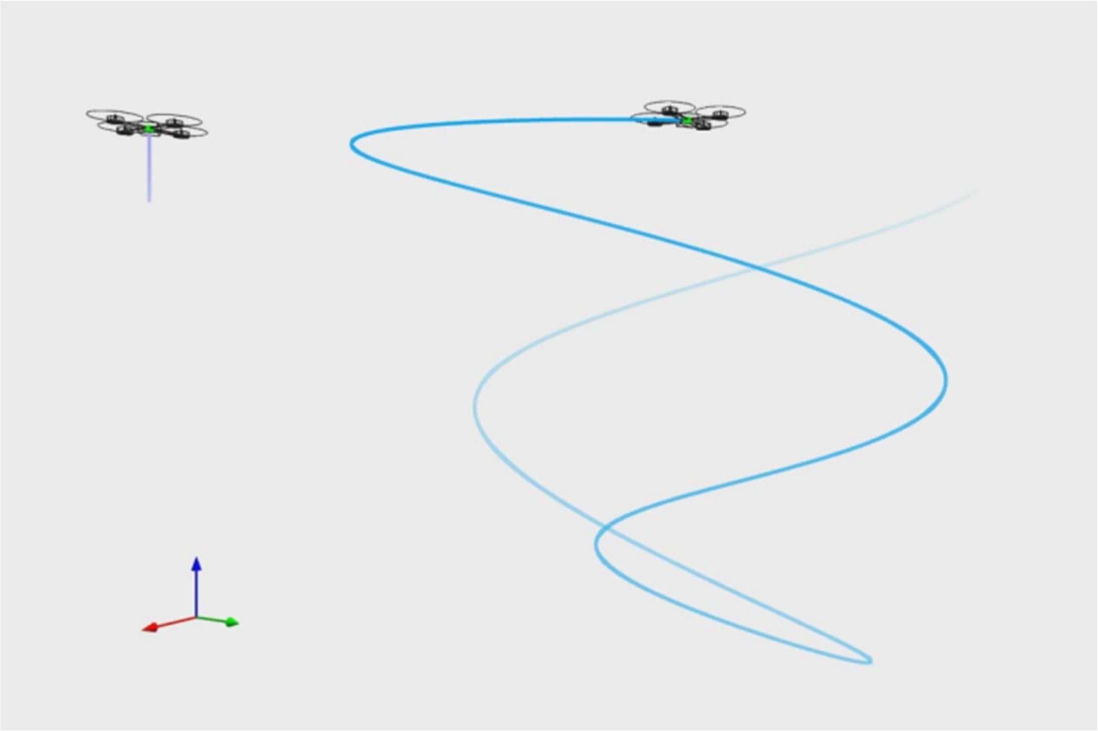


DESIGN PARADIGM. **space – time – energy – structure**

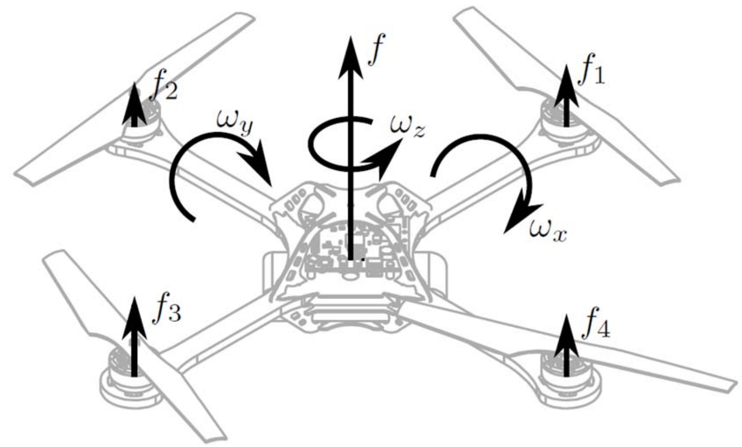
MOTION FEASIBILITY – model/constraints

First principles model.

$$\ddot{s} = {}^{O}_{V}R(\alpha, \beta, \gamma) \begin{bmatrix} 0 \\ 0 \\ f \end{bmatrix} - \begin{bmatrix} 0 \\ 0 \\ g \end{bmatrix}, \qquad f = \sum_{i=1}^{4} f_i .$$

$$\begin{bmatrix} \dot{\gamma} \\ \dot{\beta} \\ \dot{\alpha} \end{bmatrix} = \begin{bmatrix} \cos\beta\cos\gamma & -\sin\gamma & 0 \\ \cos\beta\sin\gamma & \cos\gamma & 0 \\ -\sin\beta & 0 & 1 \end{bmatrix}^{-1} \omega, \qquad \omega = (\omega_x, \omega_y, \omega_z) .$$

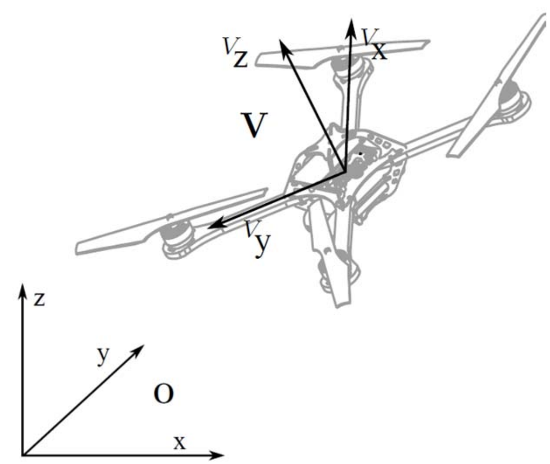
INPUTS send to vehicle



Constraints.

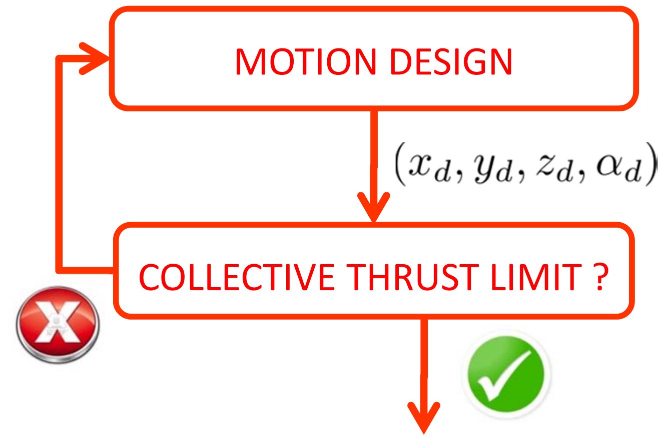
(1) Collective thrust *(input)* $f_{min} \leq f \leq f_{max}$

(2) Single motor thrust $f_{i,min} \leq f_i \leq f_{i,max}$



MOTION FEASIBILITY – check

CHECK 1: Collective thrust limits.



$$\ddot{s}_d + g = {}^{O}_{V}R(\alpha, \beta, \gamma) \begin{bmatrix} 0 \\ 0 \\ f_d \end{bmatrix} \quad \Leftrightarrow \quad f_d = \sqrt{(\ddot{x}_d)^2 + (\ddot{y}_d)^2 + (\ddot{z}_d + g)^2}$$

CHECK 2: Single motor thrust limits.

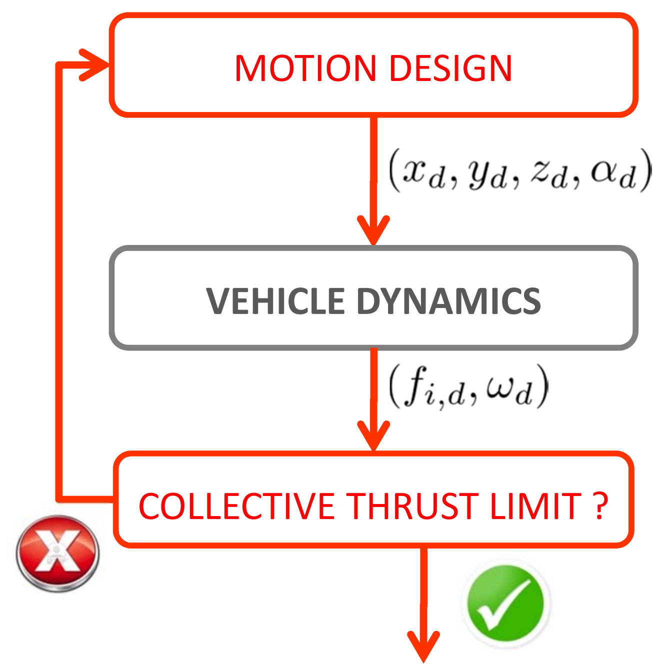
(1) Desired attitude $\rightarrow \quad (\alpha_d, \beta_d, \gamma_d), f_d$

(2) Rotational rates

$$\begin{bmatrix} \omega_{y,d} \\ -\omega_{x,d} \\ 0 \end{bmatrix} = \left({}^{O}_{V}R(\alpha_d, \beta_d, \gamma_d) \right)^T \frac{d}{dt} \left(\frac{f_d}{|f_d|} \right) \quad \rightarrow \quad \omega_d$$

(3) Single motor thrusts

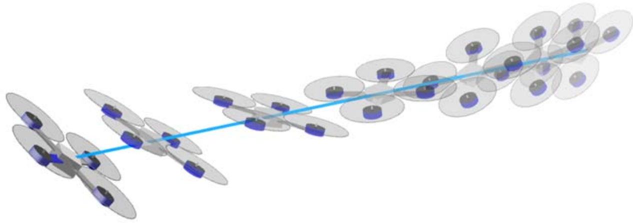
$$\begin{bmatrix} L(f_{2,d} - f_{4,d}) \\ L(f_{3,d} - f_{1,d}) \\ k(f_{1,d} - f_{2,d} + f_{3,d} - f_{4,d}) \end{bmatrix} = m \left(I\dot{\omega}_d + \omega_d \times I\omega_d \right) \quad \rightarrow \quad f_{i,d}$$



MOTION FEASIBILITY – example

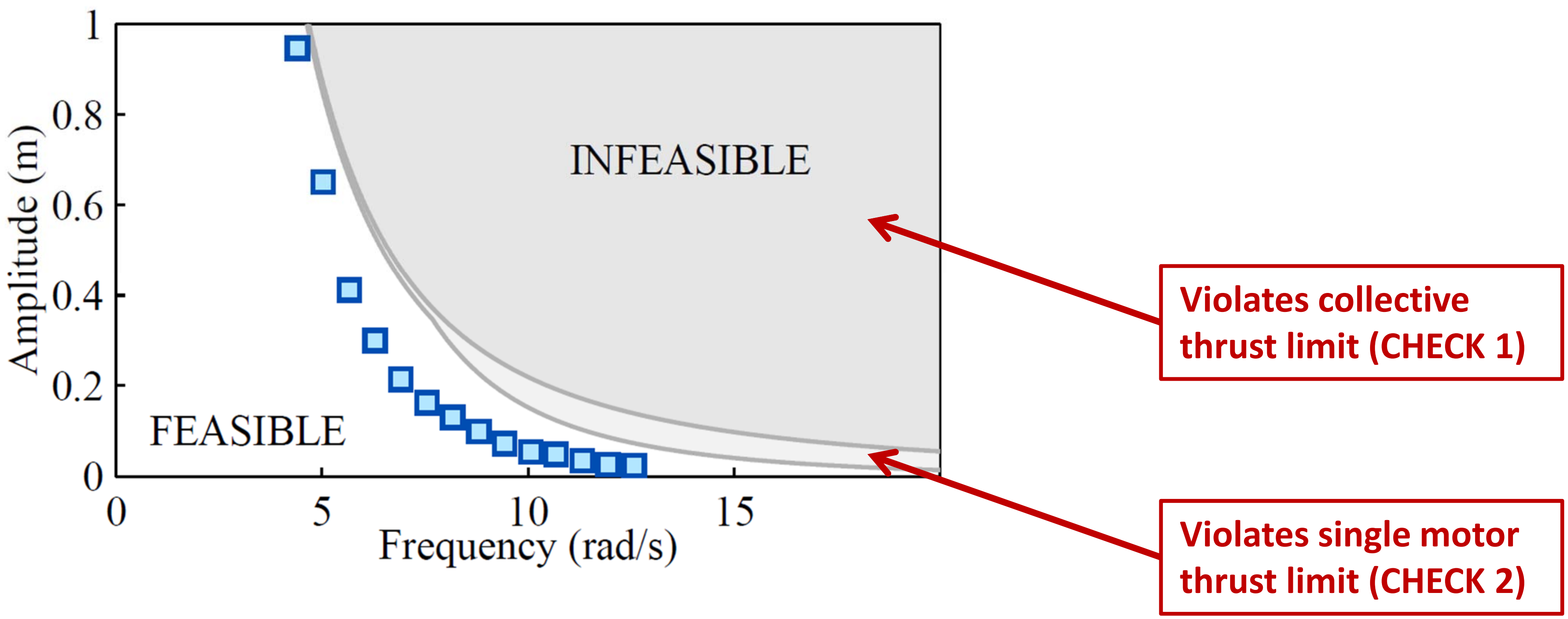
Side-to-side motion.

$$s_d(t) = \begin{bmatrix} x_d(t) \\ y_d(t) \\ z_d(t) \end{bmatrix} = \begin{bmatrix} A\cos(\Omega t) \\ 0 \\ 0 \end{bmatrix}.$$



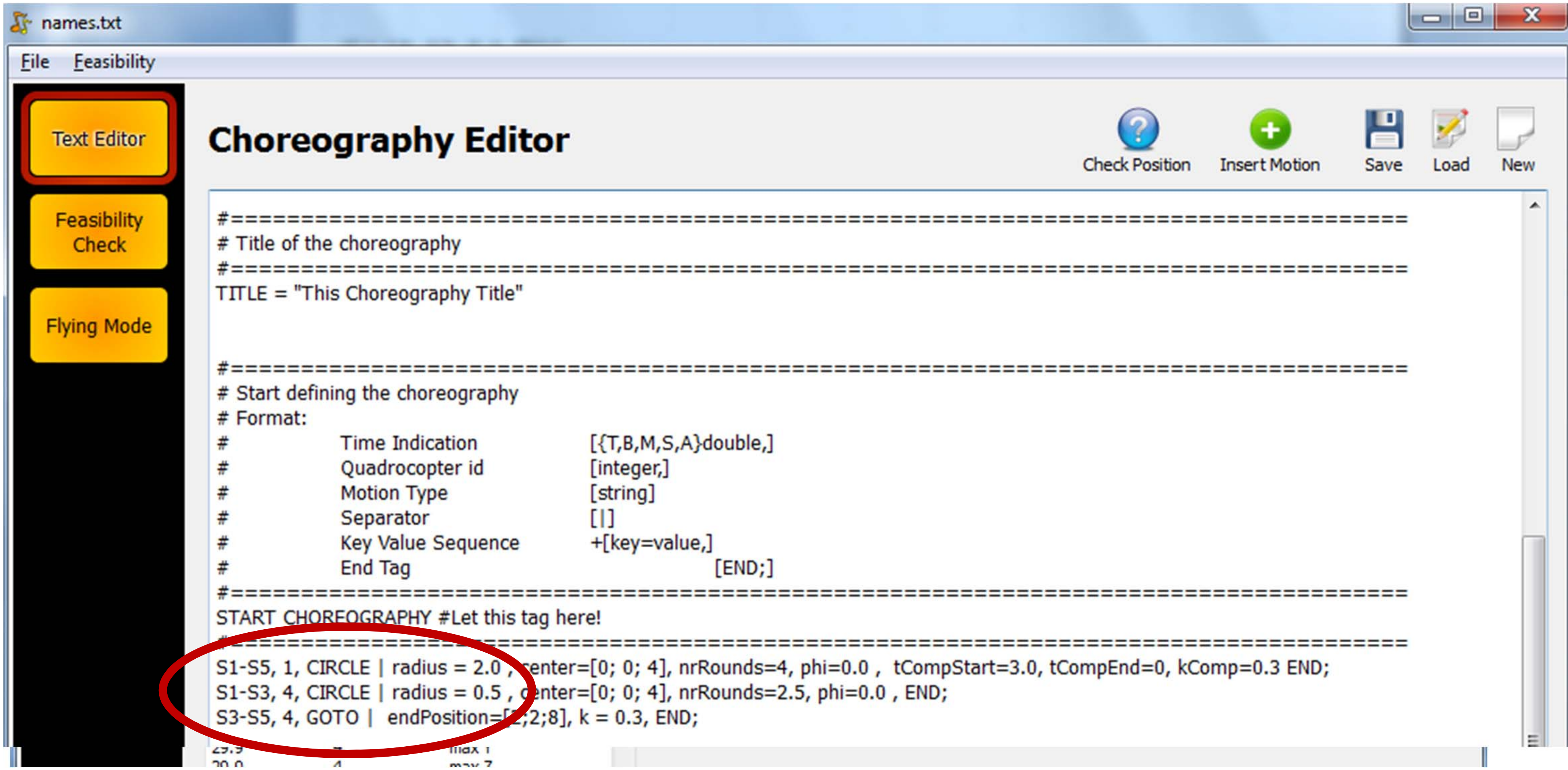
Feasibility.

EXPERIMENTAL RESULTS:
motor commands saturated 1% of the time.

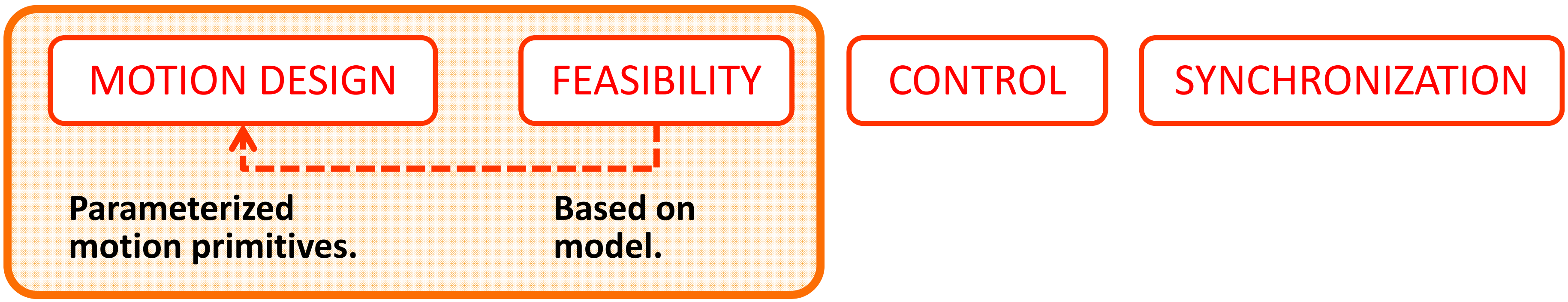


CURRENT STATUS

Work with Federico Augugliaro



SUMMARY



- choreographies based on motion primitives that are adjustable in their parameters
- check feasibility ahead of time based on first principles models

... One step towards creating choreography in a simple and intuitive way.

LET'S DANCE video https://youtu.be/7r281vgfotg?list=PLD6AAACCBFFE64AC5

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