Proseminar Roboter und Aktivmedien

Modular robots achievements

Lecturer

Houxiang Zhang

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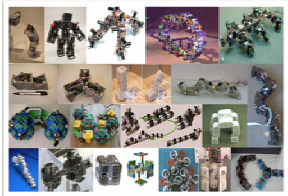

@Tams/hzhang

Outline of today’s lecture

- 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
- Conclusions

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/

- My colleague *Juan Gonzalez-Gomez* from the School of Engineering, Universidad Autonoma de Madrid in Spain.

- 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.

Technical Aspects of Multimodal System
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University of Hamburg

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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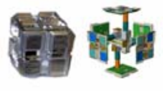

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What is a modular robot

- Definition
- Structures
- Features



What is a modular robot ?

- Definition?
  - Modular self-reconfiguring robotic systems are autonomous kinematical machines with variable morphology. Beyond conventional actuation, sensing and control typically found in fixed-morphology robots, self-reconfiguring robots are also able to deliberately change their own shape by rearranging the connectivity of their parts, in order to adapt to new circumstances, perform new tasks, or recover from damage.

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 that allow for the transfer of mechanical forces and moments, electrical power and communication throughout the robot.
  - The modular building blocks usually consist of some primary structural actuated unit, and potentially additional specialized units such as grippers, feet, wheels, cameras, payload and energy storage and generation.

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. The reconfiguration ability allows a robot or a group of robots to disassemble and reassemble machines to form new morphologies that are better suited to new tasks, such as changing from a legged robot to a snake robot and then to a rolling robot. Since robot parts are interchangeable (within a robot and between different robots), machines can also replace faulty parts autonomously, leading to self-repair.
- 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

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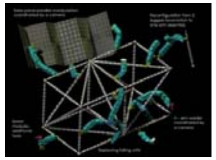

  - *One application area that highlights the advantages of self-reconfigurable systems is long-term space missions. These require long-term self-sustaining robotic ecology that can handle unforeseen situations and may require self repair. Self-reconfigurable systems have the ability to handle tasks that are not known apriori especially compared to fixed configuration systems. In addition, space missions are highly volume and mass constrained. Sending a robot system that can reconfigure to achieve many tasks is better than sending many robots that each can carry out only one task.*

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

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. When the need arises, the consumer calls forth the robots to achieve a task such as "clean the gutters" or "change the oil in the car" and the robot assumes the shape needed and carried out the task. 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). This architecture underlies biological systems' ability to physically adapt, grow, heal, and even self replicate – capabilities that would be desirable in many engineered systems. (Example)*

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

Modular robot technology

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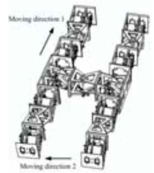
  - Inspired research.



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

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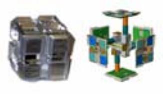

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Classification of modular robots

- 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. Chain architectures can reach any point in space, and are therefore more versatile but more computationally difficult to represent and analyze. Tree architectures may resemble a bush robot.
  - Lattice
    - Arranged and connected in some regular, space-filling three-dimensional pattern, such as a cubical or hexagonal grid. Control and motion are executed in parallel. Lattice architectures usually offer simpler a computational representation that can be more easily scaled to complex systems.
- Our classification

Chain topology

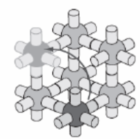
- Advantages
  - Easy to generate motion
  - few actuators needed

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

"Modular robots", Seminar presentation by Jan Gries, Eugen richter, Seminar on intelligent robot, winter semester 2007, Lecturer, Houxiang Zhang,

Lattice topology

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



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

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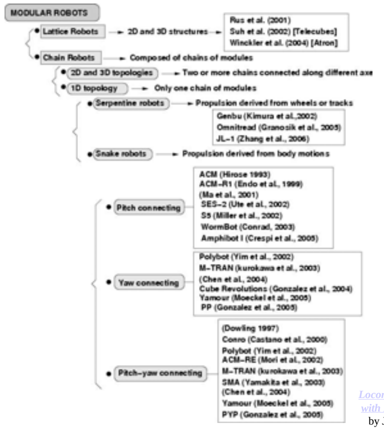

Locomotion Capabilities of a Modular Robot with Eight Pitch-Yaw-Connecting Modules, by Juan Gonzalez-Gomez, Houxiang Zhang

1D Topology:

Locomotion in 1D:

Locomotion in 2D:

Pitch-Pitch

8 pitch-connecting modules

Pitch-Yaw-Pitch

8 pitch-yaw-connecting modules

2D Topology:

Locomotion in 2D:

Star of 3 modules

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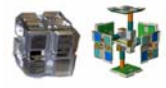
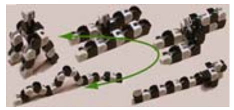


History of modular robots

- 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
  - With force torque sensors, whisker touch sensors, and infrared proximity sensors.



M-TRAN from Satoshi Murata et.al.

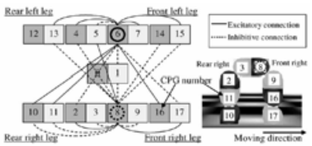
- Two blocks (active/passive) and a link
- Two parallel axes and six connectable surfaces
- Both blocks have 90 degrees rotation
- Mechanical connectors in active block
- 4 CPUs in a Master/Slave-Architecture
  - Master CPU: Algorithm computation and communication
  - Slave CPUs: Motor/Connection control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



"Modular robots", Seminar presentation by Jan Gries, Eugen richter, Seminar on intelligent robot, winter semester 2007, Lecturer Houxiang Zhang.

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 that does not require the modules to have unique IDs.


http://www.isi.edu/

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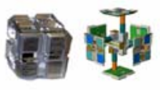

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Challenging

- Big systems:
  - Most systems of modular robots have been small in number, especially compared to, for example, the number of components in a living cell (which many researchers view as the best example of a self-organizing modular system).
  - 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.
  - It will also require new distributed algorithms that account for noise, errors, failures, and changing connection topologies.

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

- Self-repairing systems:
  - Besides reconfiguring itself into a new shape, a system comprised of modular robots would be able to recover from serious damage, such as that which might result from an external collision or internal failure.
  - 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 for reconfiguration that work from any initial condition.
  - A concrete example would be having a system blown up (randomly separated into many pieces) and then self-assemble, or recover from failure of a certain percentage of faulty units.

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Challenging

- Self-sustaining systems:
  - Recently, NASA pushed a concept called Robosphere that looks at creating a self-sustaining robotic ecology, isolated for a long period of time, which needs to sustain operation and accomplish unforeseen tasks without any human presence.
  - The current state of the art with modular robots is nowhere near this goal, and so a demonstration of a system actively running for, say, one year is crucial. New techniques in power management and energy harvesting would be required, as well as the ability to cope with the inevitable failures that would occur in such a long mission.

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Challenging

- Self-replication and self-extension:
  - While simple robotic self-replication has been demonstrated using a few high-level modules, a significant challenge remains to demonstrate self-replication using many low-level modules, and ultimately from elementary components and even raw materials.
  - Such a system could build active elements as well as passive structures, leading to a self-replicating and even self-improving system from environmental resources.
  - The demonstration of a "seed" group of modular robots that can build copies of themselves from raw materials would require advancing beyond a level of complexity that Von Neumann identified as essentially the equivalent of the sound barrier for engineered systems.

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Challenging

- Reconciliation with thermodynamics:
  - Most existing systems overcome entropy through brute force and unreasonable amounts of energy. Molecular systems, on the other hand, employ random diffusive processes in fundamental ways.
  - Furthermore, they are entirely robust to the intrinsic noise found at the nanoscale. If modular robots are to be miniaturized to micro- and/or nanoscale, or if the ideas discovered in this community are even to be tied to nanotechnology, the stochastic nature of nanoscale systems must be addressed.
  - The demonstration of a system where stochastic fluctuations are the dominant factor would represent a fundamental advance: For example, pour a large collection (e.g., 1,000) of simple robots into a solution, mix them, and have them aggregate into a predetermined structure, independent of initial conditions.

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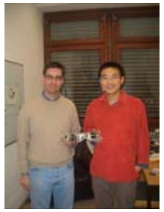
Modular robot cooperation

- Since 2006, my Spanish friend Juan González-Gómez and I have been working on the modular robot project.

At TAMS, Feb. 2006

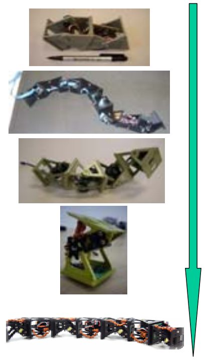
In Brussels, Sept. 2006



At TAMS, Dec.2006

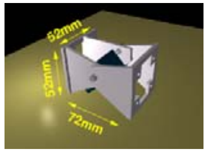
Modular robot cooperation

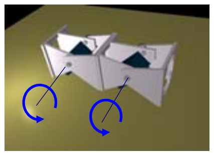
- Y1 module, 2004
- Y1 modular minimmin configuration, 2005
- Y1 pitching-yawing connecting research, 2006
- GZ-I mechanical improvement design, 2006
- GZ-I system integration, 2007
- Related research, 2008.
- The GZ-I was started in 2006.
  This system has been developed and is currently still under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

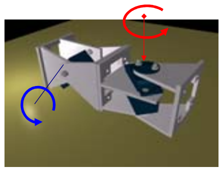


Y1 module

- **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**:

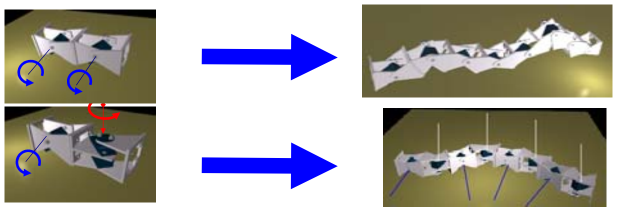






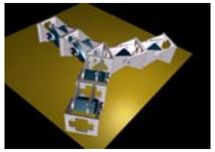
Possible tasks using the Y1 module

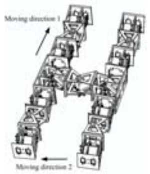
- 1D Topology
- 8 Pitch-yaw connecting modules
- 4 rotate around the pitch axes
- 4 rotate around the yaw axes
- Based on the Y1 modules



Other interesting possibilities

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





Other interesting possibilities

- Other possibilities
  - Three-legged robot
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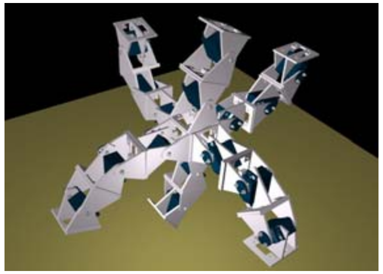
  - Biped robot

- Be creative!



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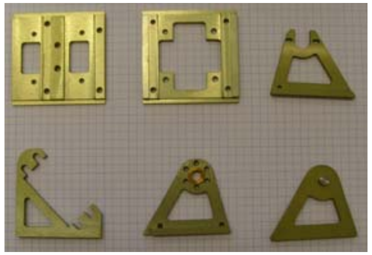
GZ-I system introduction

- 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.
  - *Cost-efficient mechanical design with only six aluminium parts making up a strong module;*
  - *Simple robust modules that can be assembled manually and in a quick-to-build, easy-to-handle design;*
  - *Four faces for interconnecting modules to implement pitching and yawing movements, and two crossed connecting modes so that the system can be extended to build different kinds of inspired robots*
  - *Onboard controller and sensors completing the system and making sensor-servo-based active perception of the environment possible.*

Build your first module

- Step 1
  - Find all six mechanical parts, some blots and blot caps;

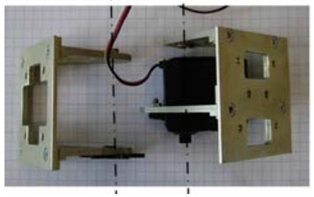


Build your first module

- Step 2
  - Firstly the driving RC servo is fixed to the mechanical ear 5 using bolts through four holes while the rotating plate of the servo is fixed to the mechanical ear 8.

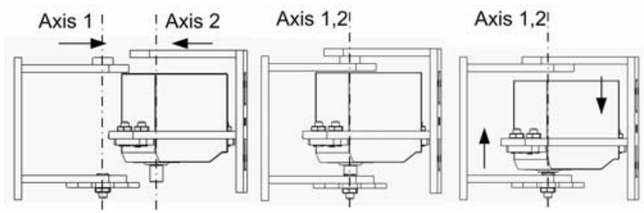
Build your first module

- Step 3
  - Then we fix the mechanical ears 2 and 8 with the rotating plate to the left connecting face by blots respectively. Now the left part of the GZ-I module is finished.
  - In the same way, the mechanical ears 3 and 5 with RC servo will be fixed to the right connecting face, as shown below.



Build your first module

- Step 4
  - The left part and right part approach each other, superimposing axes 1 and 2.



(a) *(b)* *(c)*

Fig. Assemble procedure (From the top view)

Build your first module

- Step 5
  - Firstly power on the servo, let the servo rotate to “0” degree position.
  - then the two modules will connect automatically as soon as the rotating plate is fixed to the servo again.

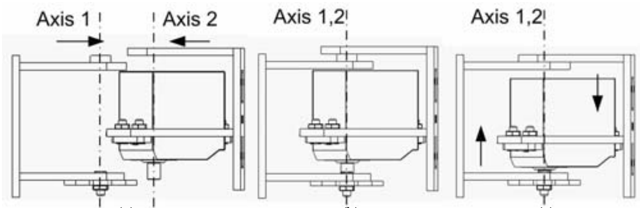
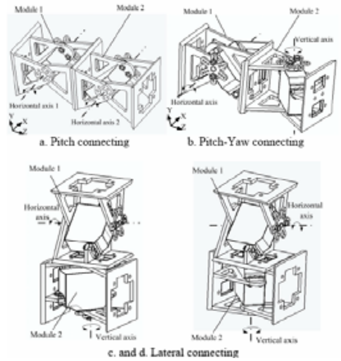
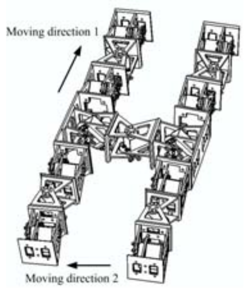


Fig. Assemble procedure (From the top view)

GZ-I with four connecting faces

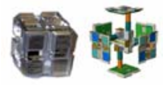


Robots with various shapes



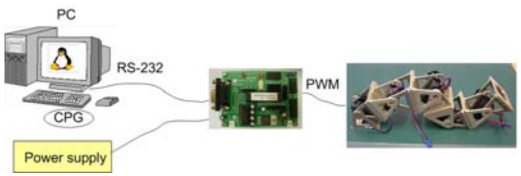
Outline of today’s lecture

- 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
- Conclusions



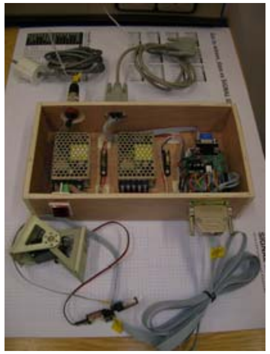
Control hardware realization

- 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



Components

- Control box with a controller
- Cable for power
- Serial port cable (PC to the control box)
- Output cable
- Two connectors
- Modules



Introduction to the controller

- Two different independent power supplies are needed.
  - Apply **+8 to +12v dc** to the MSCC20 PWR connector. This power supply is for the electronic part. The current needed is very low: 10mA.
  - Apply **+5 to 6.5v dc** to the S+ servos connector (J-connector at HDR1) . This is the power supply for the servos.
- Very simple commands in ASCII to control the movements of RC servos.

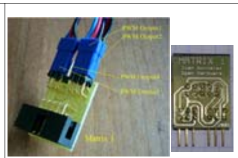
Control your module

- Step 1
  - Make sure the control box is switched off;
  - Connect the PC and control box with a RS232 cable;

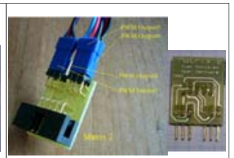
Control your module

- Step 2
  - Connect the control box and three modules with output cable (Matrix 1, output 1,2, 3);
  - !!!CONNECTION Between servos and Matrixes

PWM outputs



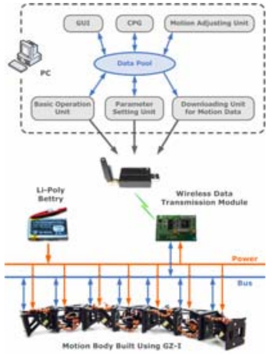
Matrix 1



Matrix 2

Attention: "Red" is 5V; "Black" is GND; "Blue" is the PWM signal; S3003 servo the signal is "White" as shown in the left picture.

System integration of GZ-I (wireless)



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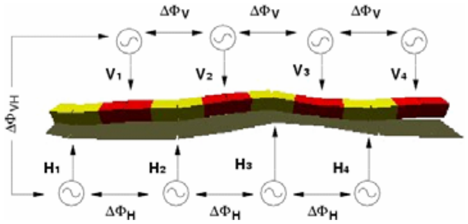
Locomotion controlling method

- 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.

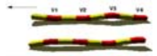
Locomotion controlling method (cont')



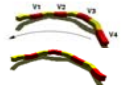
- They are divided into horizontal and vertical groups, which are described as H_i and V_i respectively. Where i means the module number;
- $\Delta \Phi_V$ is the phase difference between two adjacent vertical modules;
- $\Delta \Phi_H$ is the phase difference between two adjacent horizontal modules;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

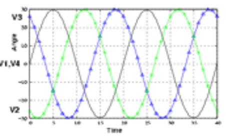
Locomotion capabilities-linear gait

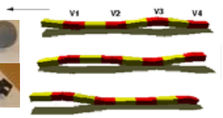
- **Parameters**:

$A_V \neq 0$ $A_H = 0$

$O_V = 0$ $O_H = 0$

$\Delta \Phi v = 120$





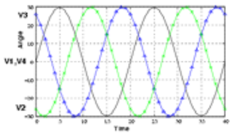
Locomotion capabilities-turning gait

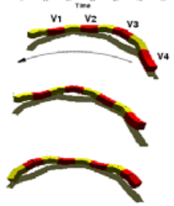
- **Parameters**:

$A_V \neq 0$ $A_H = 0$

$O_V = 0$ $O_H \neq 0$

$\Delta \Phi v = 120$





Locomotion capabilities-rolling gait

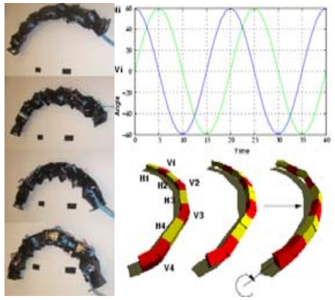
- **Parameters**:

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

$O_V = 0$ $O_H = 0$

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

$\Delta \Phi VH = 90$



Locomotion capabilities-lateral shift

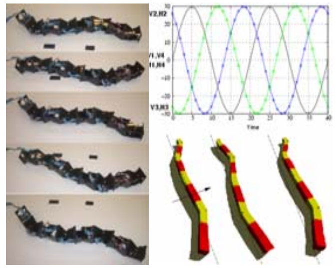
- **Parameters**:

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

$O_V = 0$ $O_H = 0$

$\Delta \Phi V=100$ $\Delta \Phi V=100$

$\Delta \Phi VH = 0$



Locomotion capabilities-rotating gait

- **Parameters**:

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

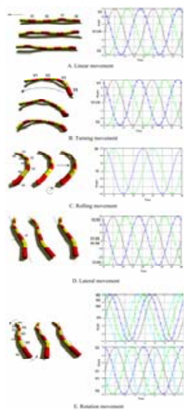
$O_V = 0$ $O_H = 0$

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

$\Delta \Phi VH = 0$

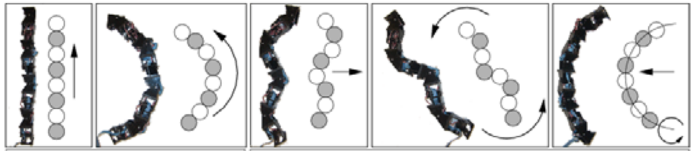
Summary

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

Sinusoidal	Turning	Lateral Shifting	Rotating	Rolling



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

Testing and demos

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Conclusions

- Brief introduction on modular robots
- Introduction to our modular system including Y1 and new improved GZ-I system
- Related topics presented in details, such as system realization, hardware design, locomotion controlling methods
- A series of relative simulations and tests confirm our design principles described above.

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?