Praktikum: 9

Introduction to modular robots and first try

Lecturers

Houxiang Zhang
Manfred Grove

TAMS, Department of Informatics
University of Hamburg, Germany

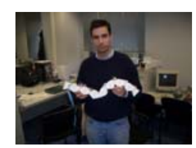
@Tams/hzhang

Outline of today's lecture

- What is a modular robot?
- Review of modular robots
  - Classification
  - History of modular robots
  - Famous prototypes
- From Y1 to GZ-I, our modular robot
  - Y1 modular robot and related research
  - GZ-I module
- Control your first module
- 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.

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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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  - Some famous prototypes introduction
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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 kinematic 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

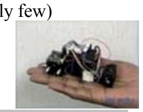
What is a modular robot ?

- 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
  - Testing new ideas

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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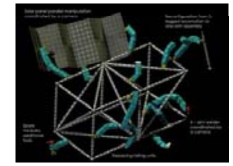

  - *One application area that highlights the advantages of self-reconfigurable systems is long-term space missions. These require long-term self-sustaining robotic ecology that can handle unforeseen situations and may require self repair. Self-reconfigurable systems have the ability to handle tasks that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

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
  - Space exploration;
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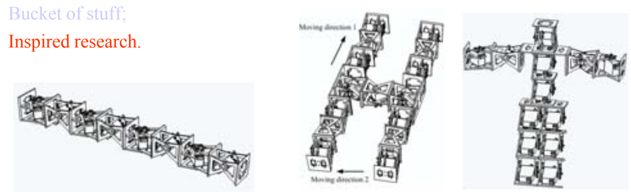
  - Inspired research.



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

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- From Y1 to GZ-I, our modular robot
  - Y1 modular robot and related
  - GZ-I module
- Control your first module
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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

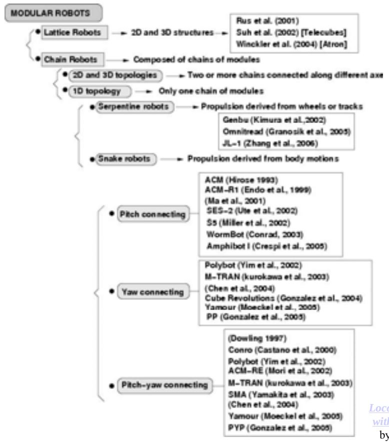
- Advantages
  - Easy to generate motion
  - few actuators needed

- Disadvantages
  - Few connections possibile
  - Hard to self-reconfiguration

Lattice topology

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

- Disadvantages
  - Difficult to generate motion
  - Many actuators required



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

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

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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Modular robot cooperation

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

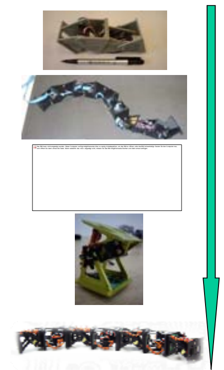
At TAMS, Feb. 2006

In Brussels, Sept. 2006

At TAMS, Dec.2006

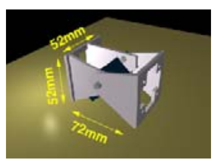
Modular robot cooperation

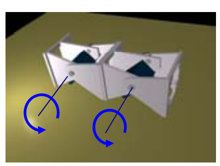
- Y1 module, 2004
- Y1 modular minimmin configuration, 2005
- Y1 pitching-yawing connecting research, 2006
- GZ-I mechanical improvement design, 2006
- GZ-I system integration, 2007
- Related research, 2008.
- The GZ-I was started in 2006. This system has been developed and is currently still under improvement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

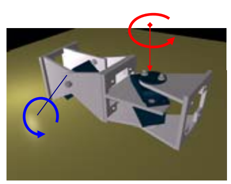


Y1 module

- **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**:

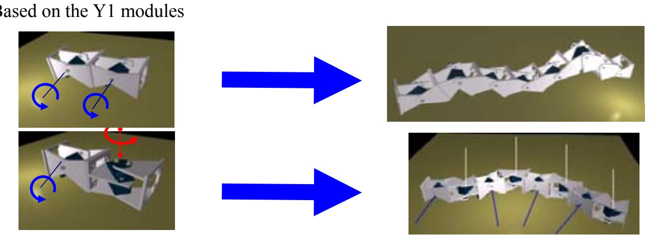






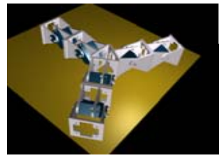
Possible tasks using the Y1 module

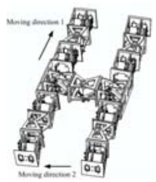
- 1D Topology
- 8 Pitch-yaw connecting modules
- 4 rotate around the pitch axes
- 4 rotate around the yaw axes
- Based on the Y1 modules



Other interesting possibilities

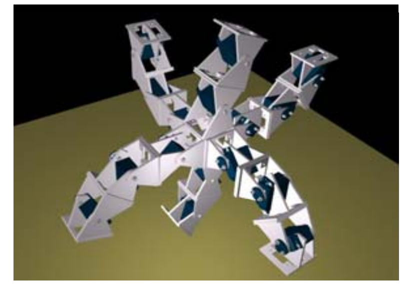
- Other possibilities
  - Three-legged robot
  - Four-legged robot
  - Six-legged robot
  - Biped robot





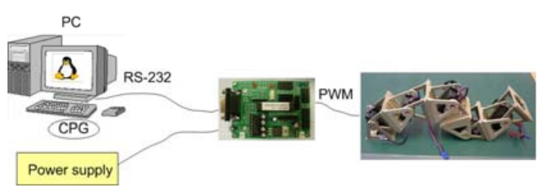
Other interesting possibilities

- Other possibilities
  - Three-legged robot
  - Four-legged robot
  - Six-legged robot
  - Biped robot
- Be creative!



Control hardware

- 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



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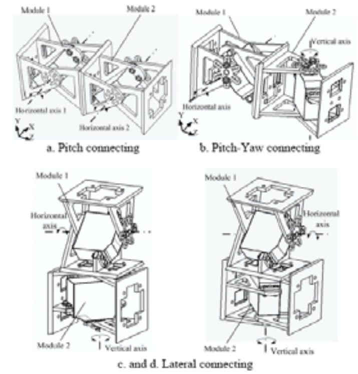
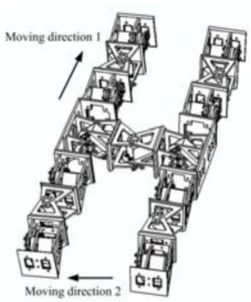
GZ-I system introduction

- 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.*

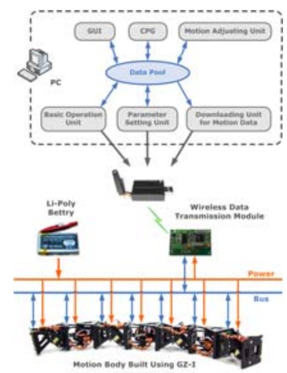
GZ-I with four connecting faces



Robots with various shapes



System integration of GZ-I (wireless)



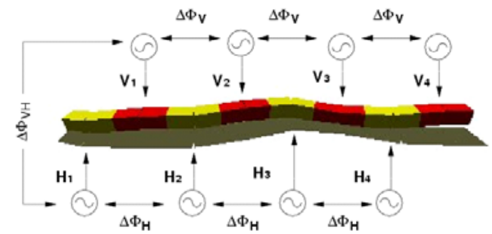
Locomotion controlling method

- 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.

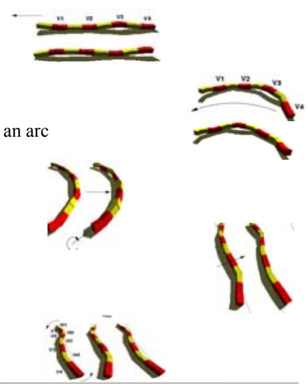
Locomotion controlling method (cont')



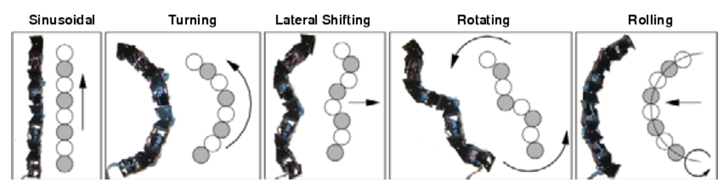
- They are divided into horizontal and vertical groups, which are described as H_i and V_i respectively. Where i means the module number;
- $\Delta\Phi_V$ is the phase difference between two adjacent vertical modules;
- $\Delta\Phi_H$ is the phase difference between two adjacent horizontal modules;
-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



Summary



Testing and demos

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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 first module

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

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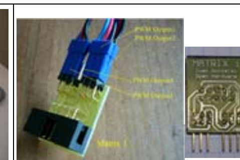
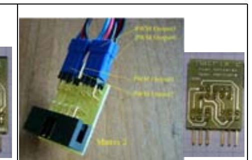
Control your first module

- 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.

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Control your first module

- Step 3
  - Power the control box;

- Now the system is ready for testing. A terminal program should be executed on the PC. This program lets us send commands to the controller.

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Control your first module

- Step 4
  - Run a terminal program to send commands to the control box;

- Hint:
  - The Hyperterminal program can be used on Windows PC, or the minicom for the Linux systems. They should be configured to work at 9600 bauds.

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Control your first module

- Step 5
  - Switch “On” the control box;

- Hint:
  - When the power is applied to the controller, the following message appears on the terminal:
    - 02.02 Oricom BCP28-MSC (c)2005
    - no cfg

Control your first module

- Step 6
  - The board is waiting for the commands. In order to test the servos, the following commands can be used. After each command, the return key should be pressed.
    - FE

- Hint:
  - This command will activate the “echo” model, so that the commands you type will be shown on the screen.

Control your first module

- Step 7
  - Then type the following commands one by one:
    - SO ---turn all servos on
    - SE00 ---enable channel 0
    - SE01 ---enable channel 1
    - SE02 ---enable channel 2
  - After that, the servos will be activated.

- Hint:
  - The meanings of related commands are shown in the documents.

Control your first module

- Step 8
  - Finally, the next command will move all the servos from one position to another:
    - YT40C0 ---move the modules

- Hint:
  - The meanings of related commands are shown in the documents.

Praktikum: 10

Single module control

Lecturer

Houxiang Zhang
Manfred Grove

TAMS, Department of Informatics
University of Hamburg, Germany

@Tams/hzhang

Please read the documents carefully
for the next week!!!

Thanks for your attention!

Any questions?