Locomotion Skills for Insects with Sample-based Controller

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Short Introduction

• Research Areas:
  – Character Animation
  – Geometry Processing

• Ph. D. at National Centre for Computer Animation, Bournemouth University, UK (2015. 9)

• B. S. at Peking University (2010. 7)

• China
Outline

• State-of-the-art
• Biological Backgrounds
• Breakdown of my framework
• Future Work
State-of-the-art

- Example-based
  - ✔ Natural-looking
  - ✗ Difficult to edit
  - ✗ Specialized system

State-of-the-art

- Simulation-based
  - ✔ Accurate control
  - ✗ Most methods are more *kinematic* than physics. Cheat?

Biological Inspirations
Biological Inspirations

Experimental results from zoologist Dr. Zollikofer, who conducted a series experiments to reveal the effects of morphology, load, speed and curvature on ants’ gait.

- **Shape** of supporting triangles does **NOT** change at different speeds and curve paths.
- **Shape of supporting triangle changes** in the cases of carrying objects or travelling on uneven terrain.
Biological Inspirations

- Distributed System: brain and body ganglia
- Motion on each joint is controlled by independent ganglion
Research Question

Can we develop an equivalent framework, based on the biological inspirations, with following features:

– Produce natural & physically-plausible movement
– Be artist-friendly
– Fast and Efficient
Fixed Gait Pattern

Distributed Nervous System
Triangle Placement Engine

Animator is able to specify a trajectory and other settings, the supporting triangles are automatically placed on the terrain.
Capture in the lab

Videos are provided by collaborators from University of Cambridge and University of Freiburg.
Triangle Placement Engine

(a) Walking on a straight path

(b) Walking on a curve path
When the ant encounters some perturbations, the supporting triangle is enlarged to improve the stability.
CPG Controller

Triangle Profile

CPG

SwingNet
2

Hopf Bifurcation

Swing Leg
Stance Leg

Fullbody Animation
The controller is modelled as a **network** of neural oscillators, and each joint is controlled by a **neural oscillator** (Ordinary Differential Equation).
CPG Controller

\[
\begin{pmatrix}
\dot{q} \\
\ddot{q}
\end{pmatrix} = 
\begin{bmatrix}
-\lambda \left( \frac{q^2 + \dot{q}^2}{\rho^2} - \sigma \right) & -\omega(t) \\
\omega(t) & -\lambda \left( \frac{q^2 + \dot{q}^2}{\rho^2} - \sigma \right)
\end{bmatrix}
\begin{pmatrix}
q \\
\dot{q}
\end{pmatrix}
\]

- \(\rho\) - amplitude
- \(\Phi\) - phase difference
- \(\omega\) - frequency
- \(\bar{q}\) - average offset

These parameters are controlled to perform the specific behavior and will be optimized in later part – Controller Look-up Table.
Hopf Bifurcation

- Bifurcation Parameter = -1
- Attraction Point
- Discrete Motion/Static Pose

Diagram showing a vector field representation of the system dynamics with an attraction point indicated.
Controller Look-up Table

Triangle Profiles $\rightarrow$ CLUT $\rightarrow$ CPG Parameters

CLUT is pre-computed offline and enquired during runtime, with the target velocity as input.
Optimization Objective Functions

- Minimize the differences between the target and simulated velocity in this stride

\[ E_t = \sum_i (\nu_{\text{target}} - \nu_{\text{simulation}})^2 \]

- Constrain the movements on the lateral and vertical directions

\[ E_d = \sum_i (||y_i - y^*||^2 + ||z_i - z^*||^2) \]

- Ensure the continuity of velocity direction

\[ E_v = \sum_i ||v_i||^2, \text{ if } v_i \cdot v_{\text{target}} < 0 \]
Result & Demo

Load Carrying
Future Directions

• Sophisticated Model
  – Control: Spiking Neurons
  – Actuator: Muscles

• Social Behavior (Collective Transport)

• Interaction with Nature through *Evolution*
Thank you for Listening!
Questions?

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