Coordination and Synchronization for a Rhythmic Flight Performance

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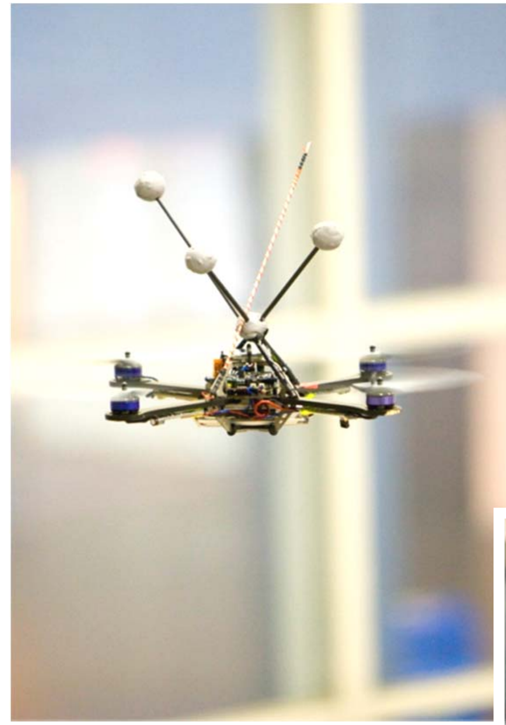
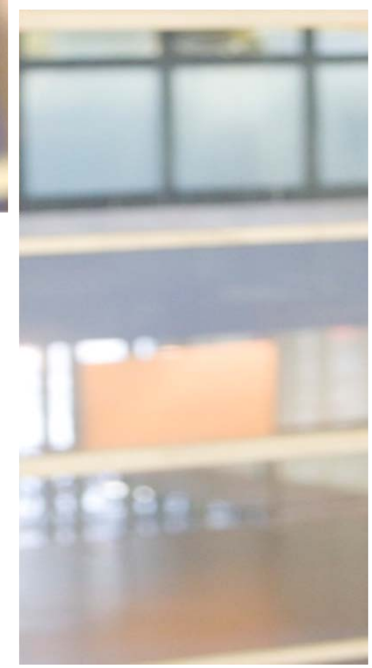
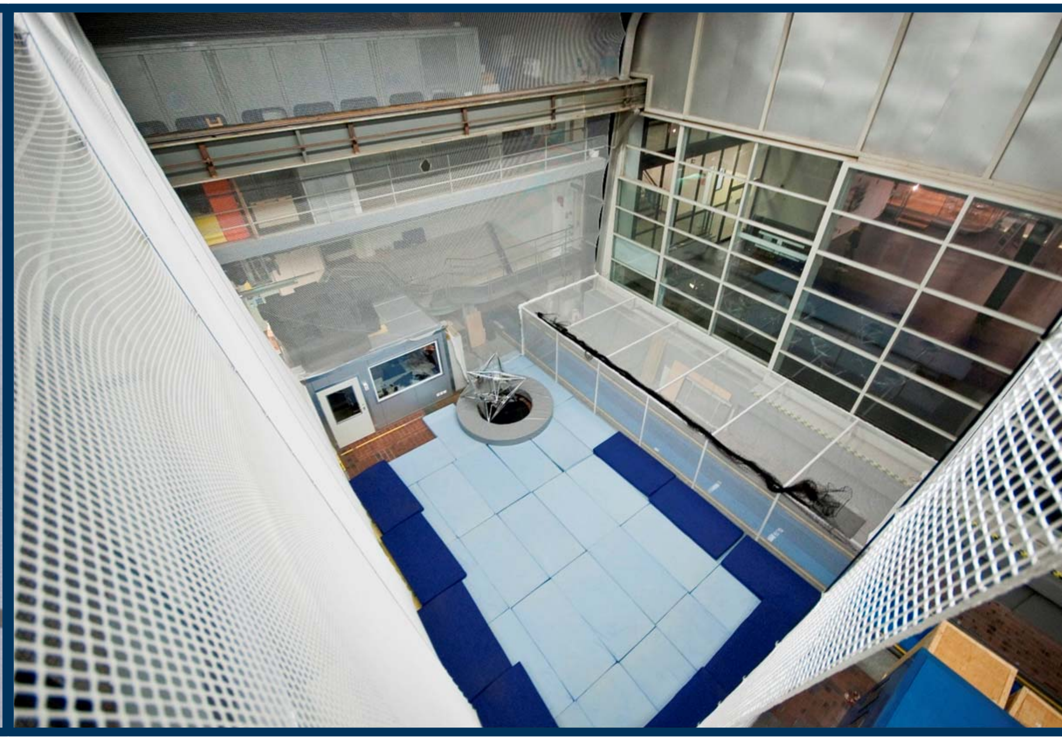
LET'S DANCE

... DANCE IN THE AIR

VISION Dance performance of multiple quadrocopters.







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**

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

OBJECTIVE & FOCUS

How do we create an ***intuitive interface*** for the design of choreographies?

←

How do we achieve a ***rhythmic* flight** performance?

... use controls and system dynamics.

MOTION DESIGN

FEASIBILITY

[Schoellig, Hehn, Lupashin and D'Andrea, ACC 2011]

PREPROGRAMMED.
DONE AHEAD OF TIME.

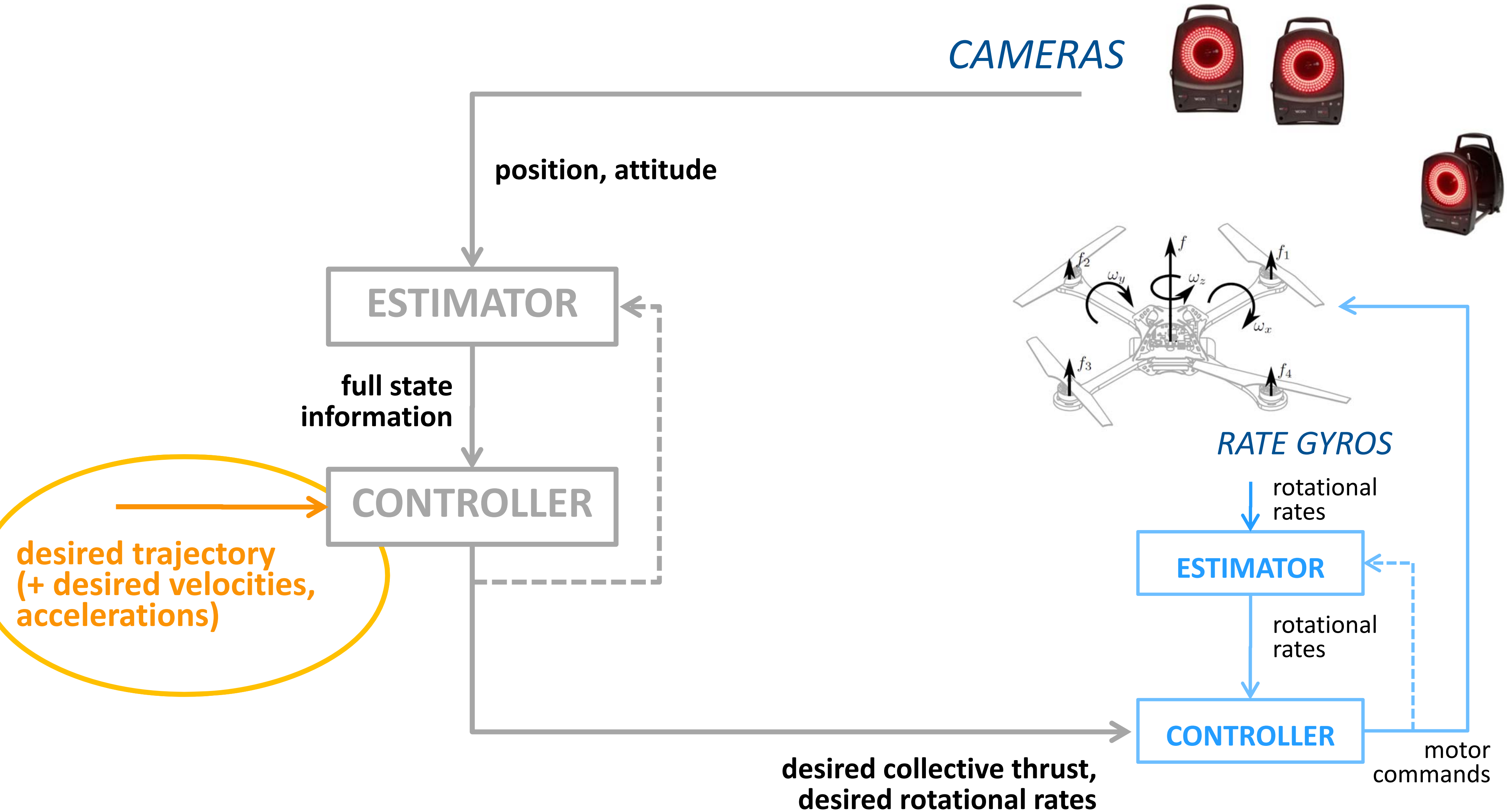
CONTROL

SYNCHRONIZATION

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

FOCUS

MOTION CONTROL



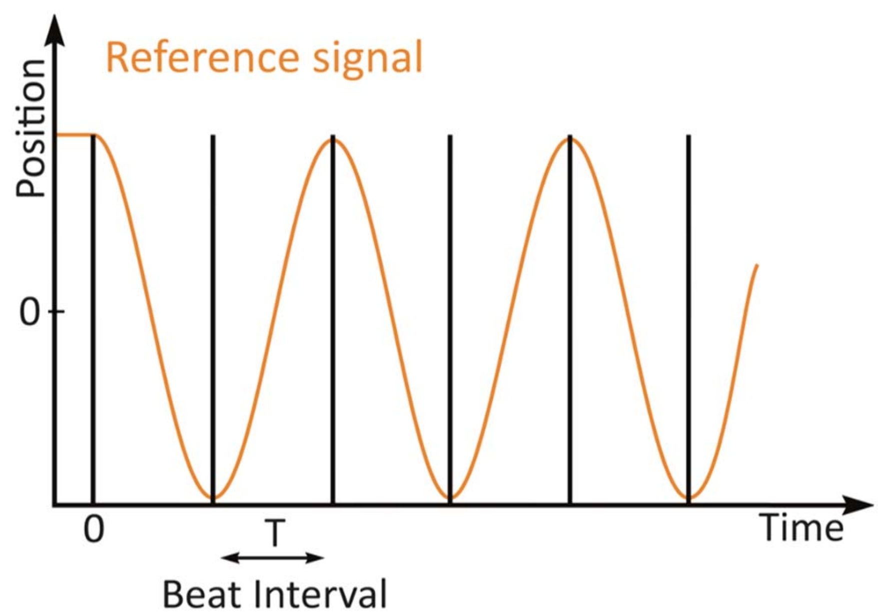
RHYTHMIC MOTION

First... Synchronize the SIDE-TO-SIDE MOTION of a quadrocopter to music.

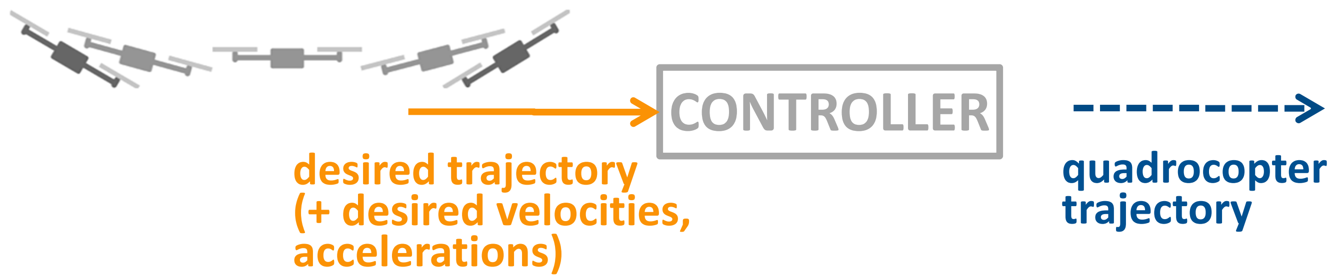
Music.

Side-to-side motion.

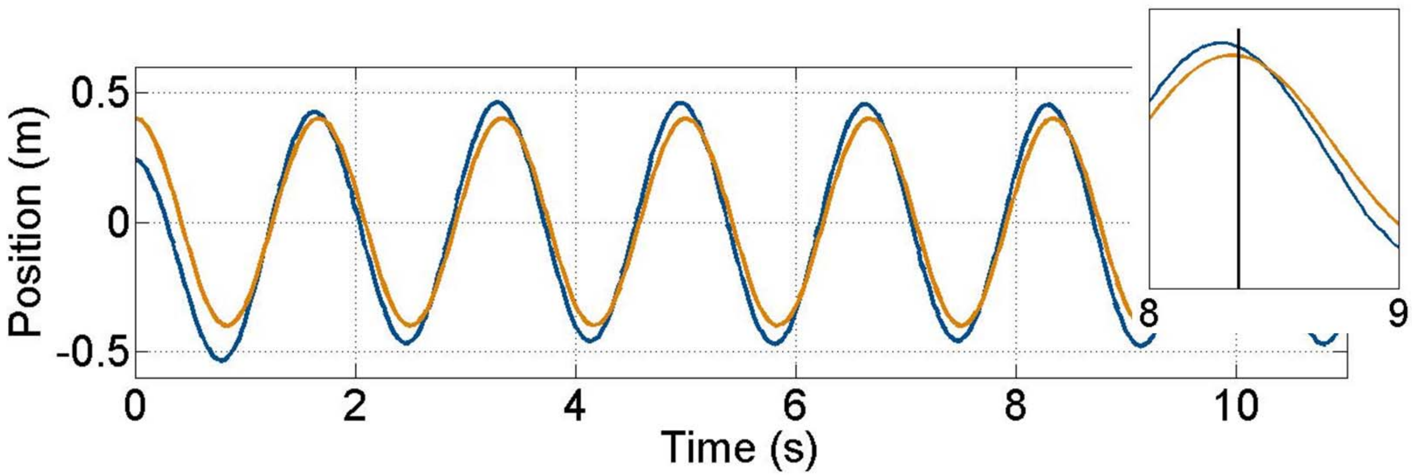
$$s_d(t) = \begin{bmatrix} x_d(t) \\ y_d(t) \\ z_d(t) \end{bmatrix} = \begin{bmatrix} A\cos(\Omega t) \\ 0 \\ 0 \end{bmatrix}.$$



PHASE ERROR



Quadrocopter response shows constant phase error after a transient phase.



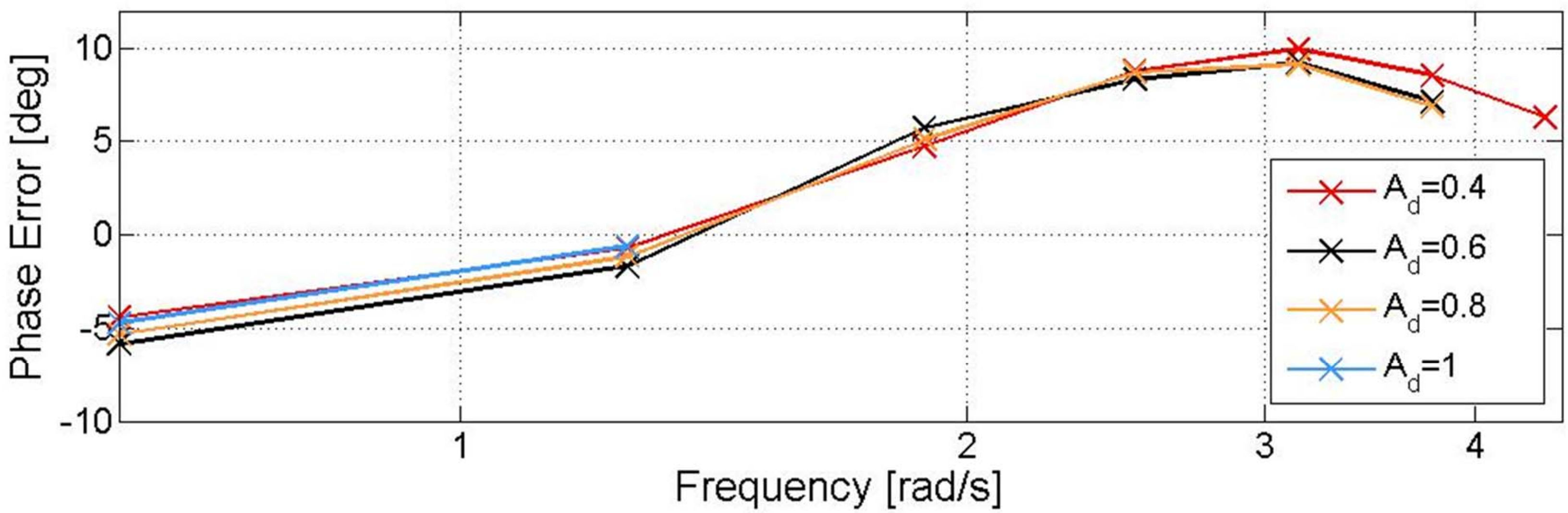
PHASE ERROR

CONTROLLER

desired trajectory
(+ desired velocities, accelerations)

quadrocopter trajectory

Quadrocopter response shows constant phase error after a transient phase.

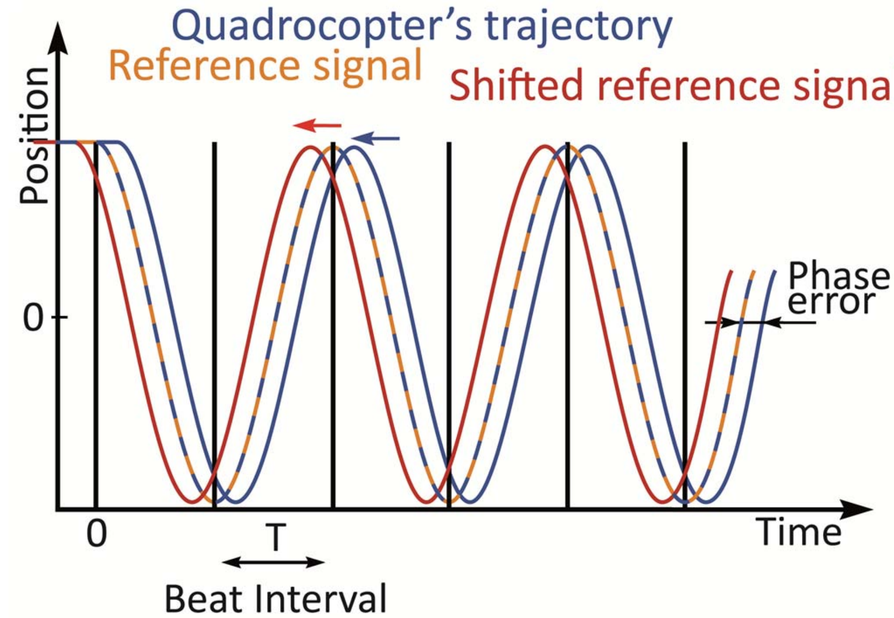


Linear system behavior. Repeatable.

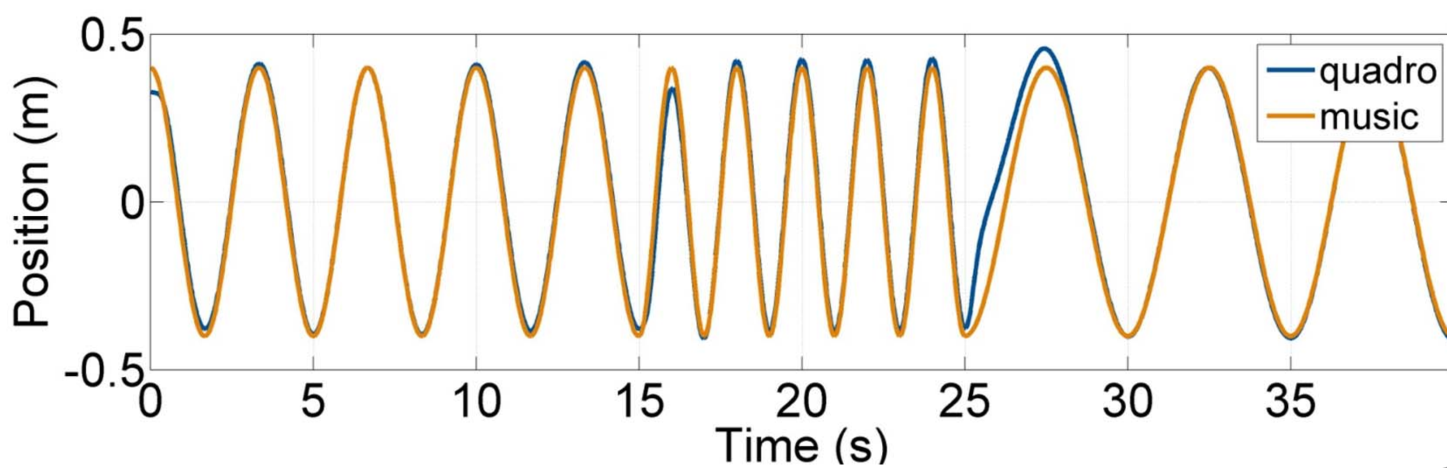
SYNCHRONIZATION

OPTION 1: Online phase detection and correction
→ transient behavior

OPTION 2: Learn phase offset ahead of time, feedforward compensation
→ less robust



COMBINE!



OBJECTIVE & FOCUS

How can we create an ***intuitive interface*** for the design of choreographies?

How can we achieve a ***rhythmic* flight** performance?

… use controls and system dynamics.

MOTION DESIGN

Parameterized motion primitives.

FEASIBILITY

Based on model.

PREPROGRAMMED.
DONE AHEAD OF TIME.

FOCUS

CONTROL

SYNCHRONIZATION

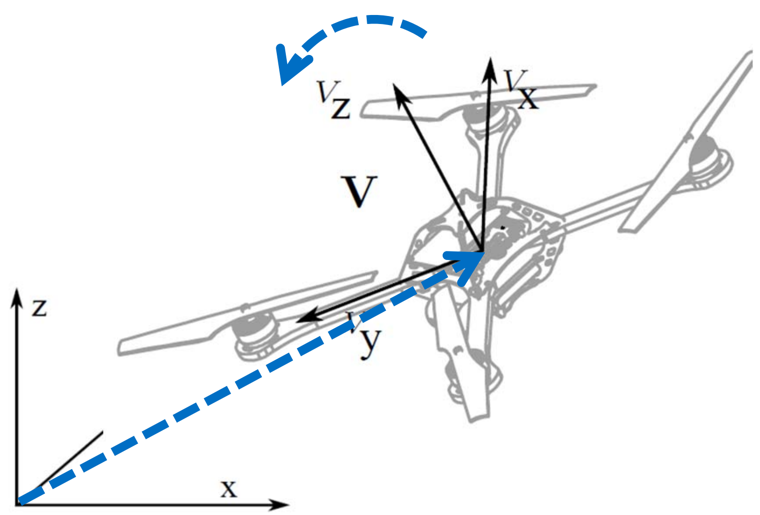
MOTION DESIGN – idea

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:

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

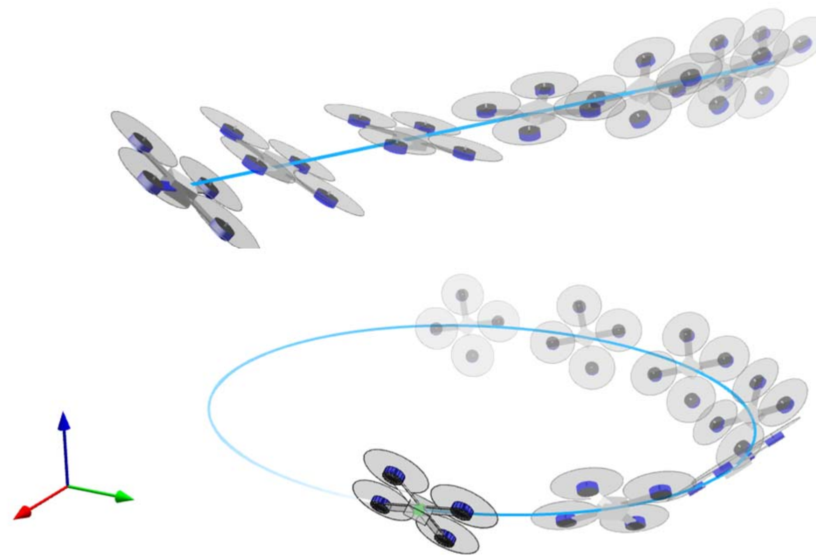
MOTION DESIGN – example

Periodic motion primitive.

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

includes

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



DESIGN PARADIGM. space – time – energy – structure

MOTION DESIGN – example

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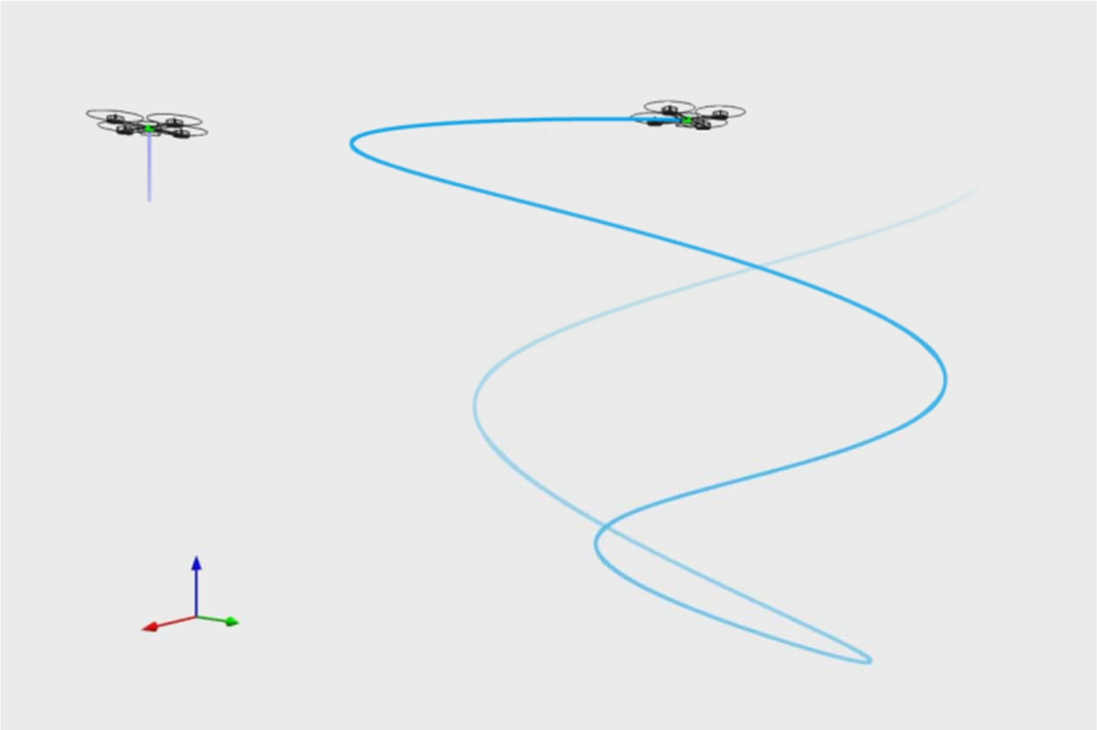
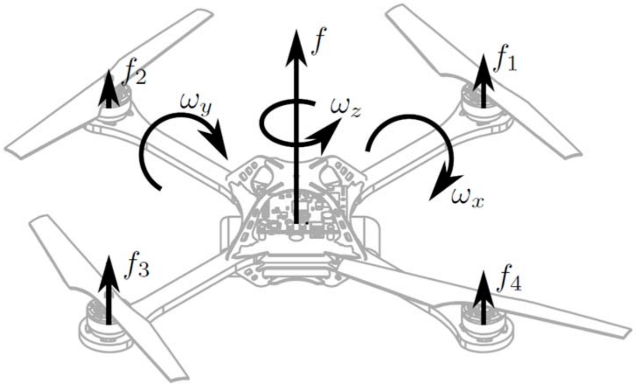


MOTION FEASIBILITY – model/constraints

First principles model.



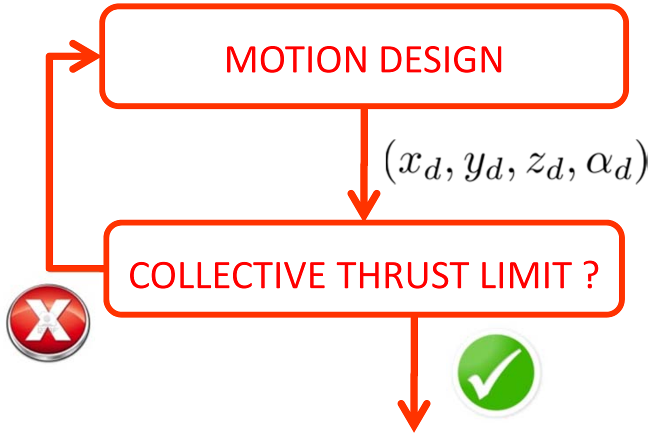
Constraints.

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

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

CHECK 1: Collective thrust limits.

$$f_d = \sqrt{(\ddot{x}_d)^2 + (\ddot{y}_d)^2 + (\ddot{z}_d + g)^2}$$



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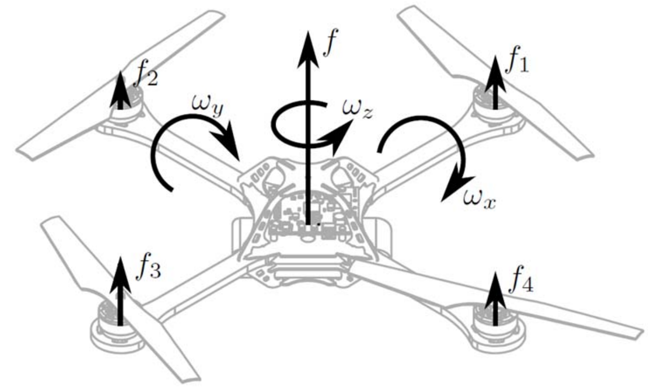

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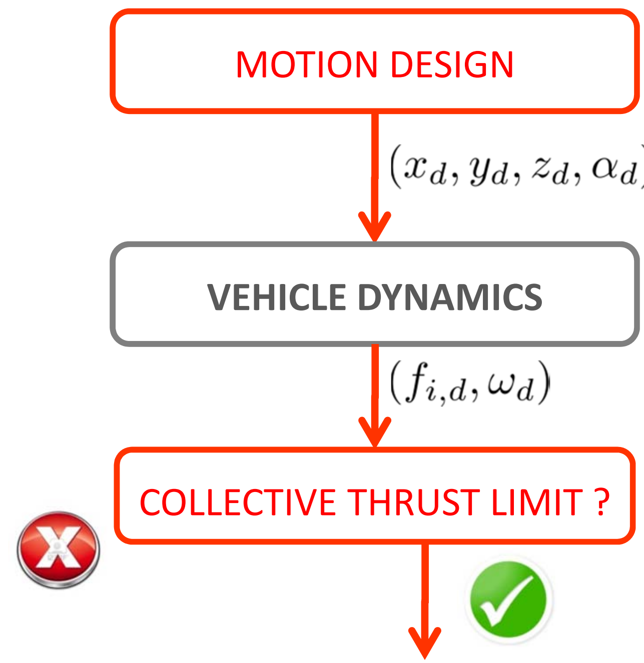

MOTION FEASIBILITY – example

Side-to-side motion.

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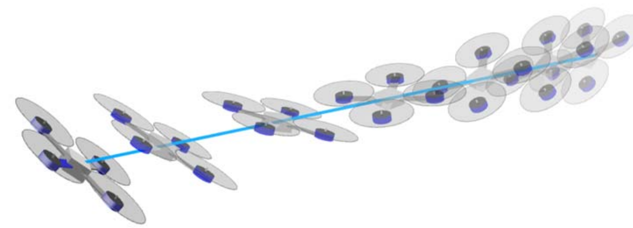
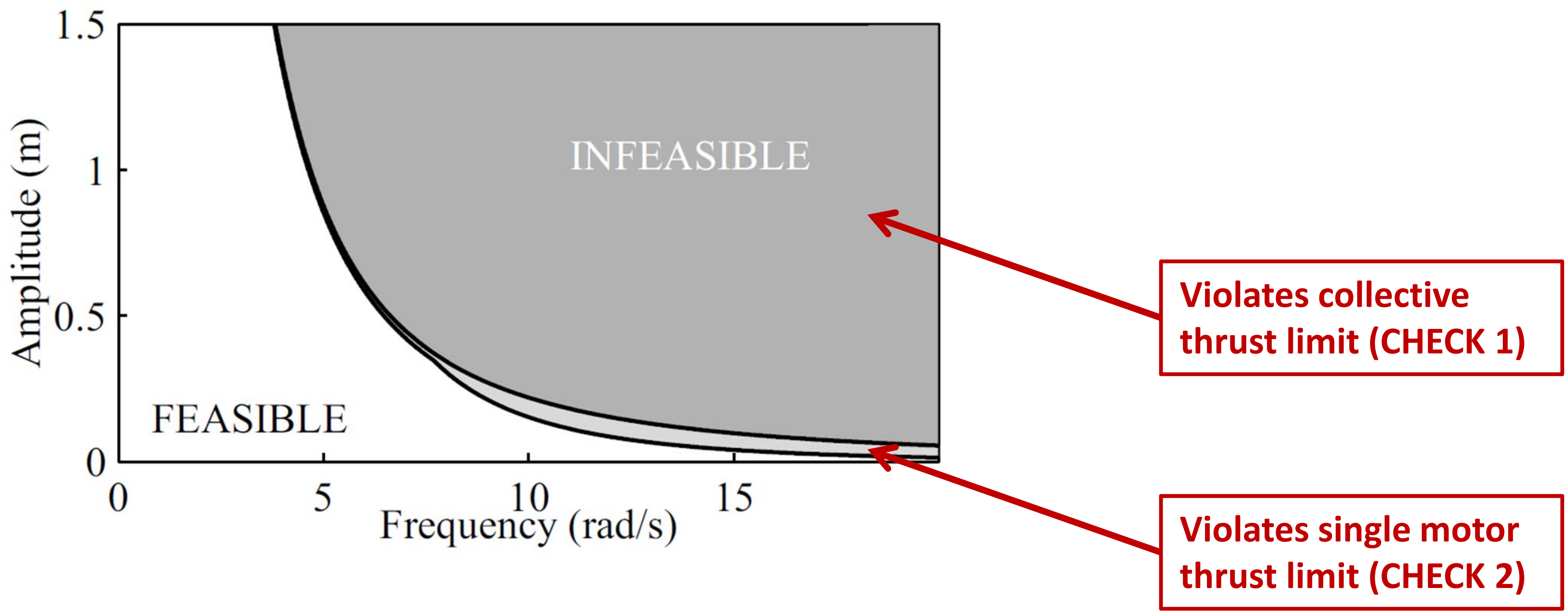


Feasibility.



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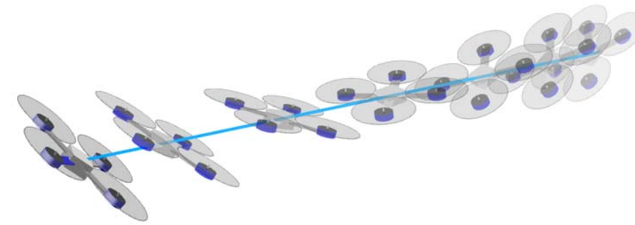
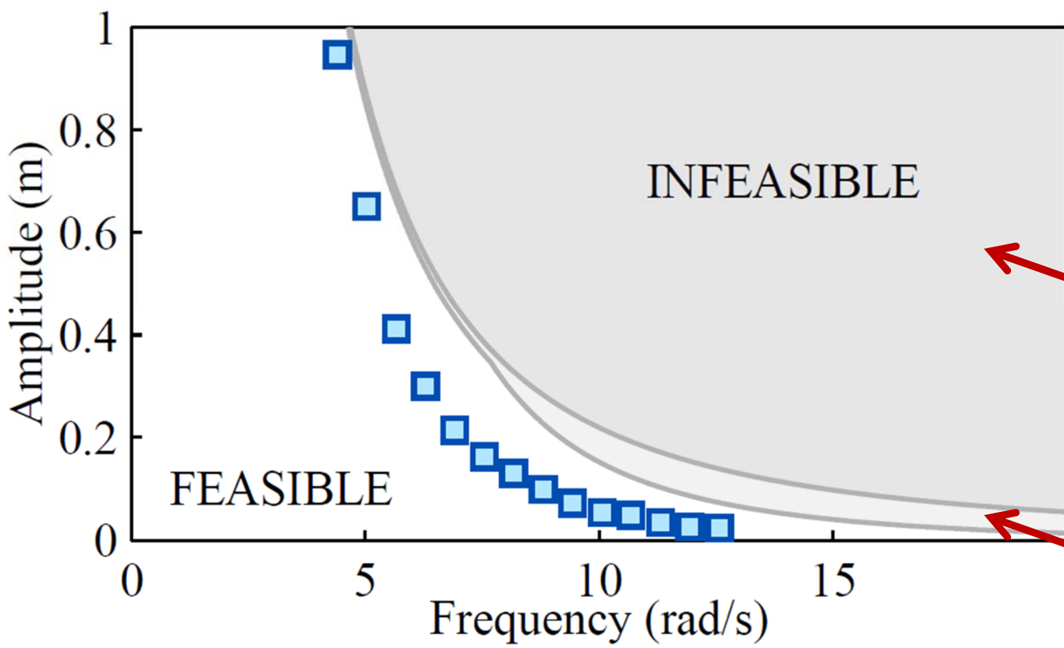


EXPERIMENTAL RESULTS:
motor commands saturated 1% of the time.



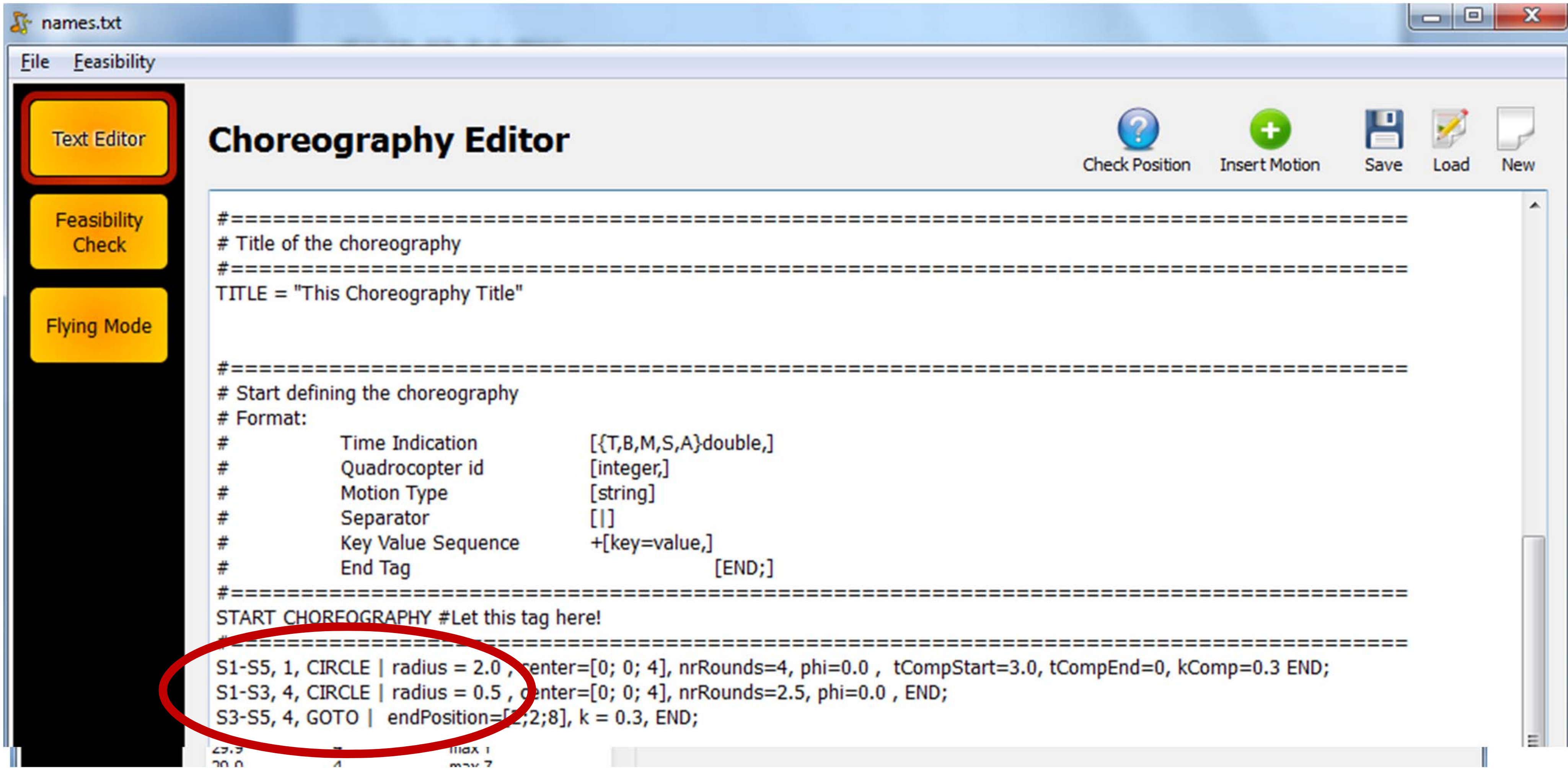
Violates collective thrust limit (CHECK 1)

Violates single motor thrust limit (CHECK 2)

CURRENT STATUS

Motion design.

Work with Federico Augugliaro



CURRENT STATUS

Feasibility.

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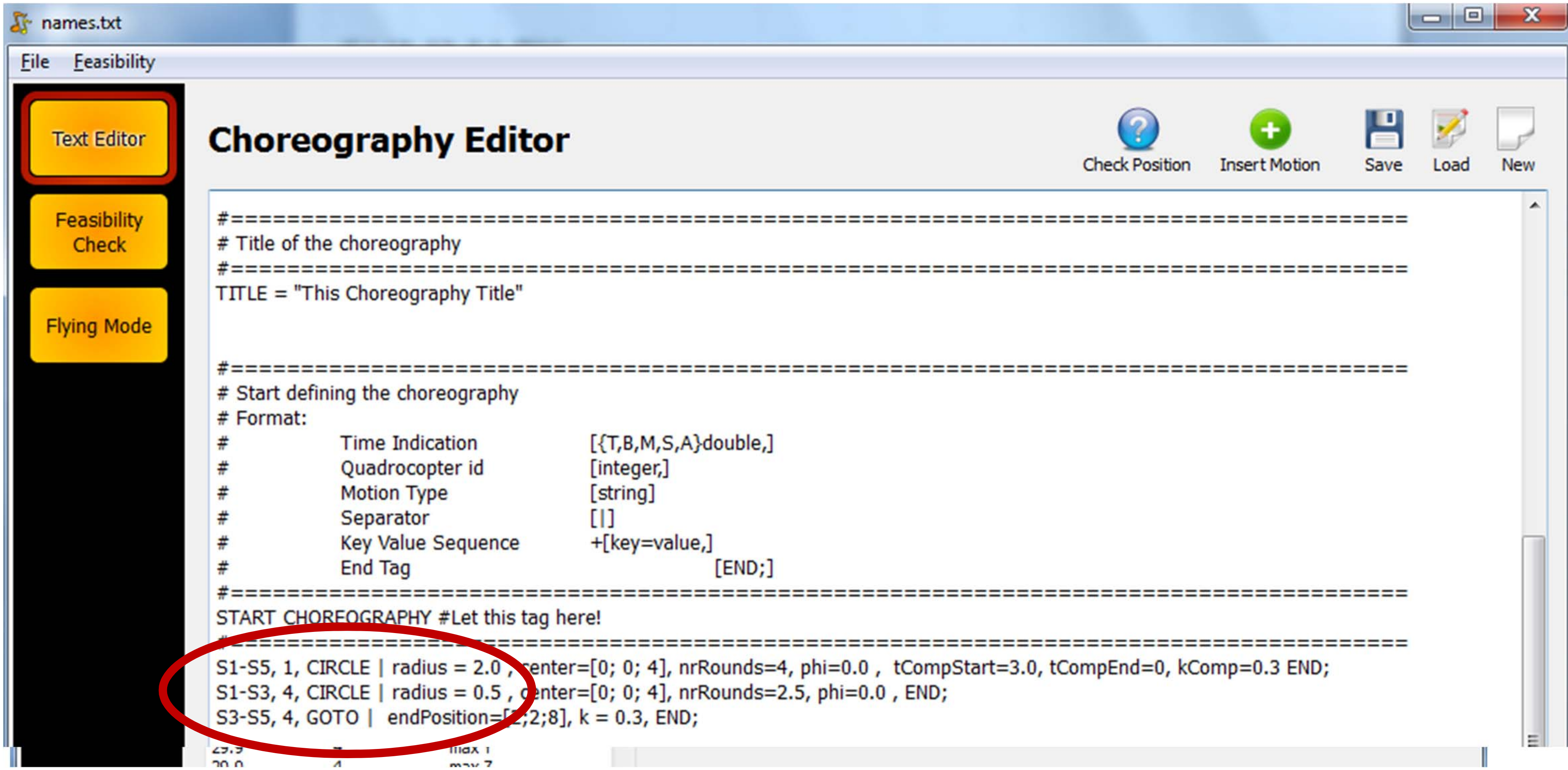
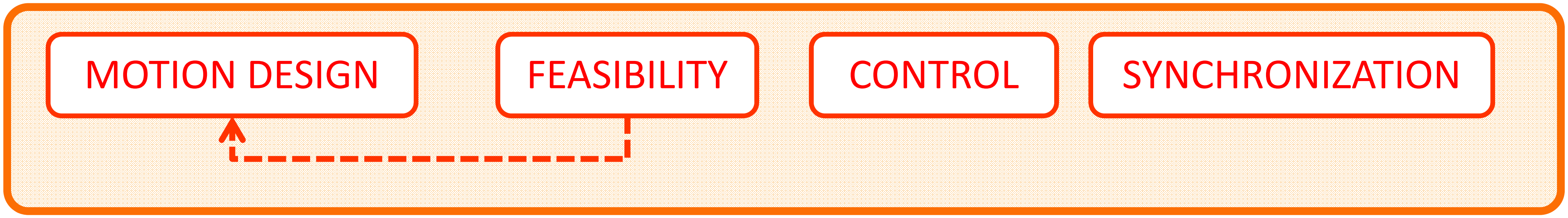


SUMMARY



- choreographies based on motion primitives that are adjustable in their parameters
- feasibility check prior to flight based on first principles models
- synchronization to the music while flying

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

LET‘S DANCE http://youtu.be/7r281vgfotg?list=PLD6AAACCBFFE64AC5

Videos:

www.tinyurl.com/dance2gether

www.tinyurl.com/tripleDance

More:

www.FlyingMachineArena.org