Research Report of Snake-like Robot

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Research Background

Atlas

BigDog Architecture

- Gyro/IMU
- Hip
- Knee
- Ankle
- Foot
- Heat Exchanger
- Engine/Pump
- Computer
- Actuators
- Leg Spring
- Force Sensor

Big Dog

Uncle Sam
Potential Application

- Rescue and Fire-fighting
- Pipeline Maintenance
- Underwater Manipulation
- Surveillance
Potential Application

- Snake robots for urban search and rescue operations:
  - Approaching (I): Locomotion
  - Approaching (II): Climbing
  - Clearing the path: Grasping
  - Reaching the person: Locomotion

- Capabilities: Locomotion, Climbing, Visioning and Grasping
Anatomy of Snakes

The skin of a snake is completely covered by scales.
Locomotion of Snakes

Snake locomotion is stable, robust, and versatile.

- **Lateral undulation**

- **Concertina locomotion**

- **Rectilinear locomotion**

- **Sidewinding locomotion**
Previous Work on Implementation of Physical Snake Robots

With a snake-like robot he launched his career as a scientist.
He created a soft, flexible robot to benefit society.

Interview with Professor Shigeo Hirose
Mechanical and Aerospace Engineering
Graduate School of Science and Engineering

1972

2001

2005

2010

ACM-III

ACM-R3

ACM-R5

ACM-R7

广濑茂男—东京工业大学教授
是世界上蛇形机器人开展最早、研究水平最高的学者
Previous Work on Implementation of Physical Snake Robots

Howie Choest—Prof. Carnegie Mellon University

One of the top 100 innovators in the world under the age of 35

Multi-version

Uncle Sam

SEA - Serial elastic actuation

Module Hexapod Robot
Previous Work on Implementation of Physical Snake Robots

Salamander EPFL

CPG-based Control

Environment Force Sensing

Kulko NYNU

Skin drive propulsion system

CMU Snake
Previous Work on Control of Snake Robots

- Control System Analysis of Snake-like Robot
  - Control Based on Morphology

\[ \kappa(s) = -\frac{2\pi\alpha}{L} \cos\left(\frac{2\pi}{L}s\right) \]

Serpenoid Curve
Previous Work on Control of Snake Robots

- Control System Analysis of Snake-like Robot
  - Control Based on Kinematics and Dynamics

Robot Kinematics in 3D Space

Robot Dynamics with Friction

Diagram of control system:
- LOS guidance
- Heading controller
- Gait pattern generator
- Joint controller
- Snake robot
Previous Work on Control of Snake Robots

- Control System Analysis of Snake-like Robot
  - Control Based on Central Pattern Generator

CPG output with changing parameters

Sketch of a chain-type CPG network
Future Research Challenges of Snake Robot Locomotion

- **Control Design Challenges**
  - Analyzable Mathematical Models
    - Complex dynamic models due to many degrees of freedom
  - Contact forces from a cluttered environments
  - Simplified interaction mathematical descriptions
Future Research Challenges of Snake Robot Locomotion

- Control Design Challenges
  - Feedback Control Laws based on Environment Sensing

Multi-layer Control Architecture based on Sensing
Future Research Challenges of Snake Robot Locomotion

- Control Design Challenges
  - SLAM (simultaneous localization and mapping)

Original Scene

Raw Point Cloud

Filtered Point Cloud

Floor Removal
Future Research Challenges of Snake Robot Locomotion

- Hardware Design Challenges
  - Environment Sensing

*Left:* FSR (force sensing resistor) used to measure contact forces.

*Right:* FSRs covered by *cotton pads* mounted to a joint module

The voltage divider circuit used to measure the resistance through the FSR
Future Research Challenges of Snake Robot Locomotion

- Hardware Design Challenges
  - Solutions for Untethered Operations

Power Consumption

- Motor
- MCU
- Sensor
- Communication

External power cable

Power circuit
Motor
Gearbox
Battery
Future Research Challenges of Snake Robot Locomotion

- Hardware Design Challenges
  - Ground Friction Force Limitation

![High friction material](image1)

![Novel structure in future](image2)
Snake-Like Robot

Thank you
### Overview of Snake-like Robot Specifications

<table>
<thead>
<tr>
<th>Features</th>
<th>Parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dimensions</td>
<td>Diameter 60mm&lt;br&gt;Length 70 cm</td>
</tr>
<tr>
<td>Mass</td>
<td>Module 0.3kg&lt;br&gt;Full 2 kg</td>
</tr>
<tr>
<td>Actuation</td>
<td>Max Torque 12.8kg.cm&lt;br&gt;Max Speed 0.07 sec/60deg</td>
</tr>
<tr>
<td>Power</td>
<td>Battery 850 mAh&lt;br&gt;Current(max) : 400mA</td>
</tr>
<tr>
<td>Communication</td>
<td>I2C Bus&lt;br&gt;Wireless NRF24L01</td>
</tr>
<tr>
<td>Sensing</td>
<td>Angular Sensor</td>
</tr>
</tbody>
</table>
Control Architecture

- CPG Network

\[
\Psi_i = \begin{cases} 
\varphi_2 - \varphi_1 = -\theta_1, & i=1, \\
\varphi_{n-1} - \varphi_n = \theta_n, & i=n, \\
\varphi_{i+1} + \varphi_{i-1} - 2\varphi_i = \theta_{i-1} - \theta_i, & \text{otherwise.}
\end{cases}
\]
Control Architecture

• CPG Network

Gradient System with Multi Balance Points

Gait Transition Process
Rolling to Sidewinding

- CPG Signals Transition Process

\[ \vec{\Theta} = \left( \frac{\pi}{2}, -\frac{\pi}{2}, \frac{\pi}{2}, -\frac{\pi}{2}, -\frac{\pi}{2}, \frac{\pi}{2} \right), \quad \text{rolling} \]

\[ \vec{\Theta} = \left( \frac{\pi}{2}, 0, \frac{\pi}{2}, 0, \frac{\pi}{2}, 0, \frac{\pi}{2} \right), \quad \text{sidewinding} \]
Simulation Demo

Turning around in circle

Crawling tree

Linear forward Locomotion

link

link
A CPG-based Control Architecture for 3D Locomotion of a Snake-like Robot

Zhenshan Bing, Long Cheng
Kai Huang and Alois Knoll

Robotics and Embedded System
Technical University of Munich
Germany

youtube link
Present Research Results

- A novel CPG model
  - Adjust the output signals parameters as desired, like amplitude, frequency and phase shift.

- 3D Locomotion in several gaits
  - Rolling
  - Sidewinding
  - Free gait transition from rolling to sidewinding
  - Crawling tree
  - Linear locomotion

- A paper is submitted to IROS-2016
Future Work

- Next generation snake-like robot
  - Solidworks model and CAD drawings have been finished. The aluminum robot will be manufactured before May.

- Locomotion Optimization
  - Explore and implement diverse locomotion gaits under un-know environment.

- Adaptive behavior Ability
  - Vision sensor in head module to sense environment.
  - Force sensor in body modules to sense external interference.