snake-like robot

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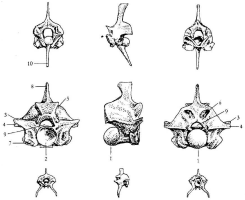
Outline

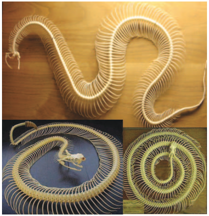
- Snakes in the real world
- snake-like robots inspired from the real world
    - Researches of snake-like robots
    - Classification of snake-like robots
    - Control approaches of snake-like robots
- Conclusion

Snakes and other limbless animals

Snakes skeletal structure

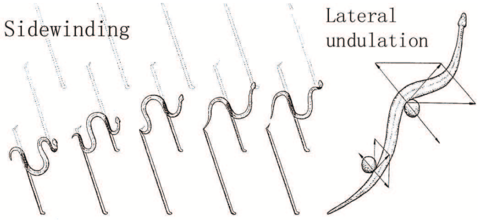
- Skull
- Backbone
  - Consist of 100-400 vertebrae
  - Allow rotation of 10-20 degrees in the horizontal plane, and between 2-3 degrees in the vertical plane
  - Act as compliant universal joints
- Ribs

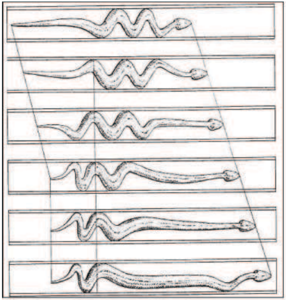




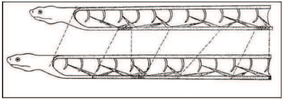
Forms of snake Locomotion

- Lateral undulation
- Sidewinding
- Concertina
- Rectilinear





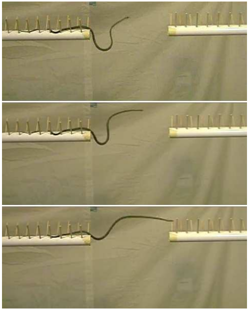
Concertina

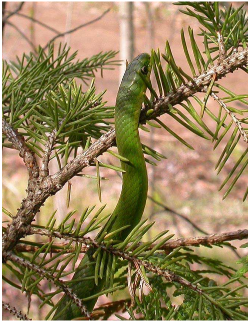


Rectilinear

Advantages of snake locomotion

- Easy to move through thin holes and gaps
- Able to climb up and over obstacles
- Versatile and can act as both locomotors and manipulators
- Stable gaits for locomotion





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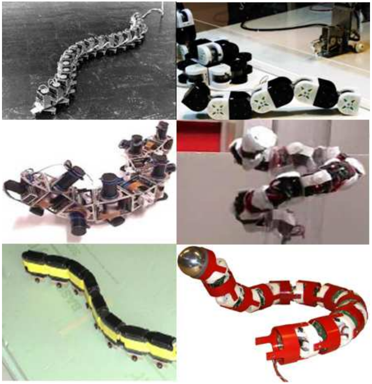
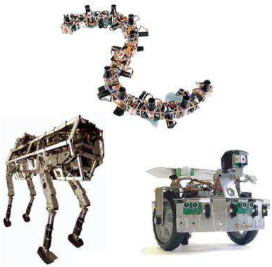
Research groups

- Adaptive Cord Mechanism (ACM)
- M-TRAN
- Polybot
- CMU
- Amphibot
- NTNU Aiko
- ...



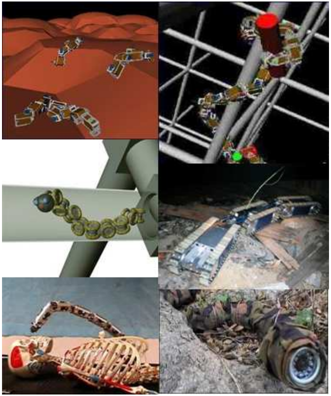
Features of snake-like robots

- Stability
  - Low center of mass
  - Not lift their bodies off the ground much during locomotion
- Terrainability
- Good traction
  - Distribution of mass
  - Large contact area
  - Forces can be below the thresholds of the plastic deformation of the soil
- High redundancy
  - Loss of short segments would still permit mobility and maneuverability



Applications

- Exploration
  - Extreme terrains
- Inspection
  - Determination for pipe blockage
  - Nuclear reactor detection
- Medical technology
  - Minimally-invasive surgery
- Search and rescue
  - Mine accident probe
  - Survivors search from disasters
- Reconnaissance



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Classification of snake-like robots

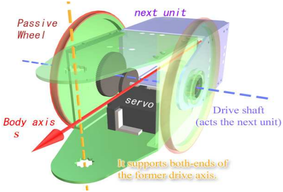
- Passive wheels
- Active wheels
- Active treads
- Undulation using body waves
- Undulation using linear expansion

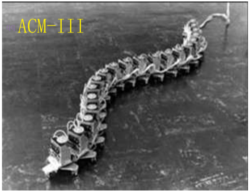
I: Robots with passive wheels

- Design
  - Place small wheels on casters at the bottom of each link, facing in the tangential direction of the length of the robot
- Function
  - Using passive wheels to resist lateral movement of the robot's segments
- Locomotion
  - Lateral undulation
- Examples
  - ACM family
  - Gavin Miller's robots
  - Amphibot

ACM family

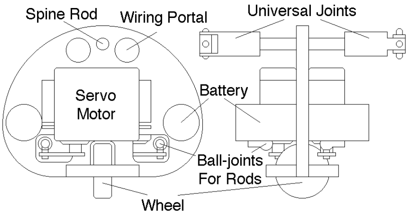
- ACM III
- ACM R2
- ACM R3
- ACM R5





Gavin Miller's robots

- S1-S6
- Utilize passive wheels at the bottom to assist in movement using a lateral serpentine gait



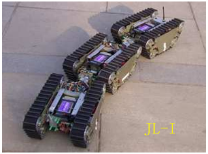
S5 Diagram

II: Robots with active wheels

- Motivation
  - Main propulsion of a moving snake came from hundreds of tiny scales that are on the bottom side of the snake
- Design
  - Each unit is supported by an independently powered single wheel, which is driven by motors
- Locomotion
  - Rectilinear motion
- Examples
  - Koryu-II
  - ACM-R4

III: Robots with active treads

- Design
  - Utilize powered treads to traverse extremely rough terrain
- Function
  - Increase contact area
  - Provide propulsion
- Locomotion
  - Rectilinear motion
- Examples
  - IRS soryu
  - OmniTread OT-4
  - JL-I
  - Moira 2

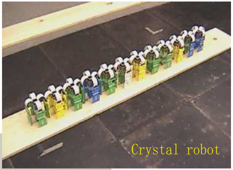


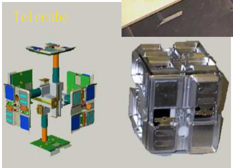
IV: Undulation using body waves

- Design
  - modular robots
  - Each module consists of a single servomotor, which provided the torque to move and maintain angles
- Function
  - Using pure undulation in body shape to generate waveforms
- Locomotion
  - Lateral undulation, Sidewinding, Concertina, Rectilinear...
- Examples
  - M-TRAN III
  - CMU’s snake robot
  - NASA’s snakebot
  - ...

V: Undulation using linear expansion

- Motivation
  - Muscular contractions are capable of producing tensions between the vertebral column and the ventral skin and thus propel the ventral surface forward against frictional resistance
- Design
  - Modular robot
  - Contracting and expanding
  - Connecting and disconnecting
- Locomotion
  - Rectilinear motion
- Examples
  - Crystal robot
  - Telecubes





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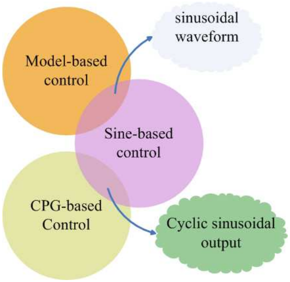
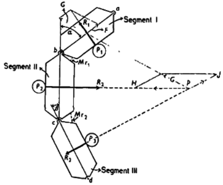
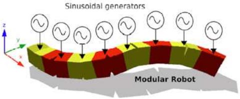
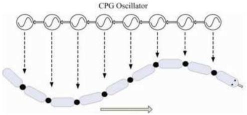
Control approaches

- Model-based control
- Sine-based control
- CPG-based control



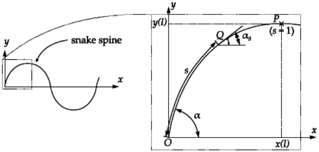


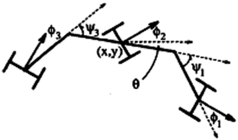




Model-based control

- Use kinematical or dynamic models of snake-like robot to design control laws for gait generation
- Offer a way to identify fastest gaits for a given robot by using kinematical constraints





$$x(s) = sJ_0(\alpha) + \frac{4l}{\pi}\sum_{m=1} \frac{(-1)^{2m}}{2m} J_{2m}(\alpha)\sin\left(m\pi\frac{s}{l}\right);$$

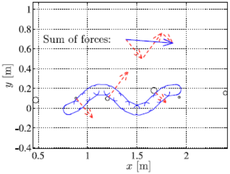
$$y(s) = \frac{4l}{\pi}\sum_{m=1} (-1)^{m-1}\frac{J_{2m-1}(\alpha)}{2m-1}\sin\left(\frac{2m-1}{2}\pi\frac{s}{l}\right);$$

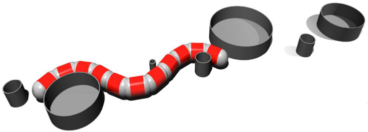
A model for the kinematic snake

serpenoid curve

Model-based control (cont')

- Advantage
  - Useful for helping to design controllers
- Limitations
  - Not always suited for interactive modulation by a human operator
  - Performance deteriorate when models become inaccurate
- Example
  - NTNU Aiko





Sine-based control

Use simple sine-based functions for generating traveling waves

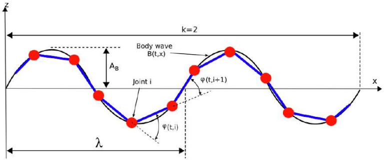
- Advantages
  - Simple expression
  - Explicitly defined important quantities such as frequency, amplitude and wavelength

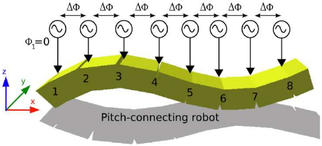
$$\varphi_i(t) = A_i sin\left(\frac{2\pi}{T_i} t + \phi_i\right) + O_i \quad i \in \{1 \dots M\}$$

Symbols	Descriptions	Range
$\varphi_i(t)$	Bending angle of the module i	[-90,90] degrees
A_i	Amplitude of generator i	[0,90] degrees
$T_i(t)$	Period of generator i	Time units
$\phi_i(t)$	Phase of generator i	(-180,180]
O_i	Offset of generator i	[-90,90] degrees
M	Number of modules of the robot	M>=2

Sine-based control (cont')

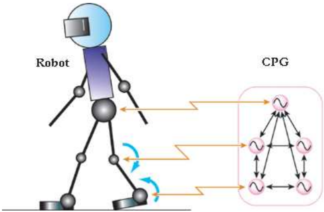
- Disadvantages
  - Not offer simple ways of integrating sensory feedback signals
  - Lead to discontinuous jumps of setpoints during online modifications
- Example
  - TAMS modular robot

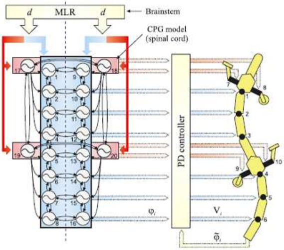




CPG-based control

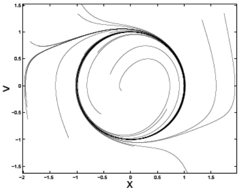
- What is CPG?
  - Central pattern generators (CPG) are neural circuits found in both invertebrate and vertebrate animals that can produce rhythmic patterns of neural activity without receiving rhythmic inputs. (*Wikipedia*)

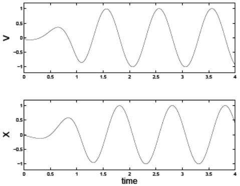




CPG-based control (cont')

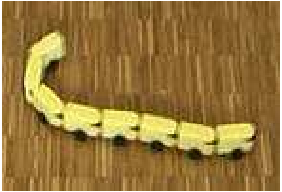
- Interesting properties
  - Exhibit limit cycle behavior
  - Suited for distributed implementation
  - Use a few control parameters
  - Suited to integrate sensory feedback signals
  - Offer a good substrate for learning and optimization algorithms





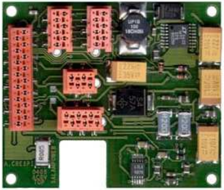
CPG-based control (cont')

- CPG-based approach
  - Use dynamical systems for generating the traveling waves necessary for locomotion
  - Implemented as differential equations integrated over time
- Example
  - AmphiBot II

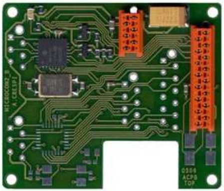


AmphiBot II: mechanism

- Actuated elements
  - Three printed circuits
    - A power board
    - A PD motor controller
    - A small water detector
  - A flat cable
  - A DC motor
  - A set of gears
  - A rechargeable Li-Ion battery
- Head element
  - A PIC18F2580 microcontroller



Power and motor circuits

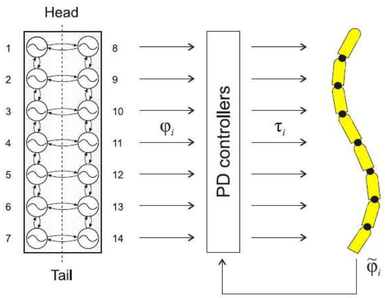


Microcontroller circuit

Water sensor

AmphiBot II: locomotion control

- The central pattern generator structure
  - Inspired from the lamprey
  - A double chain of oscillators with nearest neighbor coupling



AmphiBot II: locomotion control (cont')

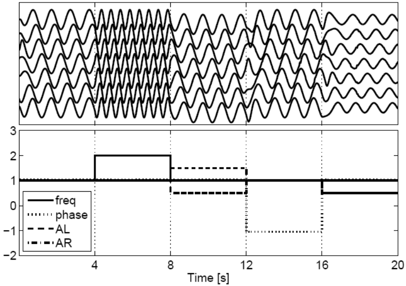
Amplitude controlled phase oscillator

$$\begin{cases} \dot{\theta}_i &= 2\pi\nu_i + \sum_j w_{ij} \sin\left(\theta_j - \theta_i - \phi_{ij}\right) \\ \ddot{r}_i &= a_i\left(\frac{a_i}{4}(R_i - r_i) - \dot{r}_i\right) \\ x_i &= r_i\left(1 + \cos(\theta_i)\right) \end{cases}$$

- θ_i and r_i: The phase and the amplitude of the i^{th} oscillators
- v_i and R_i : The intrinsic frequency and amplitude
- w_{ij}: Connecting weight
- ϕ_{ij}: The phase biases between oscillators
- x_i: The rhythmic and positive output signal

AmphiBot II: locomotion control (cont')

$$\varphi_i = x_i - x_{N+i}$$
$$e_i = \varphi_i - \tilde{\varphi}_i$$
$$\tau_i = K_p e_i + K_d \dot{e}_i$$



- φ_i: The desired angles for the i_{th} actuated joints
- e_i: The tracking error
- τ_i: The voltage (i.e. torque) applied to the motor

- t=4s ν =2.0 Hz
- t=8s AL=0.5, AR=1.5
- t=12s $\triangle\phi$ =-1.0
- t=16s AL=0.5, AR=0.5

Conclusion

- Achievements of snake-like robots
  - Different types of snake-like robots
  - A number of useful gaits
- Challenges of snake-like robots
  - Small cross-sections
  - Multi-gait functionality
  - High velocities
  - Much longer operational time

Thanks for your attention!

Any questions?