Synchronizing the Motion of a Quadrocopter to Music

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THE FLYING MACHINE ARENA

Angela Schöllig - ETH Zürich
OUR VEHICLES
DANCING QUADROCOPTERS

We envision... A dance performance of multiple vehicles in the Flying Machine Arena

First, ....

Desired Side-To-Side Motion

GOAL Synchronize the SIDE-TO-SIDE MOTION of a quadrocopter to music
MUSIC REFERENCE

PRE-PROCESS MUSIC

DEFINE REFERENCE SIGNAL

\[ x_d(t) = A_d \cos(\omega_d t) \]
\[ z_d(t) = z_d = \text{constant} \]

FOCUS Timing between music reference and quadrocopter motion

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VIDEO: https://youtu.be/Kx4DtXv_bPo?list=PLD6AAACCBFFE64AC5

Dancing Quadrocopters
IDSC, ETH Zurich

Synchronizing Motion and Music Beat
THREE STEPS

• Stabilize the vehicle and impose oscillating motion
• Compare the phase
• Correct for phase errors
CONTROL APPROACH: Oscillating System

MODEL
\[
\begin{align*}
\ddot{z}(t) &= f(t) \cos \theta(t) - g \\
\ddot{x}(t) &= f(t) \sin \theta(t) \\
\dot{\theta}(t) &= u(t)
\end{align*}
\]

HEIGHT STABILIZATION
\[
f(t) = \frac{1}{\cos \theta(t)} \left( g - 2\delta_x \omega_z \dot{z}(t) - \omega_z^2 (z(t) - z_d) \right)
\]

TRAJECTORY TRACKING
\[
u(t) = \frac{1}{g} \left( \bar{u}_1(t) + \bar{u}_2(t) \right)
\]

with
\[
\begin{align*}
\bar{u}_1(t) &= \ddot{x}_d(t) = A_d \omega_d^3 \sin(\omega_d t) \\
\bar{u}_2(t) &= \alpha (\ddot{x}_d(t) - \ddot{x}(t)) + \beta (\dot{x}_d(t) - \dot{x}(t)) \\
&\quad + \gamma (x_d(t) - x(t))
\end{align*}
\]

\[
\begin{align*}
\dddot{x}(t) &= g \tan \theta(t) \\
\dddot{x}(t) &= g \dot{\theta}(t) = g u(t)
\end{align*}
\]
OBSERVATION

EXPERIMENTS

LINEAR SYSTEM BEHAVIOR
Constant phase error resulting from unmodelled dynamics. Deterministic.

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CONTROL APPROACH: Phase Correction

OUTPUT

\[ x(t) = A \cos(\omega_d t + \varphi_t) \]

PHASE DETECTION

\[ q_{\cos}(t) = x(t)r_{\cos}(t) \]
\[ q_{\sin}(t) = x(t)r_{\sin}(t) \]

\[ \eta_1(t) = \frac{1}{T_d} \int_{t-T_d}^{t} q_{\cos}(t) \, dt = \frac{A}{2} \cos \varphi_t \]
\[ \eta_2(t) = \frac{1}{T_d} \int_{t-T_d}^{t} q_{\sin}(t) \, dt = -\frac{A}{2} \sin \varphi_t \]

\[ \varphi_t = -\arctan \left( \frac{\eta_2(t)}{\eta_1(t)} \right) \]

PHASE CORRECTION

\[ x_d^s(t) = A_d \cos(\omega_d t + e(t)) \]

with

\[ e(t) = -k \int_0^t \varphi_t \, dt \]

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CONTROL APPROACH: Results

No Phase Correction

With Phase Correction

Phase Error
Additional FEEDFORWARD term allows for dynamic changes in dancing motions.
VIDEO: https://youtu.be/NPvGxIBt3Hs?list=PLD6AAACCBFFE64AC5

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Pirates of the Caribbean

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