Motion camouflage with sensorimotor delay

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Abstract
In recent work, a particular high-gain feedback law was shown to drive a pursuer-evader system arbitrarily close to a state of motion camouflage in finite time. However, data collected from bat-insect encounters, in which a strategy akin to motion camouflage is used by the bat to pursue the insect, reveal that a modest feedback gain is used, and significant sensorimotor delay is present. We derive bounds on the performance of the feedback law in achieving motion camouflage. Besides helping us to better understand pursuit in nature, such pursuit laws have applications in missile guidance and unmanned vehicle control.

Background

Curves and Moving Frames

Frame equations:
\[ r = x(T) \parallel x(T) \parallel e(T) \]
\[ y = y(T) \parallel y(T) \parallel e(T) \]
\[ T = \frac{dx}{dt} \]
\[ e = \frac{d}{dt} \]

Pursuer trajectory: \( x = x_0 \parallel x_0 \parallel e_0 \)
Evader trajectory: \( y = y_0 \parallel y_0 \parallel e_0 \)

The Constant Absolute Target Direction (CATD) Strategy used by the bat is given by:
\[ \Gamma = \frac{y_0 - x_0}{\|y_0 - x_0\|} \]

Delay-Free Planar Pursuit Model

Auditory Neuroethology Lab: www.bsos.umd.edu/psyc/batlab

Free-flying Bat-Insect Engagements

Background

Motion camouflage with sensorimotor delay is a time-dependent scalar.

Equivalent infinitesimal condition:
\[ \Gamma(t) = \frac{y(t) - x(t)}{\|y(t) - x(t)\|} \]

Transverse component of relative velocity:
\[ e(t) = e_0 \]

Distance function:
\[ \Gamma = \frac{y(t) - x(t)}{\|y(t) - x(t)\|} \]

Pursuer control law:
\[ u_p = -\mu \Gamma \]

Definition: motion camouflage is achievable in finite time if for any \( \epsilon > 0 \) there exists a time \( t_{stop} \) such that \( \Gamma(t_{stop}) \leq \epsilon \).

Pursuit Model with Delay

Motion camouflage condition:
\[ \epsilon \leq \frac{1}{2\Gamma} \mu \leq \frac{1}{2\epsilon} \]

Planar simulation of motion camouflage pursuit law

Notation:
\[ \mu \]

Remark: this condition is non-vacuous (P.V. Reddy, M.S. Thesis, University of Maryland, 2007.)

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Analysis
Summary of analytic techniques:
• \( \epsilon > 0, \mu(\|x\|) > 0, \) and \( \epsilon_{min} = \min\{\epsilon\} \) are given; choose \( 0 < \epsilon < \mu(\|x\|) \).
• Differentiate the distance function \( \Gamma(t) \) along trajectories of the pursuer-evader system.
• Derive bounds on \( \epsilon \) in the expression for \( \Gamma(t) \) to obtain conditions under which \( \epsilon(t) \leq \mu \Gamma(t) \leq \epsilon_{min} \) for some \( 0 < \epsilon < \mu \).

Further calculation needed to derive bounds on \( \mu \) from bound on \( \epsilon \).

Evader trajectory:
\[ y = \frac{1}{2\|y(t) - x(t)\|} \mu \left( \frac{y(t) - x(t)}{\|y(t) - x(t)\|} \right) \]

Given \( 0 < \epsilon < \epsilon_{min} \) and \( \Gamma(t) \leq \epsilon_{min} \),
\[ \Gamma(t) < \Gamma_{stop} \leq \frac{\epsilon_{min}}{\epsilon} \]

Acknowledgements

Pursuit with mate, rival, or prey is a basic behavior at all scales.

Stealth: pursuit moves so as to avoid detection by a target.

Eptesicus fuscus: the big brown bat.

Figure 1. Synopsis of a skater disk: a disc with a mount for an individual as a point. The disc rotates during the entire time interval. A run experiment involves counting a sensorimotor delay as a point or vehicle’s (a) behavior; (b) in the presence of a (b) system. Figure from Srinivasan and Davey, Proc. R. Soc. B 259(1354):19-25, 1995.

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• Support for the motion camouflage hypothesis in dragonfly data. (Mjdefault, Chal and Srinivasan, Nature 423:664, 2005.)

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• Motion Camouflage

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