Modeling and Simulation of Pursuit Control Laws in Bat Prey Capture
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Introduction

- Pursuit is a subject of interest in various contexts. What are different pursuit strategies?
- What control law enables bats to successfully capture prey?
- What in the course of evolution caused bats to behave in the way they do now?

Planar Model Set-up

Three Pursuit Manifolds and Controls

<table>
<thead>
<tr>
<th>Strategy</th>
<th>Cost Function</th>
<th>Control Laws</th>
</tr>
</thead>
<tbody>
<tr>
<td>Classical pursuit</td>
<td>( \Lambda = \frac{1}{2} \dot{r}_p \cdot r_p )</td>
<td>( u_{pcp} = -\mu (\dot{y}_p \cdot y_p - \left| \frac{y_p}{|y_p|} \right| \cdot \frac{y_p}{|y_p|}) )</td>
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<tr>
<td>CATD (^1)</td>
<td>( \Gamma = \frac{2}{|x_p|} r = \frac{x}{|x|} )</td>
<td>( u_{pcatd} = -\mu (\frac{r_p}{|r_p|} \cdot \frac{r_p}{|r_p|}) )</td>
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<tr>
<td>Constant Bearing</td>
<td>( \Phi = r_p \cdot R(\theta) x_p )</td>
<td>( u_{pcvb} = -\mu (y_p \cdot (\frac{R(\theta) x_p}{|R(\theta) x_p|}) - \frac{1}{|r_p|} \cdot \frac{r_p}{|r_p|}) )</td>
</tr>
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Three pursuit manifolds are defined using cost functions, from which control laws are derived.

Classical pursuit: Pursuer's velocity is pointing directly toward the evader.
CATD (Constant Absolute Target Direction): Pursuer keeps the absolute target direction constant, i.e. baselines are parallel.
Constant Bearing: Pursuer keeps the bearing angle (angle between base line and pursuer velocity vector) constant.

Subscript \( p \) for pursuer
Subscript \( e \) for evader
\( r \) is position vector
\( x \) is unit vector normal to \( x \)
\( y \) is unit vector normal to \( y \)
\( h \) is unit vector indicating head direction
\( g \) is unit vector normal to \( h \)

Evolutionary Game \(^2\)

- Population was broken into three subpopulation groups, which use CP, CATD, CB respectively.
- The three subgroups are given as three proportions, \( p_i \), with
  \[ \sum_{i=1}^{3} p_i = 1 \quad 0 \leq p_i \leq 1, \forall i \]
- The population distribution is evolved as
  \[ p_i' = \frac{p_i W_i}{W} \quad \text{where} \quad W = \sum W_i \]
  \( p_i' \) represents the proportion of successive generation to \( p_i \) and \( W_i \) is payoff for that population
- For simulation 1, 3, 5, the payoffs are defined as (1), for simulation 2, 4, 6 the payoffs are defined as (2)
  \[ W_i = \frac{1}{n} \sum_{k=1}^{n} \frac{1}{\sum_{i=1}^{3} \tau_i} \quad (1) \]  
  \[ W_i = \frac{1}{\sum_{i=1}^{3} \tau_i} \quad (2) \]

Conclusion

- The simulated evolutionary game shows that CATD under various circumstances yields a better payoff when measured by time. This can help explain why bats today use CATD pursuit strategy in prey capture.
- Derived control laws can also be used to analyze head motion of the bat head.