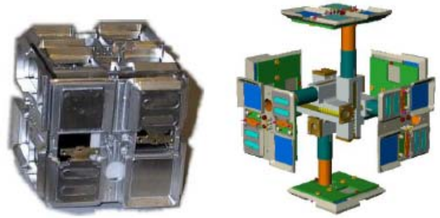
Introduction to modular robots

Speakers

Houxiang Zhang
Juan González Gómez

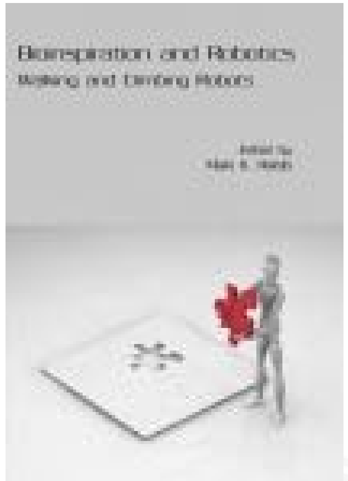
Outline of today's talk

- What is a modular robot?
- Review of modular robots
  - Classification
  - History of modular robots
  - Challenging
- From Y1 to GZ-I, our modular robot
  - Y1 modular robot and related research
  - GZ-I module
- Control hardware realization
- Locomotion controlling method
- Current research



Acknowledgments

- ***"Bioinspiration and Robotics: Walking and Climbing Robots "***
  Edited by: Maki K. Habib, Publisher: I-Tech Education and Publishing, Vienna, Austria, ISBN 978-3-902613-15-8.
  - http://s.i-techonline.com/Book/



- Other great work and related information on the internet
  - http://en.wikipedia.org/wiki/Self-Reconfiguring_Modular_Robotics

Lecture material

- *Modular Self-Reconfigurable Robot Systems: Challenges and Opportunities for the Future* , by Yim, Shen, Salemi, Rus, Moll, Lipson, Klavins & Chirikjian, published in IEEE Robotics & Automation Magazine March 2007.
- *Self-Reconfigurable Robot: Shape-Changing Cellular Robots Can Exceed Conventional Robot Flexibility*, by Murata & Kurokawa, published in IEEE Robotics & Automation Magazine March 2007.
- *Locomotion Principles of 1D Topology Pitch and Pitch-Yaw-Connecting Modular Robots*, by Juan Gonzalez-Gomez, Houxiang Zhang, Eduardo Boemo, One Chapter in Book of "Bioinspiration and Robotics: Walking and Climbing Robots", 2007, pp.403-428.
- *Locomotion Capabilities of a Modular Robot with Eight Pitch-Yaw-Connecting Modules* , by Juan Gonzalez-Gomez, Houxiang Zhang, Eduardo Boemo, Jianwei Zhang: The 9th International Conference on Climbing and Walking Robots and their Supporting Technologies for Mobile Machines, CLAWAR 2006, Brussels, Belgium, September 12-14, pp.150-156, 2006.

Web links on modular robots

- **Distributed Robotics Laboratory at MIT**
  - http://groups.csail.mit.edu/drl/wiki/index.php/Main_Page
- **Modular Robots at PARC**
  - http://www2.parc.com/spl/projects/modrobots/
- **ModLab at University of Pennsylvania**
  - http://modlab.seas.upenn.edu/
- **Claytronics Project at Carnegie Mellon University**
  - http://www.cs.cmu.edu/%7Eclaytronics
- **Juan Gonzalez-Gomez's web page**
  - http://www.iearobotics.com/personal/juan/index_eng.html
- **GZ-I project at TAMS group**
  - http://tams-www.informatik.uni-hamburg.de/people/hzhang/projects/index.php?content=Modular%20robot
- Modular Robotics Google Group

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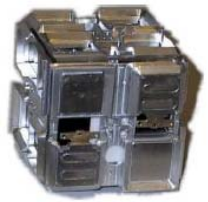
What is a modular robot?

- Definition




- Structures

- Features

What is a modular robot?

- Definition?
  - Modular self-reconfiguring robotic systems are autonomous kinematical machines with variable morphology …

http://en.wikipedia.org/wiki/Self-Reconfiguring_Modular_Robotics

What is a modular robot?

- Structures
  - Modular robots are usually composed of multiple building blocks of a relatively small repertoire, with uniform docking interfaces.
  - The modular building blocks usually consist of some primary structural actuated unit, and potentially additional specialized units.

http://en.wikipedia.org/wiki/Self-Reconfiguring_Modular_Robotics

Motivation and inspiration

- Functional advantage:
  - Self reconfiguring robotic systems are potentially more **robust** and more **adaptive** than conventional systems.

- Economic advantage:
  - Self reconfiguring robotic systems can potentially lower overall robot cost by making a range of complex machines out of a single (or relatively few) types of mass-produced modules.

Modular robots

- Main idea: Building robots composed of **modules**
- The design is focused on the module, not on a particular robot
- The different combinations of modules are called **configurations**

@ Juan Gonzalez-Gomez

- Some advantages:
  - Versatility
  - Fast prototyping
  - Low-cost

Modular robot technology

- The last decade has seen an increasing interest in developing and employing modular robots for
  - Space exploration;
  - Bucket of stuff;
  - Inspired research.

Modular robot technology (cont')

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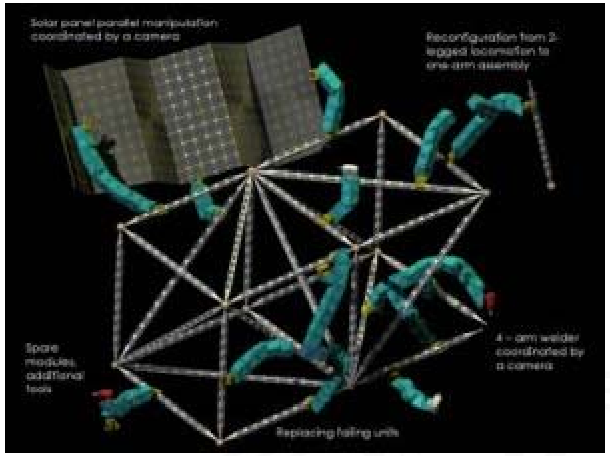
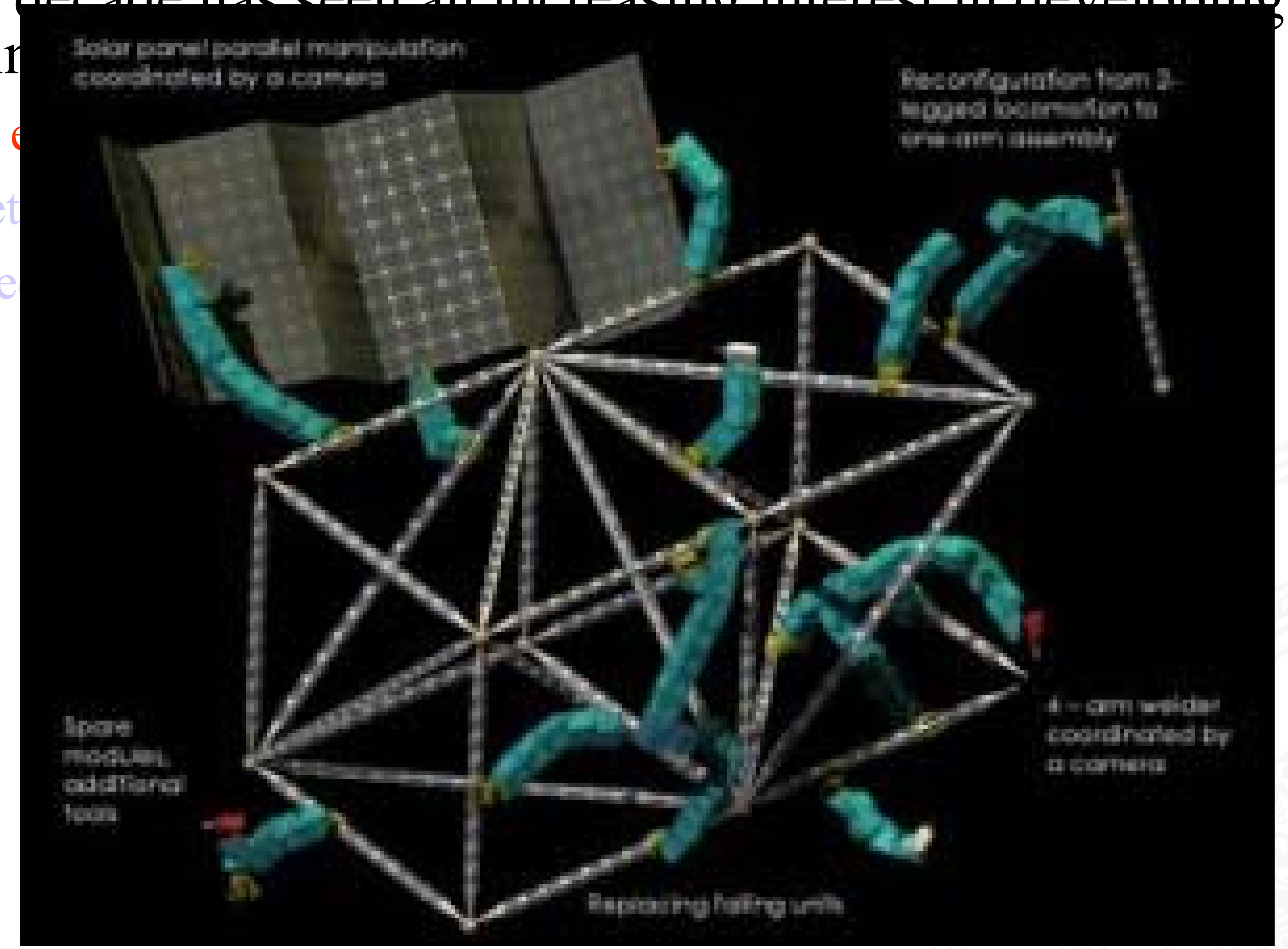


  - *One application area that highlights the advantages of self-reconfigurable systems is long-term space missions. These require long-term self-sustaining robotic ecology that can handle unforeseen situations and may require self repair.*

***[1]** Modular Reconfigurable Robots in Space Applications . Palo Alto Research Center (PARC) (2004).*

Modular robot technology (cont')

- The last decade has seen an increasing interest in developing and employi
  - Space e
  - Bucket
  - Inspire
  -



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Modular robot technology

- The last decade has seen an increasing interest in developing and employing modular robots for
  - Space exploration;
  - Bucket of stuff;
  - Inspired research.

  - *Consumers of the future have a container of self-reconfigurable modules say in their garage, basement, or attic.*

    - *One source of inspiration for the development of these systems comes from the application.*
    - *A second source is biological systems that are self-constructed out of a relatively small repertoire of lower-level building blocks (cells or amino acids, depending on the scale of interest). (Example)*

http://en.wikipedia.org/wiki/Self-Reconfiguring_Modular_Robotics#Grand_Challenges

Modular robot technology

- The last decade has seen an increasing interest in developing and employing modular robots for
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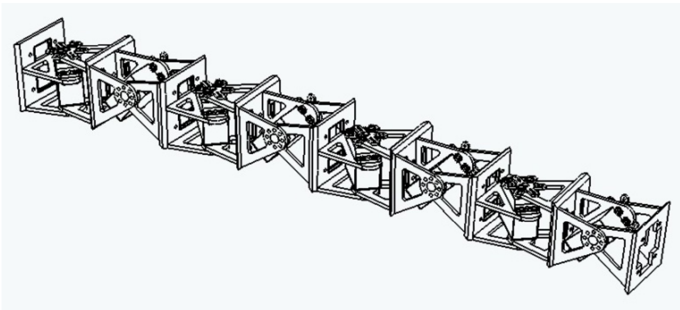
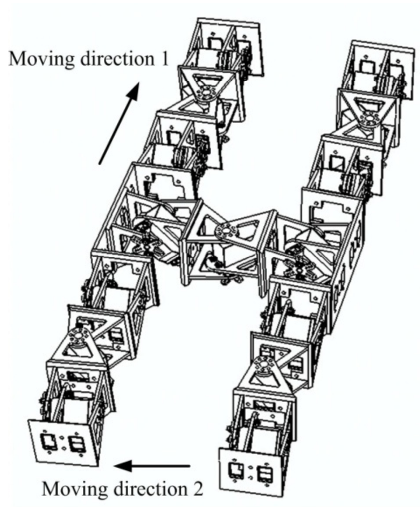
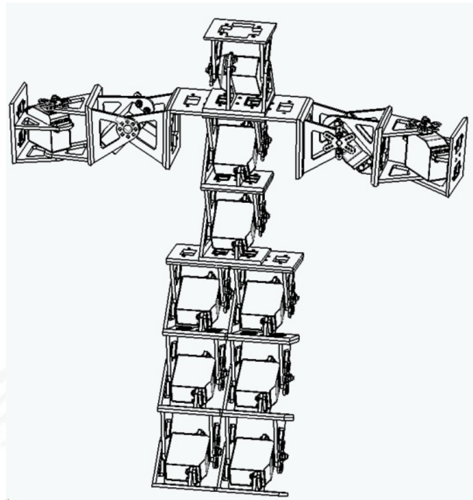
  - Inspired research.



  - To build and test different inspired robots such as two legged, four-legged and other robots quickly.

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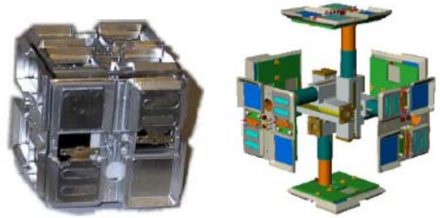
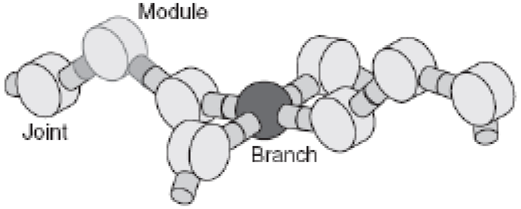


Classification of modular robots

- General classification
  - Chain
    - Connected in a string or tree topology. This chain or tree can fold up to become three-dimensional, but underlying architecture is serial.
  - Lattice
    - Arranged and connected in some regular, space-filling three-dimensional pattern, such as a cubical or hexagonal grid.
- Our classification

Chain topology

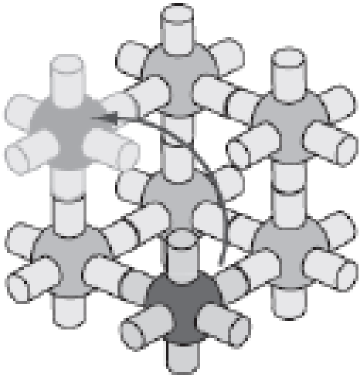
- Advantages
  - Easy to generate motion
  - few actuators needed



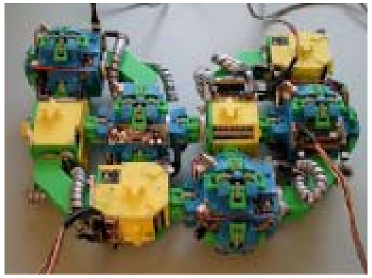
- Disadvantages
  - Few connection possibility
  - Hard to self-reconfiguration

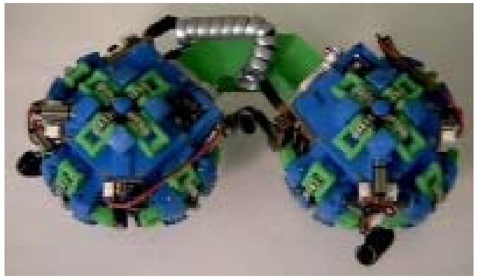
Lattice topology

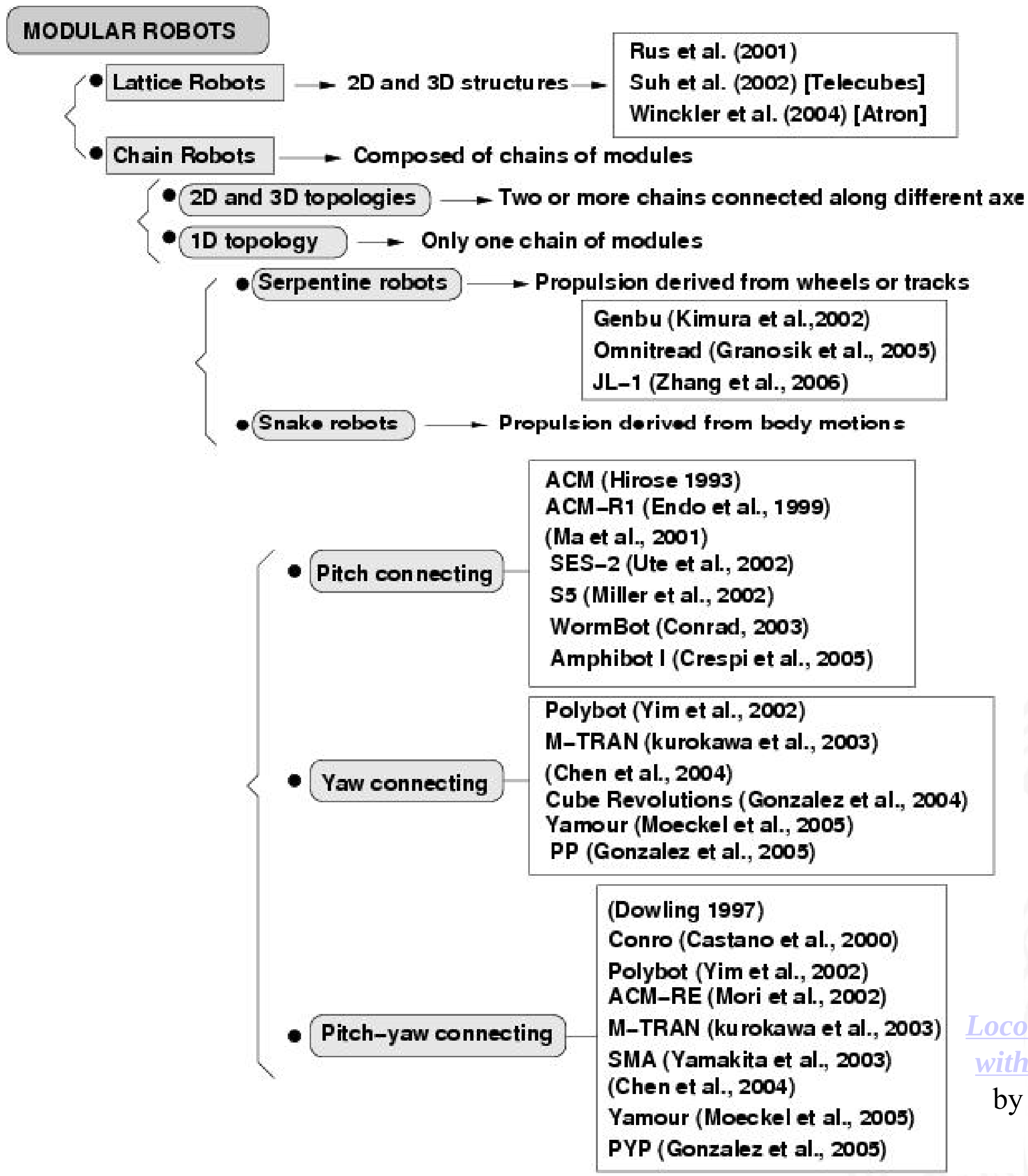
- Advantages
  - Easy self-reconfiguration
  - Possible to connect in different directions



- Disadvantages
  - Difficult to generate motion
  - Need of many actuators





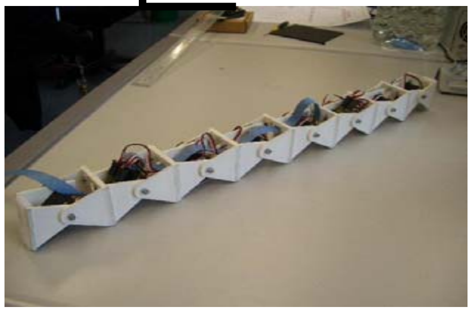


Locomotion Capabilities of a Modular Robot with Eight Pitch-Yaw-Connecting Modules ,
by Juan Gonzalez-Gomez, Houxiang Zhang

1D Topology:

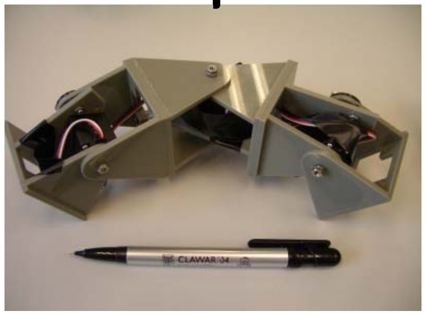
Locomotion in 1D:

Pitch-Pitch

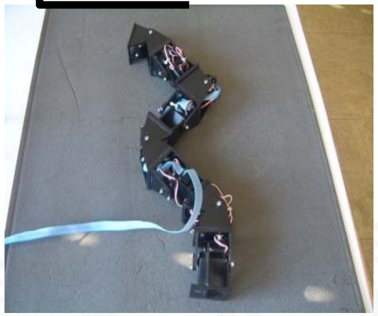


8 pitch-connecting modules

Locomotion in 2D:



Pitch-Yaw-Pitch

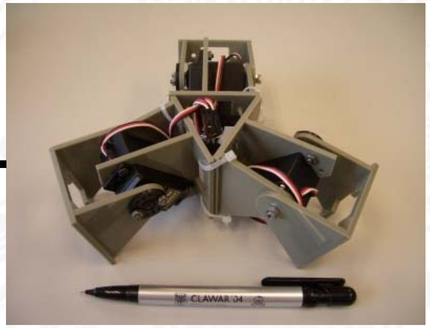


8 pitch-yaw-connecting modules

2D Topology:

Locomotion in 2D:

Star of 3 modules



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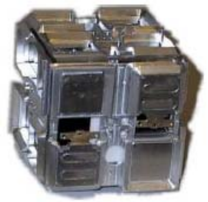
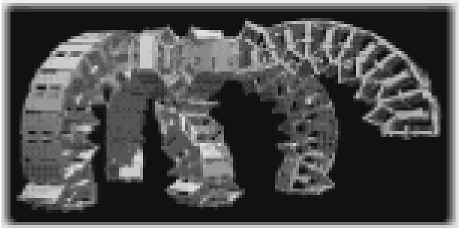
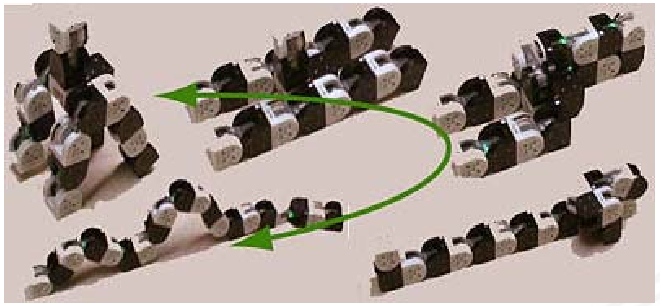
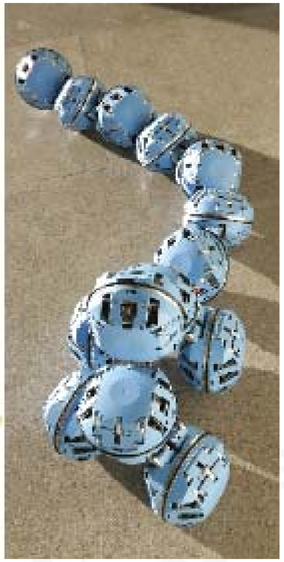
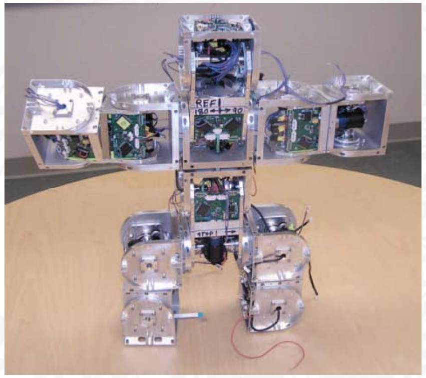
- Locomotion controlling method
- Conclusions



History of modular robots

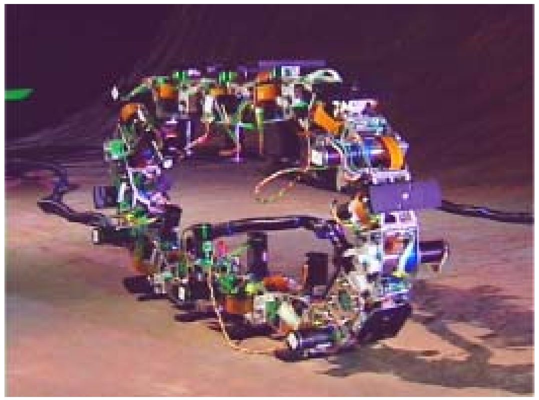
- CEBOT (1988)
- Polypod (1993)
- ATRON (2003)
- M-TRAN III (2005)
- Superbot (2006)
- Miche (2006)
- GZ-I (2007)
- Other…

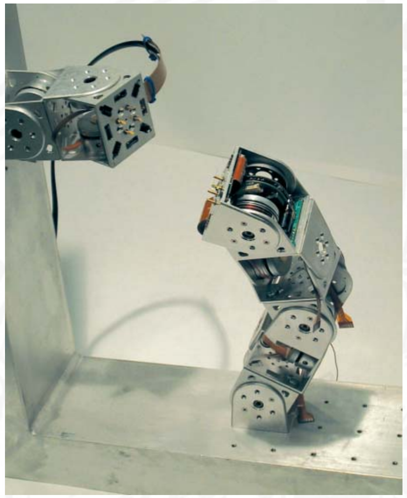




PolyBot from Mark Yim

- PolyBot, created at Palo Alto Research Center (PARC)
  - Chain self-reconfiguration system
  - Each module is roughly cubic shaped, with about 50 mm of edge length, and has one rotational degree of freedom (DOF)
  - Features demonstrated many modes of locomotion
  - CKbot new version with force torque sensors, whisker touch sensors, and infrared proximity sensors. (*Link*)





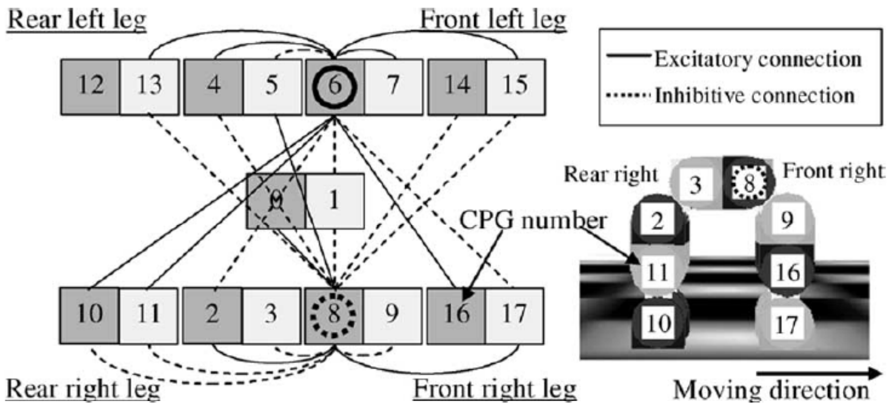
M-TRAN from Satoshi Murata et.al.

- Two blocks (active/passive) and a link
- Two parallel axes and six connectable surfaces
- Both blocks have 90 degrees rotation
- Mechanical connectors in active block
- 4 CPUs in a Master/Slave-Architecture
  - Master CPU: Algorithm computation and communication
  - Slave CPUs: Motor/Connection control and sensor data
- Virtual shared memory for inter-module communication

M-Tran prototype

M-tran from Satoshi Murata

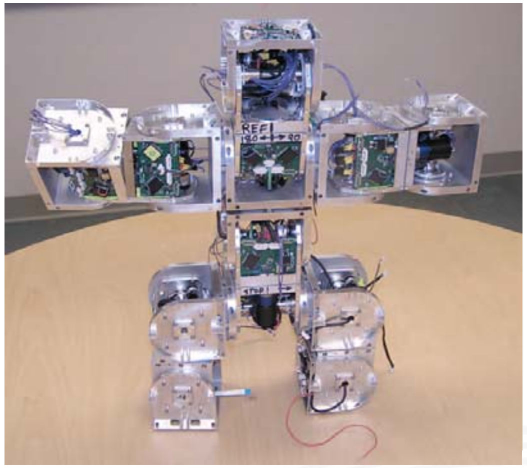
- Successful approach to stable and efficient (whole body) motion generation involving the combination of
  - CPGs - central pattern generators
  - Genetic algorithms
  - Dynamics simulation
- CPGs are well suited for modular systems being asynchronous and decentralized
- ALPG - Automatic Locomotion Pattern Generation, a software implementation of the combination

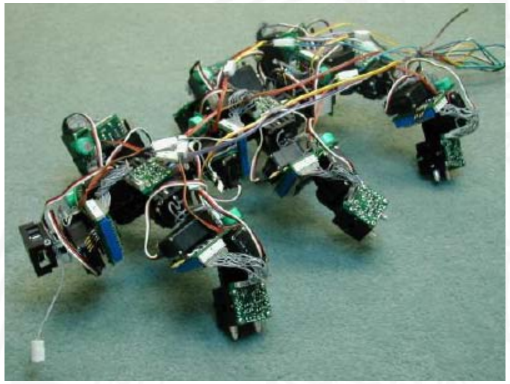


http://unit.aist.go.jp/is/frrg/dsysd/mtran3/

Superbot from Wei-min Shen

- Developed at the University of Southern California as a deployable self-reconfigurable robot
- Hybrid chain and lattice architecture.
- Three DOF (pitch, yaw, and roll), modules interconnect through one of the six identical dock connectors.
- Modules communicate and share power through their dock connectors.
- For high-level communication and control, the modules use a real-time operating system and the hormone-inspired control developed for CONRO as a distributed, scalable protocol.





http://www.isi.edu/

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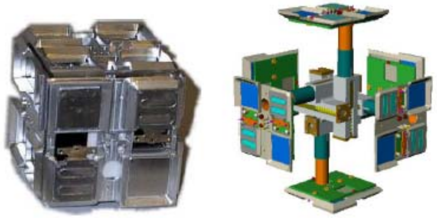

Challenging

- Big systems:
  - Most systems of modular robots have been small in number.
  - The demonstration of a system with at least 1,000 individual units would suggest that modular robots have come of age.
  - The physical demonstration of such a system will require rethinking key hardware issues, such as binding mechanisms, power distribution, dynamics, and vibrations.

Modular Self-Reconfigurable Robot Systems: Challenges and Opportunities for the Future, *by Yim, Shen, Salemi, Rus, Moll, Lipson, Klavins & Chirikjian, published in IEEE Robotics & Automation Magazine March 2007*.

Challenging (cont')

- Self-repairing systems:
  - Besides reconfiguring itself into a new shape, a system comprised of modular robots would be able to recover from serious damage.
  - A demonstration of a self-healing structure made up of many distributed, communicating parts would require rethinking algorithms for sensing and estimation of the global state, as well as truly robust hardware and algorithms.

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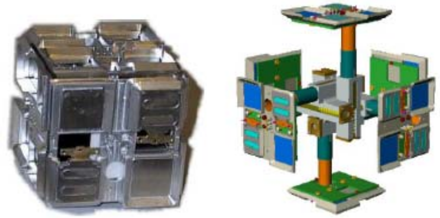


Modular robot cooperation

- Since 2004, Juan González-Gómez and I have been working on the modular robot project.

At TAMS, Feb. 2006

In Brussels, Sept. 2006

At TAMS, Dec.2006

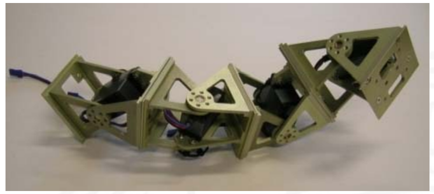
In Madrid, Nov. 2007

In Madrid, Nov. 2008

Modular robot cooperation

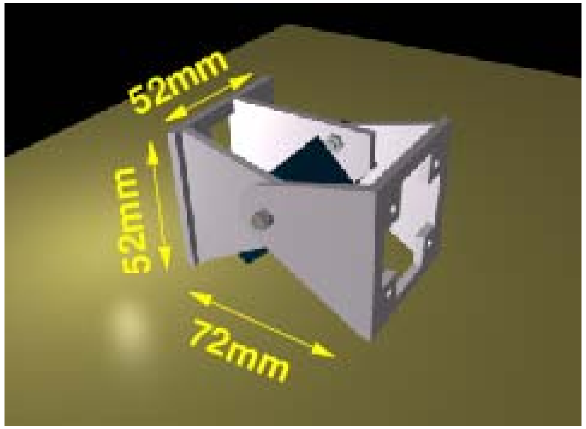
- Y1 module, 2004
- Y1 modular minimmin configuration, 2005
- Y1 pitching-yawing connecting research, 2006
- GZ-I mechanical improvement design, 2006
- GZ-I system integration, 2007
- Related research, 2008.
- The GZ-I was started in 2006.
  This system has been developed and is currently
  still under improvement by our consortium.

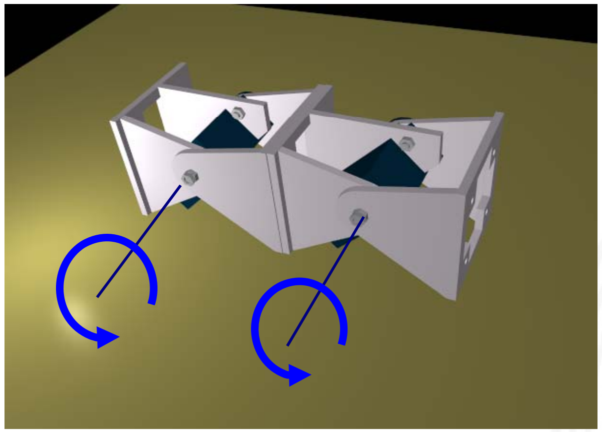


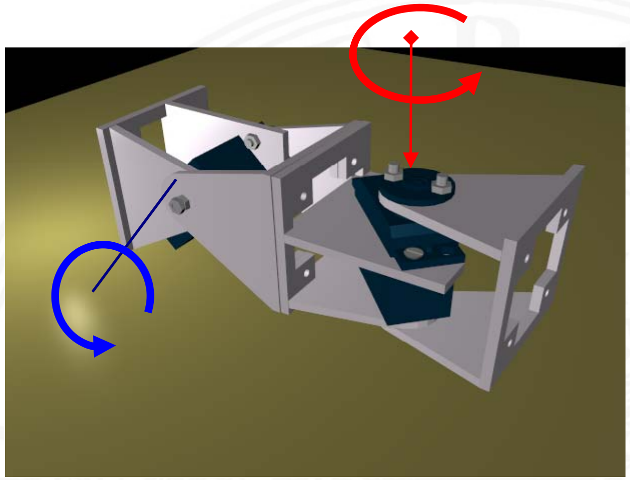


Y1 module

- **DOF**: 1
- **Material**: 3mm Plastic
- **Servo:** Futaba 3003
- **Dimension**: 52 x 52 x 72mm
- **Rotation Range**: 180 degrees
- Cheap and easy to build
- Two types of **connection**:

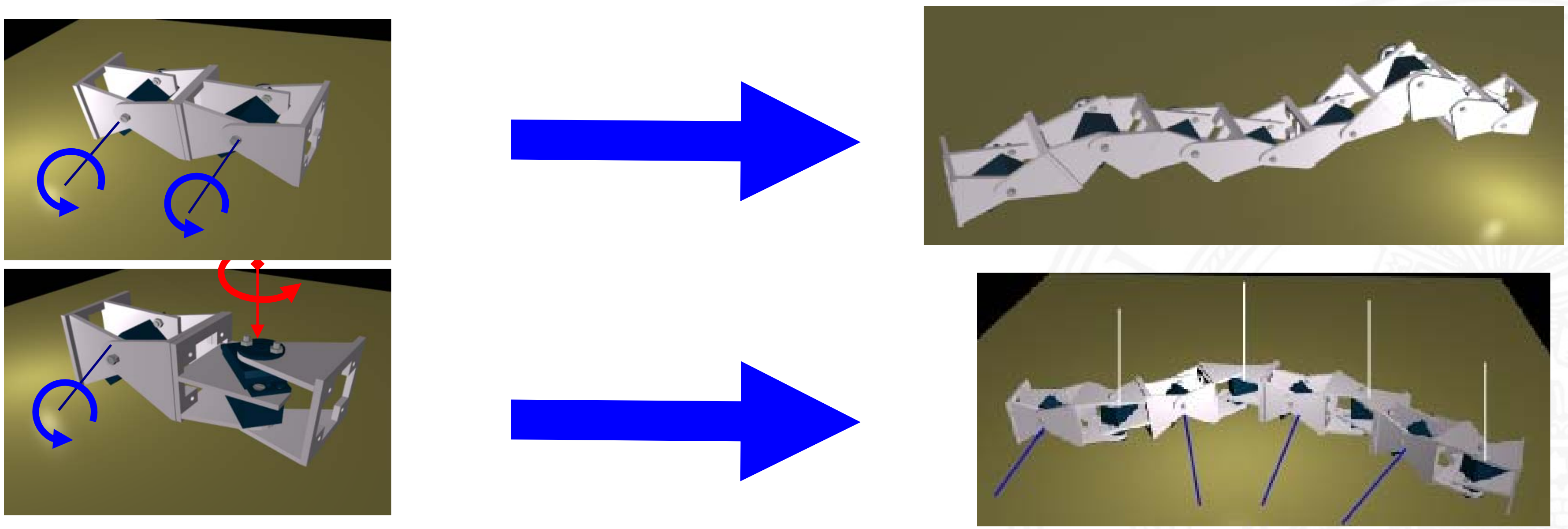






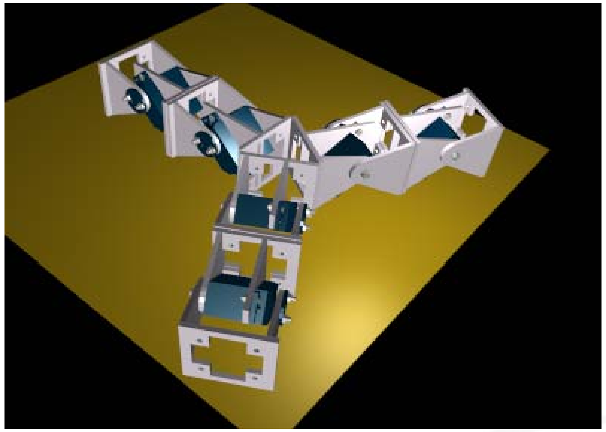
Possible tasks using the Y1 module

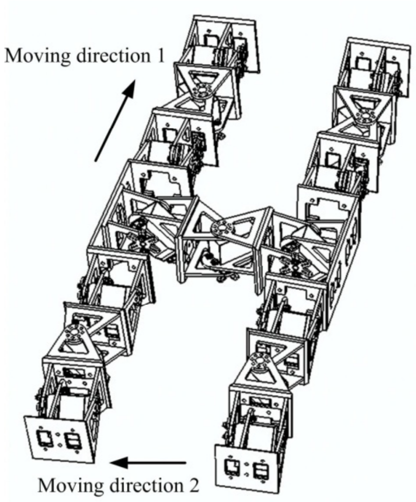
- 1D Topology
- 8 Pitch-yaw connecting modules
- 4 rotate around the pitch axes
- 4 rotate around the yaw axes
- Based on the Y1 modules

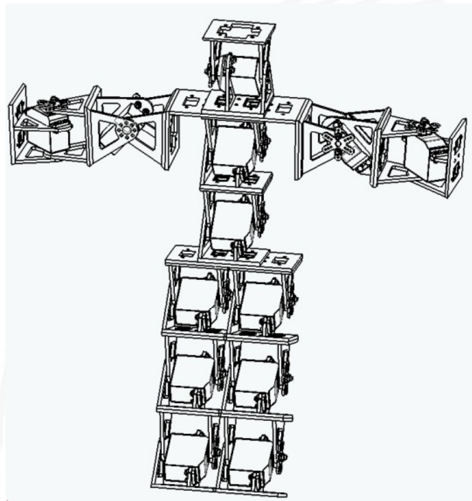


Other interesting possibilities

- Other possibilities
  - Three-legged robot
  - Four-legged robot
  - Six-legged robot
  - Biped robot







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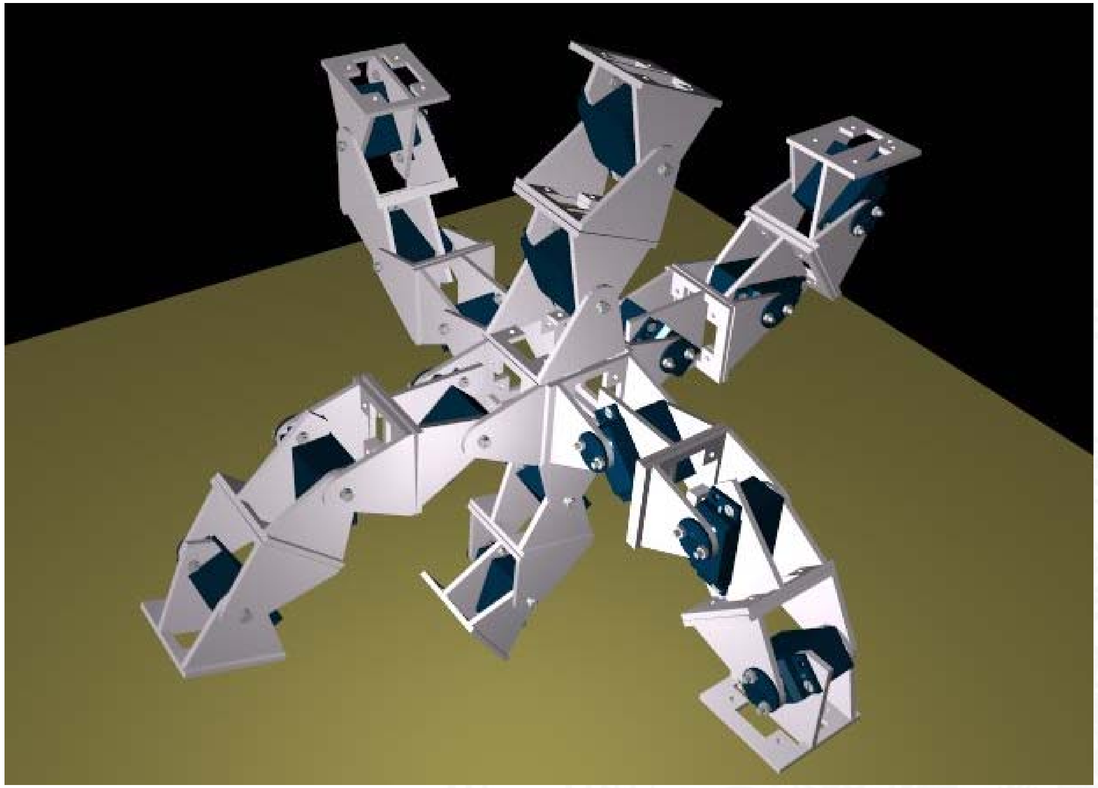

- Be creative!

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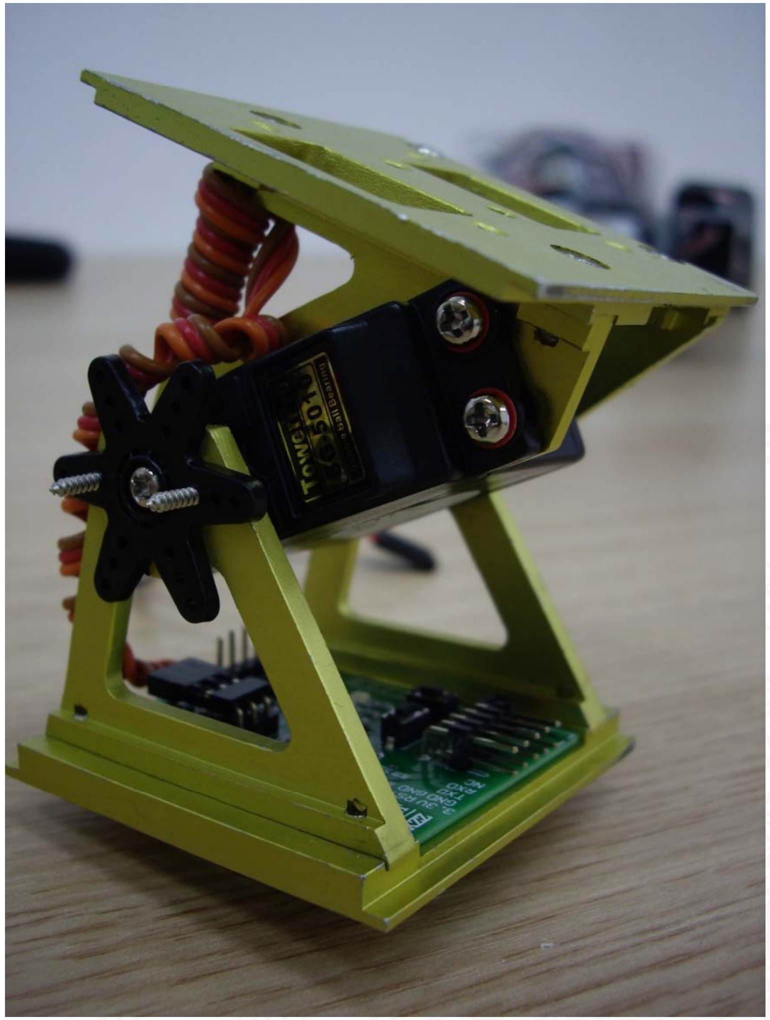
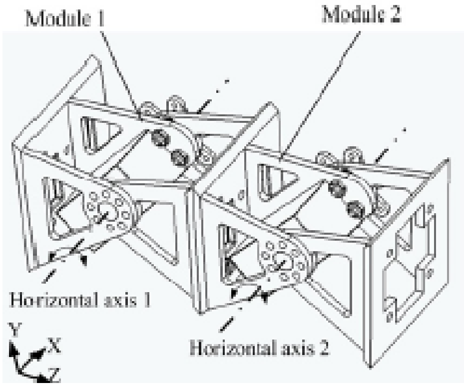
GZ-I system introduction

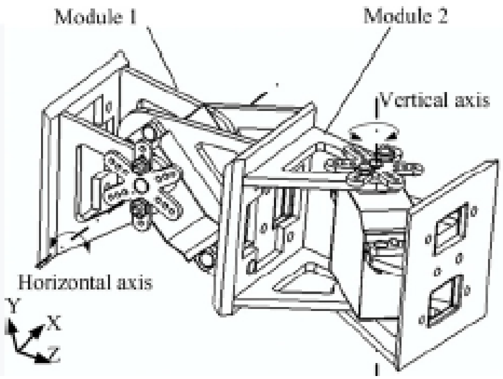
- GZ-I was developed in 2006 in cooperation with my colleague Juan González-Gómez.
- This system has been developed and is currently still under improvement by our consortium.



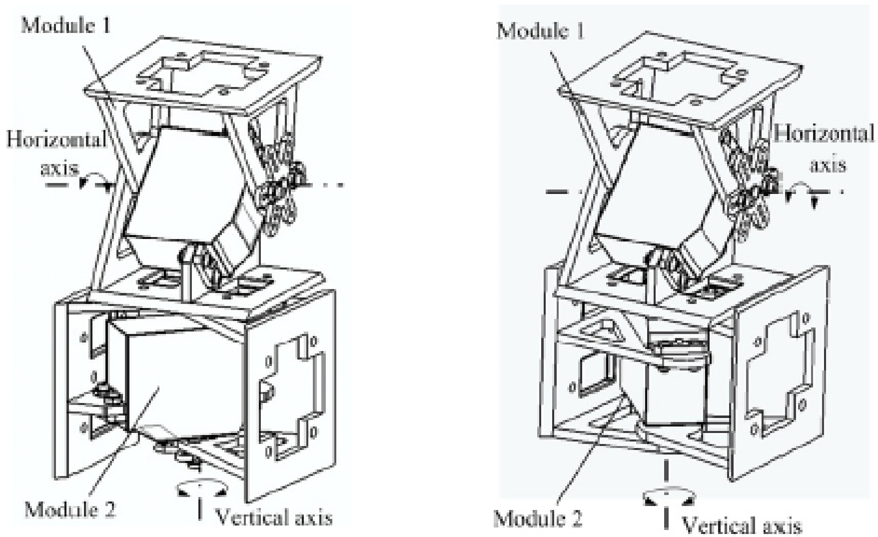
GZ-I with four connecting faces



a. Pitch connecting

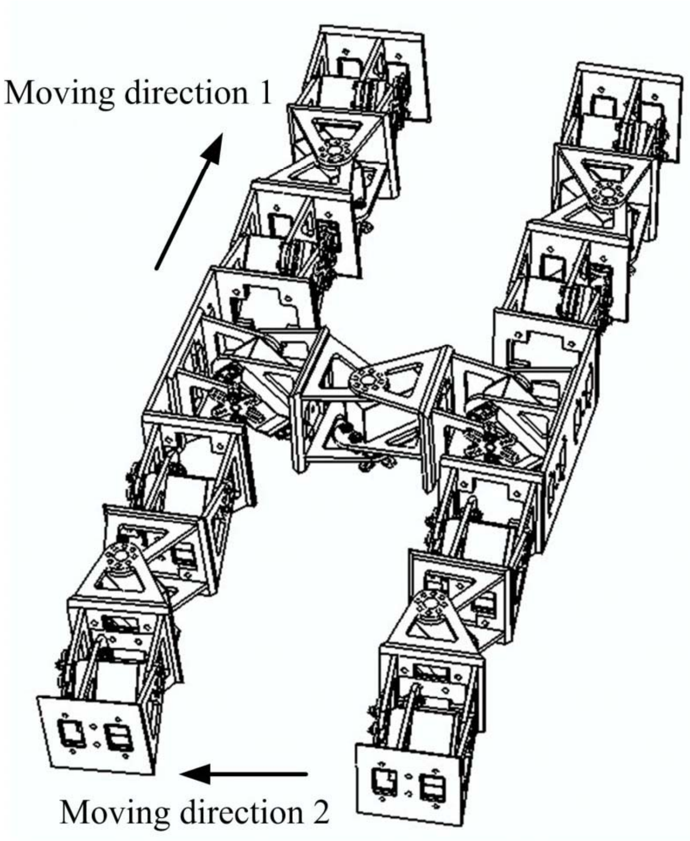


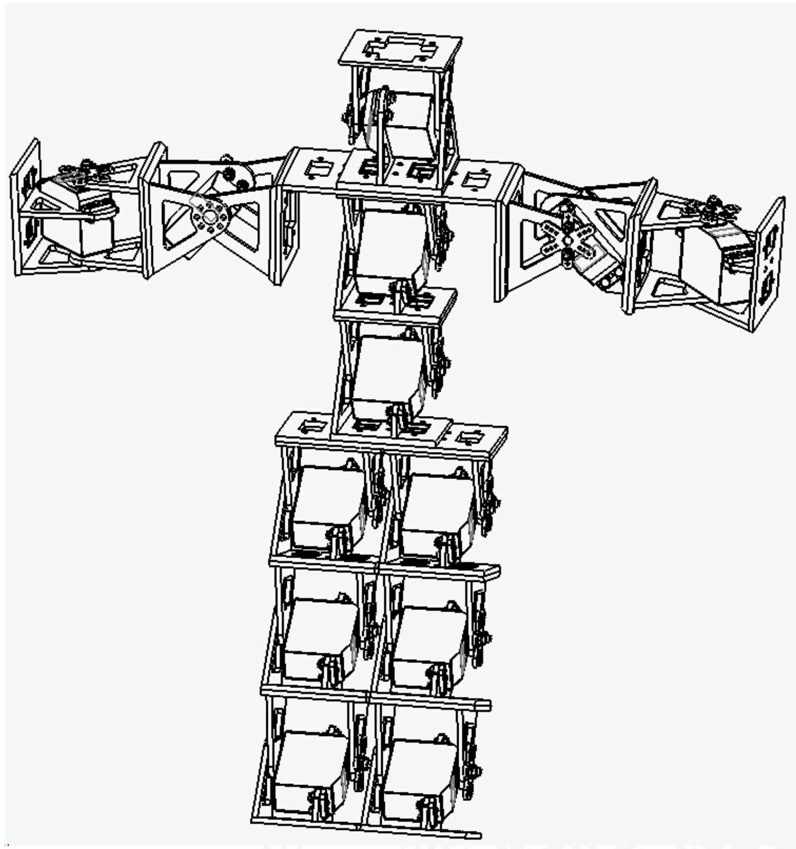
b. Pitch-Yaw connecting



c. and d. Lateral connecting

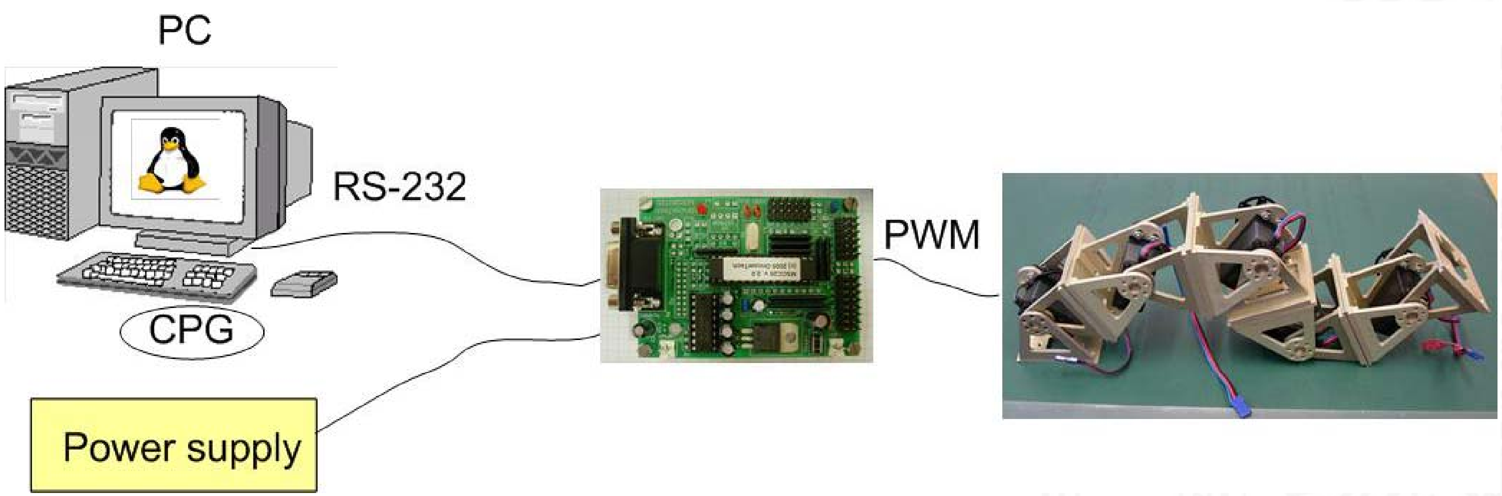
Robots with various shapes



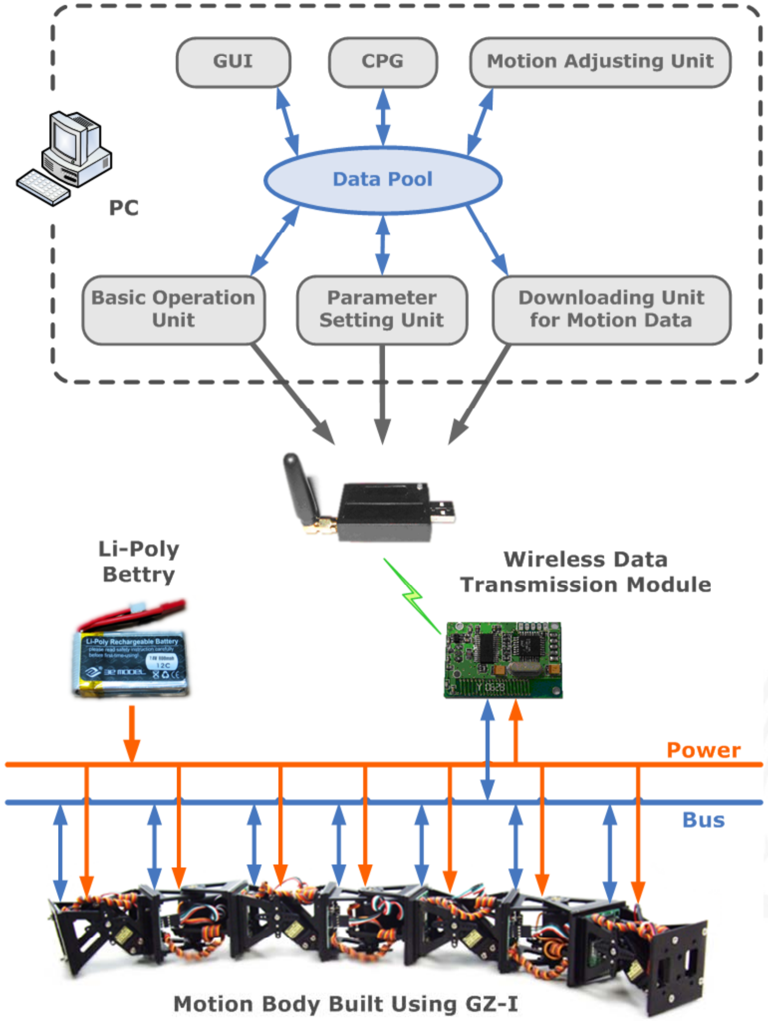


Control hardware realization

- A small board
- Power supply and controller located off-board
- The locomotion algorithms are executed on a PC
- The PC is connected to the controller by RS-232



System integration of GZ-I (wireless)



Outline of today's talk

- What is a modular robot?
- Review of modular robots
  - Classification
  - History of modular robots
  - Challenging
- From Y1 to GZ-I, our modular robot
  - Y1 modular robot and related research
  - GZ-I module
- Control hardware realization
- Locomotion controlling method
- Current research

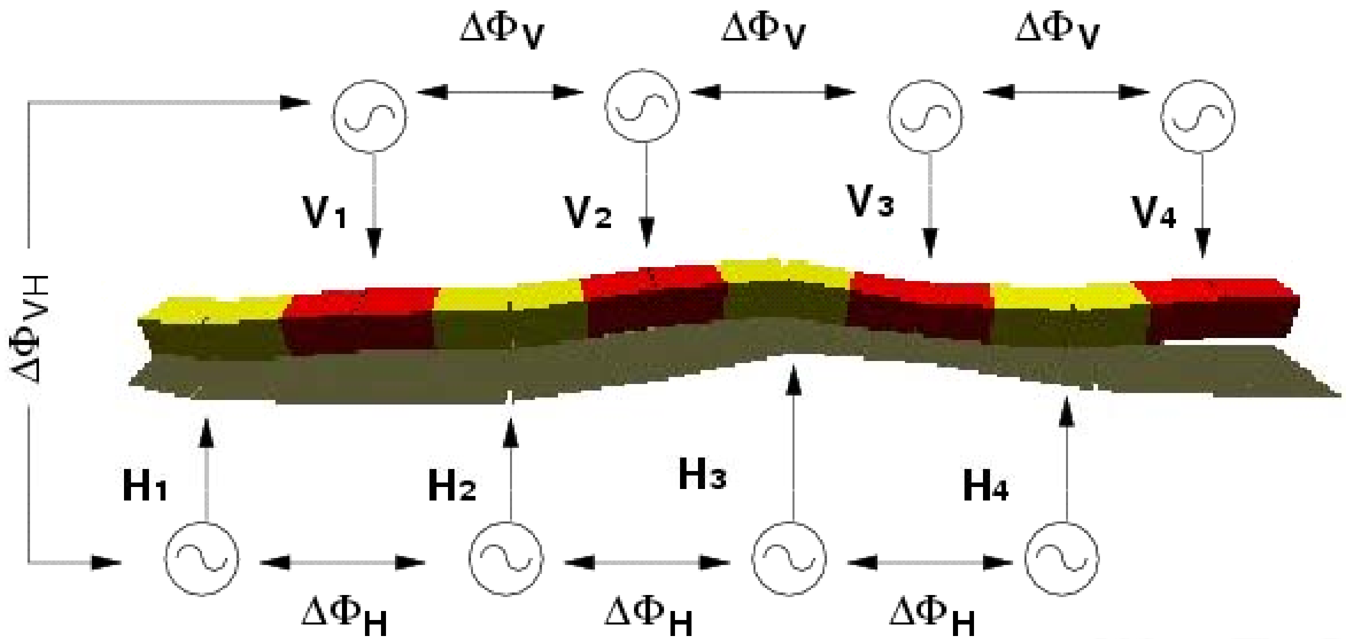
Locomotion controlling method

- The sinusoidal generators produce very smooth movements and have the advantage of making the controller much simpler. Our model is described by the following equation .

$$y_i = A_i \sin(\frac{2\pi}{T} t + \phi_i) + O_i$$

- Where y_i is the rotation angle of the corresponding module; A_i is the amplitude; T is the control period; t is time; Φ_i is the phase; O_i is the initial offset.

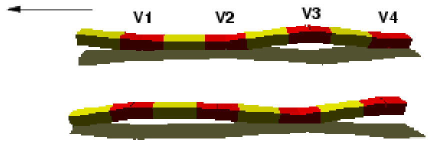
Locomotion controlling method (cont’)



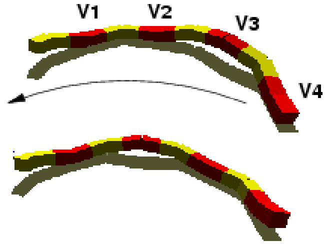
- They are divided into horizontal and vertical groups, which are described as H_i and V_i respectively. Where i means the module number;
- $\Delta\Phi_V$ is the phase difference between two adjacent vertical modules;
- $\Delta\Phi_H$ is the phase difference between two adjacent horizontal modules;
- $\Delta\Phi_{HV}$ is the phase difference between two adjacent horizontal and vertical modules.

Locomotion capabilities

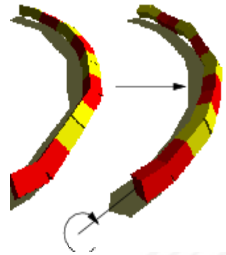
- Linear gait
  - Forward and backward movement



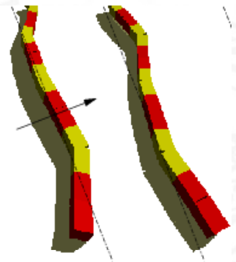
- Turning gait
  - Turn left and right; or the robot moves along an arc



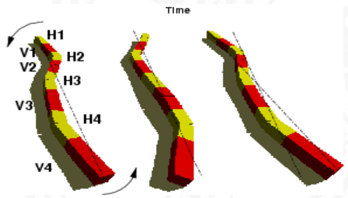
- Rolling gait
  - The robot rolls around its body axis



- Lateral shift
  - The robot moves parallel



- Rotation
  - The robot rotates around its body axis



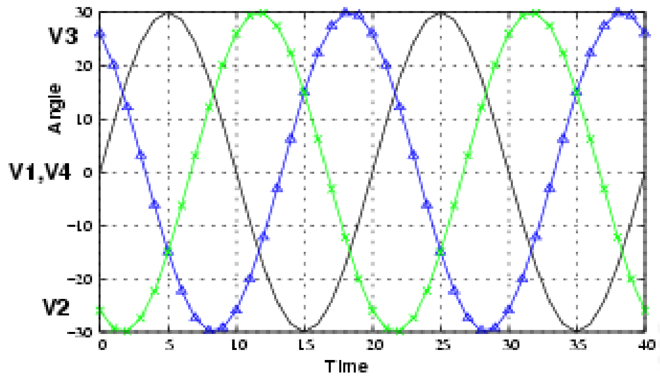
Locomotion capabilities-linear gait

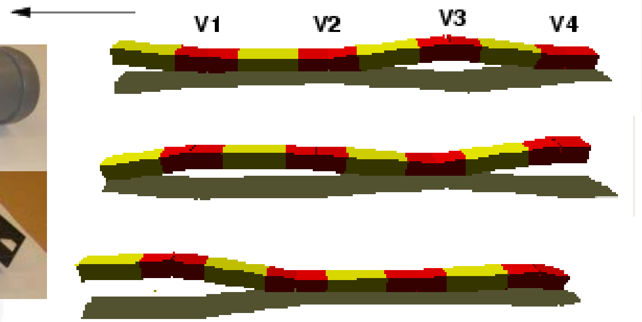
- **Parameters**:

$A_V \neq 0$ $A_H = 0$

$O_V = 0$ $O_H = 0$

$\Delta\Phi_V = 120$





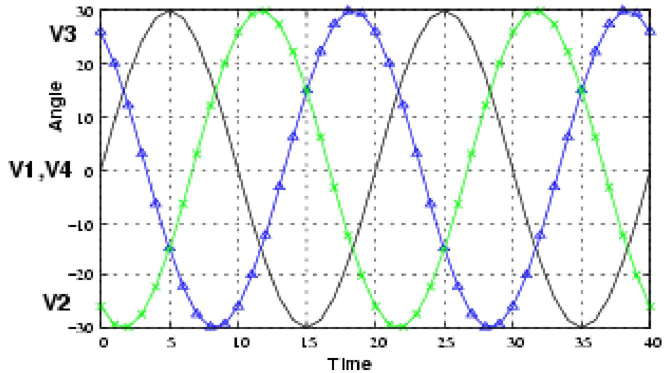
Locomotion capabilities-turning gait

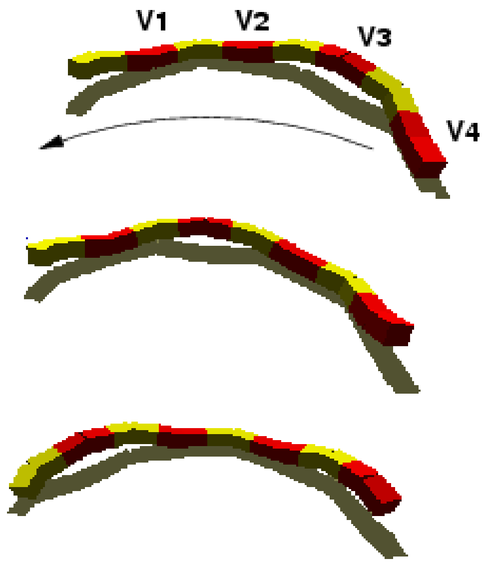
- **Parameters**:

$A_V \neq 0$ $A_H = 0$

$O_V = 0$ $O_H \neq 0$

$\Delta\Phi_V = 120$





Locomotion capabilities-rolling gait

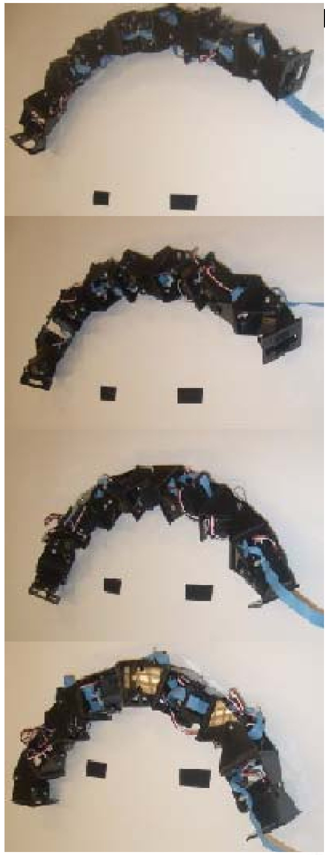
- **Parameters**:

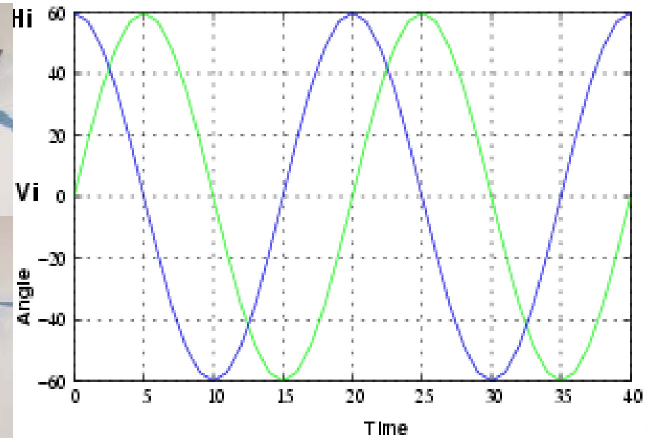
$A_V \neq 0$ $A_H \neq 0$

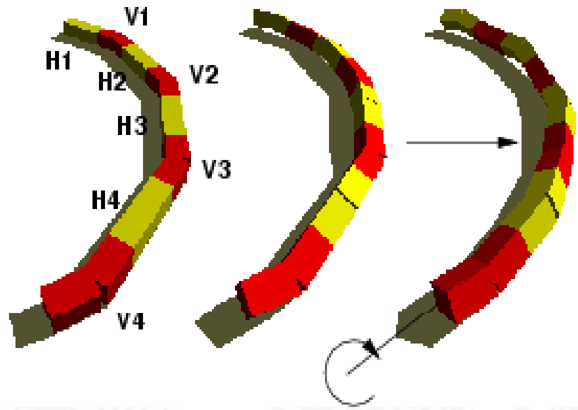
$O_V = 0$ $O_H = 0$

$\Delta\Phi V = 0$ $\Delta\Phi V = 0$

$\Delta\Phi VH = 9\ 0$







Locomotion capabilities-lateral shift

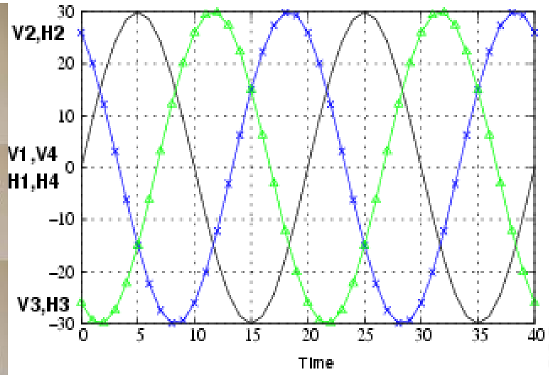
- **Parameters**:

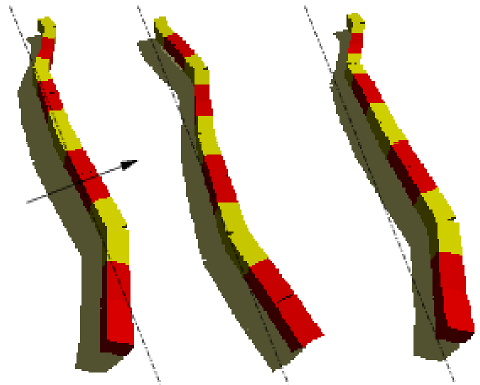
$A_V \neq 0$ $A_H \neq 0$

$O_V = 0$ $O_H = 0$

$\Delta\Phi_V = 100$ $\Delta\Phi_V = 100$

$\Delta\Phi_{VH} = 0$





Locomotion capabilities-rotating gait

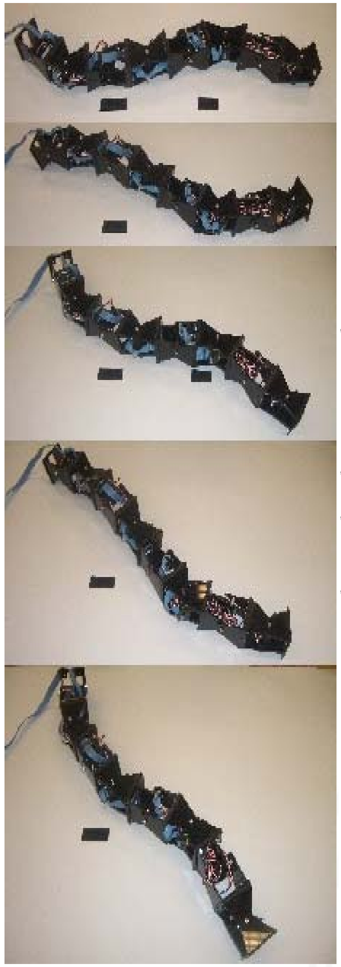
- **Parameters**:

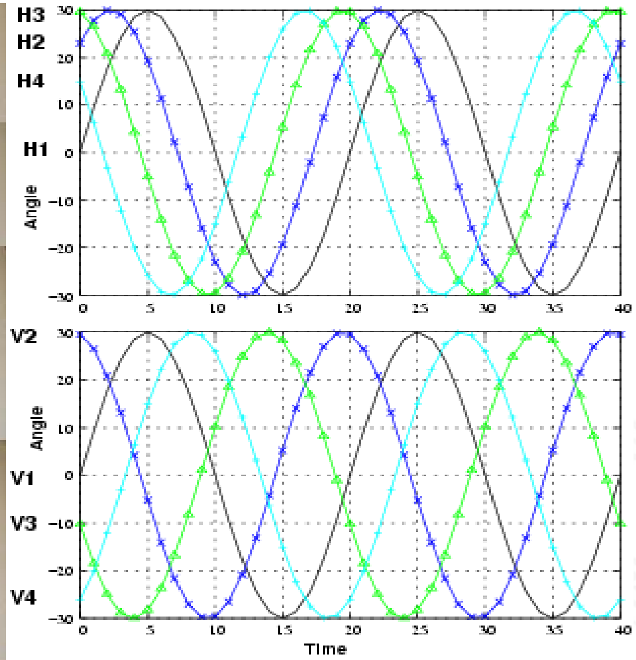
$A_V \neq 0$ $A_H \neq 0$

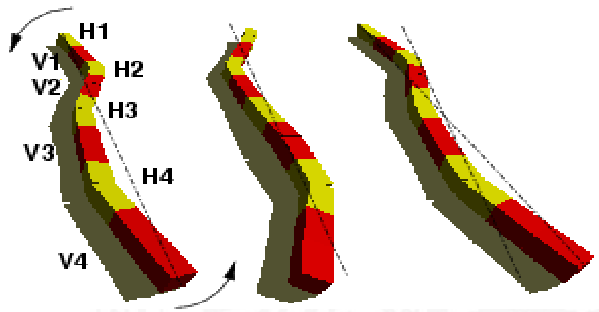
$O_V = 0$ $O_H = 0$

$\Delta\Phi V=120$ $\Delta\Phi V=50$

$\Delta\Phi VH = 0$

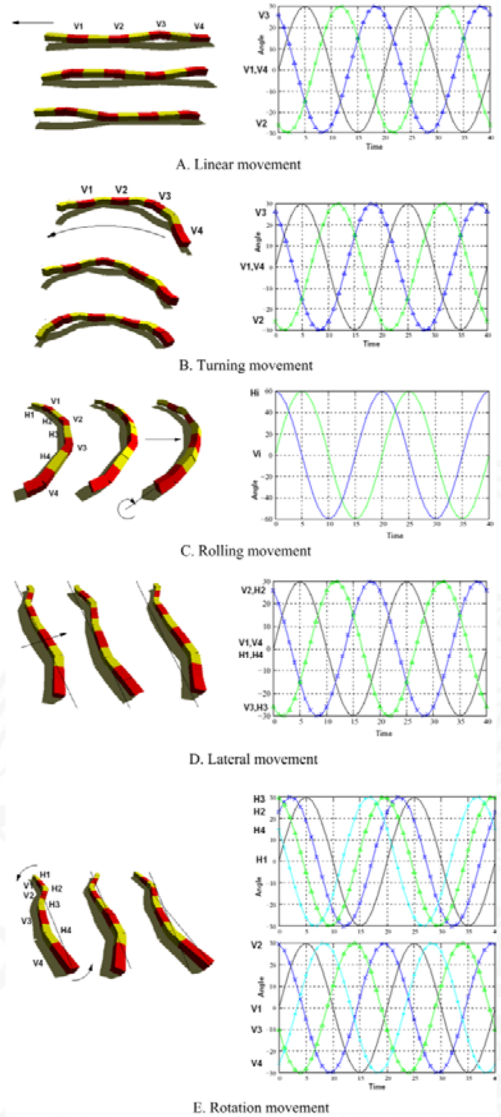




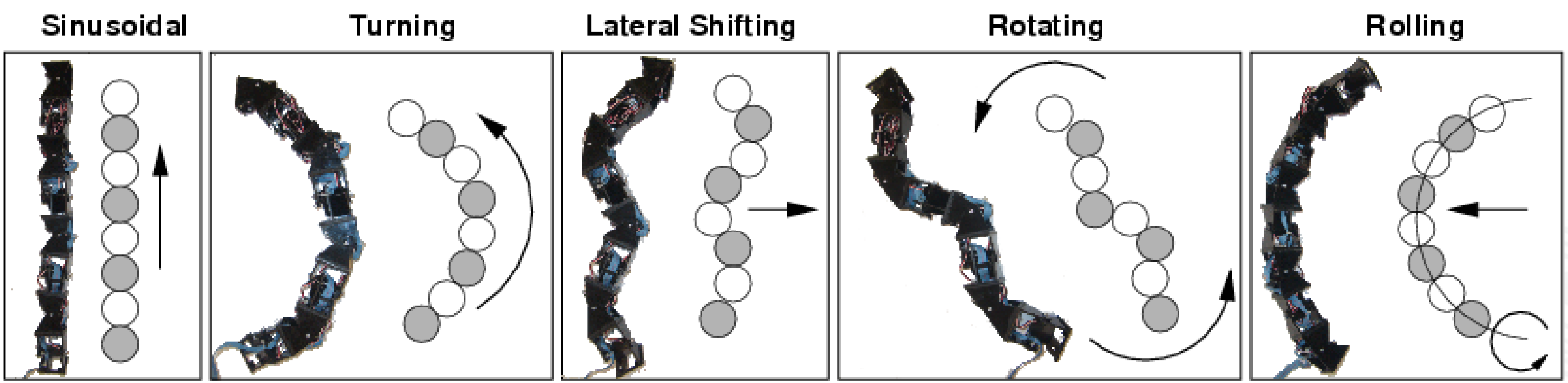


Summary

Gate types	Parameters for sinusoidal generators	
Linear movement	A_{Vi} 0; A_{Hi}=O_{Vi} =0	$\Delta\Phi_V$=100-120, O_{Hi} 0
Turning movement		$\Delta\Phi_V$=100-120, O_{Hi}=0
Rolling movement	A_{Hi}, A_{Vi} 0; O_{Hi}=O_{Vi} =0	$\Delta\Phi_V$=$\Delta\Phi_H$=0, $\Delta\Phi_{VH}$=90
Lateral movement		$\Delta\Phi_V$=$\Delta\Phi_H$=100, $\Delta\Phi_{VH}$=0
Rotation movement		$\Delta\Phi_V$=120, $\Delta\Phi_H$=0, $\Delta\Phi_{VH}$=50

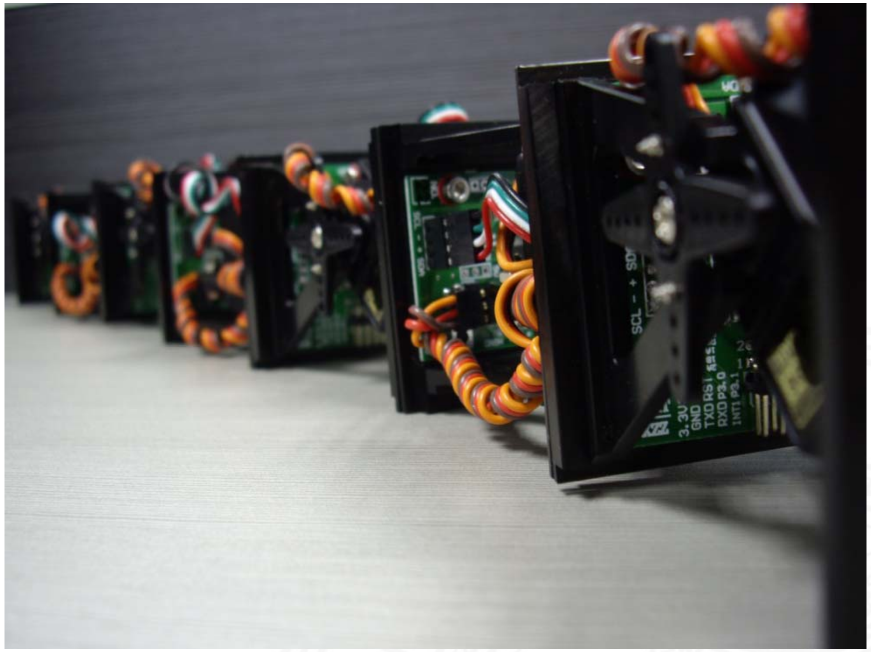


Summary



$A_V \neq 0$ $A_H = 0$ $O_V = 0$ $\Delta\Phi_V = 120$		$A_V \neq 0$ $A_H \neq 0$ $O_H = 0$ $O_V = 0$		
$O_H = 0$	$O_H \neq 0$	$\Delta\Phi_{VH} = 0$ $\Delta\Phi_H = 100$ $\Delta\Phi_V = 100$	$\Delta\Phi_{VH} = 0$ $\Delta\Phi_H = 50$ $\Delta\Phi_V = 120$	$\Delta\Phi_{VH} = 90$ $\Delta\Phi_H = 0$ $\Delta\Phi_V = 0$

Testing and demos



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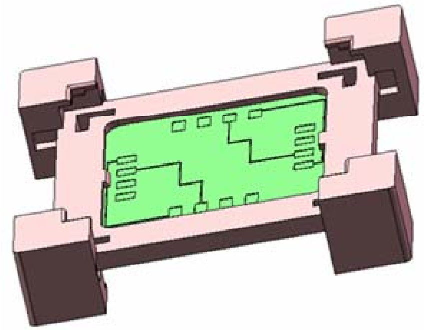
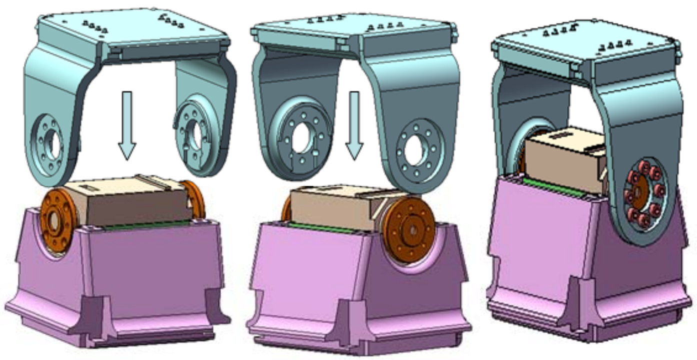
Current research

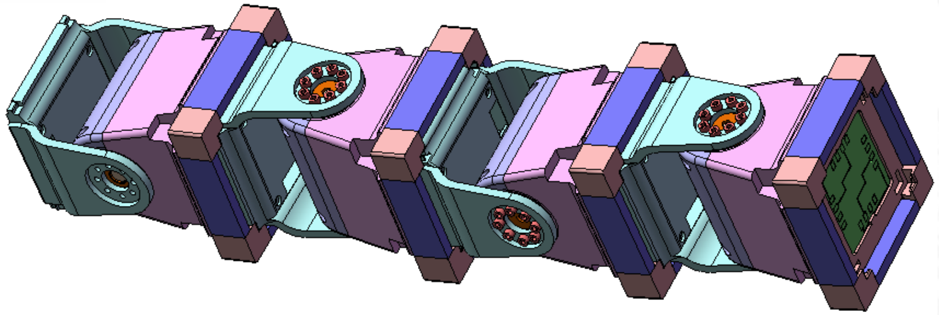
- New version of modular robot
- New modular robotic configuration
- Modular grasping
- Modular climbing caterpillar robot
- Locomotion capability of modular limbless configuration

New version of modular robot

- Strong and robust
- With more mechanical parts in ABS material
- With more connecting possibilities
- With sensor interface

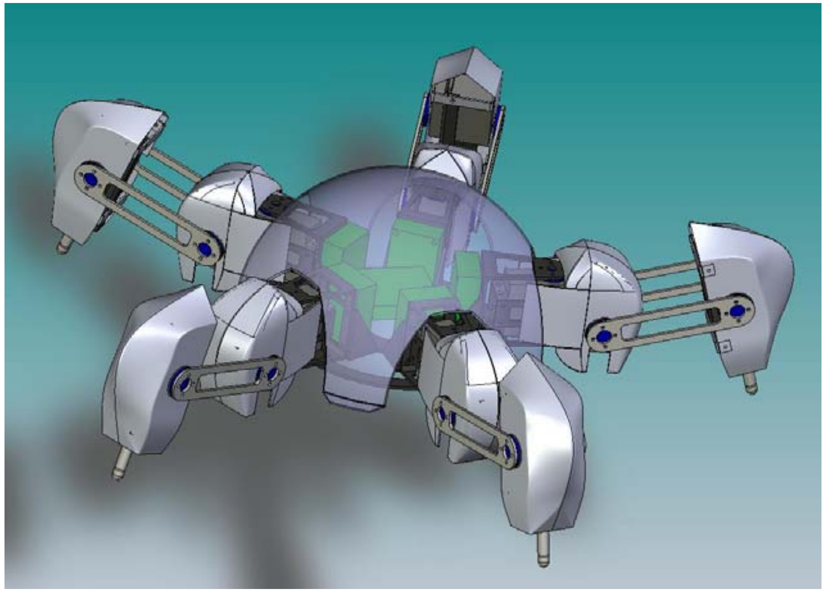


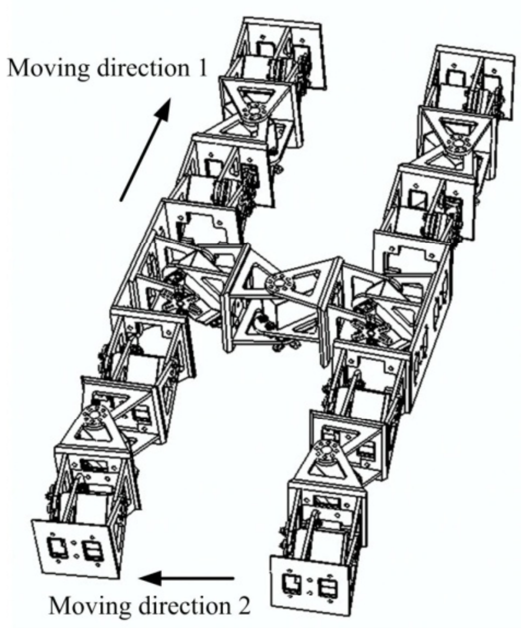




New modular robotic configuration

- "H" Structure
- Five-legs configuration





Modular grasping

- Melting various grasping and flexible mobility based on modular approach

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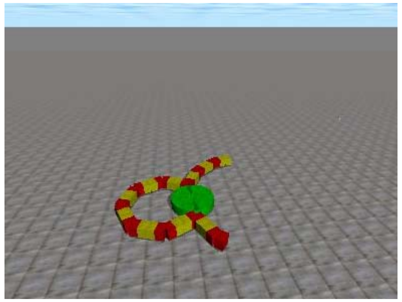

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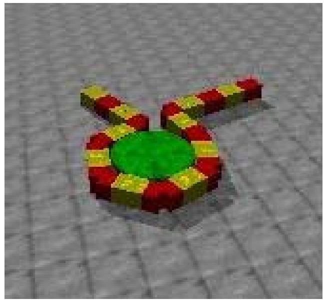
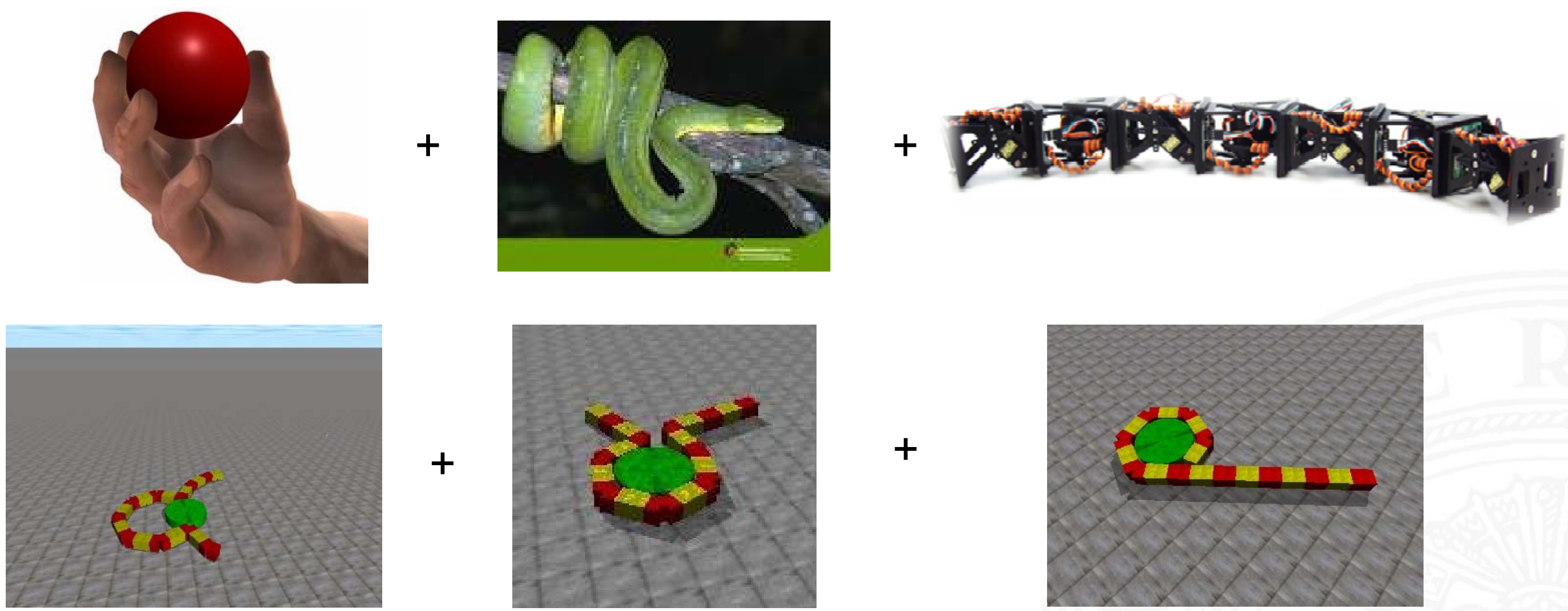


- From kinematics viewpoint, a solid result to confirm the idea

Modular grasping

- Melting various grasping and flexible mobility based on modular approach



- From kinematics viewpoint, a solid result to confirm the idea

Related publications

- H. Zhang, J. González-Gómez, "**Design and Development of Low-cost Modular robot-GZ-I**", Proceeding of AIM2008, Xi'an, 2-5, July, China.
- H. Zhang. (2007), "***A Bio-inspired Climbing Caterpillar***", Patent (200710056722.9).
- J. González-Gómez, H. Zhang, et.al. "***Locomotion Capabilities of a Modular Robot with Eight Pitch-Yaw-Connecting Modules***", The 9th International Conference on Climbing and Walking Robots and their Supporting Technologies for Mobile Machines, CLAWAR2006, Brussels, Belgium, September 12-14, 2006.
- J. Gonzalez-Gomez, H. Zhang, E. Boemo, "**Locomotion Principles of 1D Topology Pitch and Pitch-Yaw-Connecting Modular Robots**", One Chapter in Book of " Bioinspiration and Robotics: Walking and Climbing Robots ", 2007, pp.403-428.
- H. Zhang, J. Gonzalez-Gomez, S. Chen, W. Wang, R. Liu, D. Li, J. Zhang, "***A Novel Modular Climbing Caterpillar Using Low-frequency Vibrating Passive Suckers***", Proceeding of 2007 IEEE/ASME International Conference on Advanced Intelligent Mechatronlics, ETH Zurich , Switzerland, 4 - 7 Sept.2007.

Thanks for your attention!

Any questions?