Proseminar Roboter und Aktivmedien

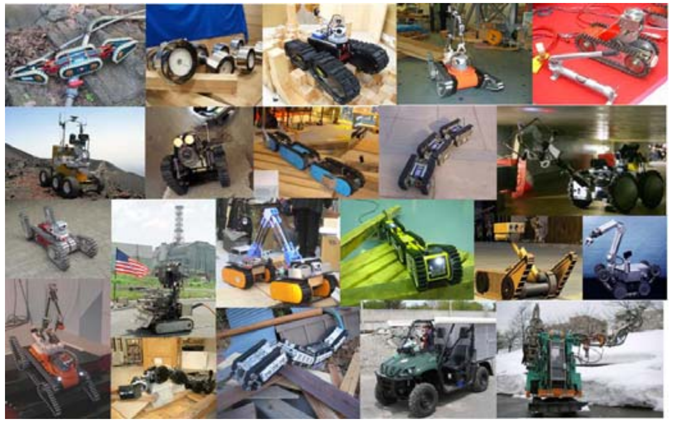
Urban Search and Rescue robots achievements and challenging

Lecturer

Houxiang Zhang

TAMS, Department of Informatics
University of Hamburg, Germany

http://sied.dis.uniroma1.it/ssrr07/



Outline of today’s lecture

- What is a urban search and rescue robot ?
- Review of urban search and rescue robots
  - Brief introduction to research background
  - Several famous prototypes
  - Challenging issues
- Introduction to JL-I modular rescue robot
  - Basic functions of urban search and rescue robots
  - A novel rescue robot
  - Locomotion capability
  - Experiments
  - Conclusions
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What is a rescue robot?

- A **rescue robot** is a robot that has been designed for the purpose of aiding rescue workers. Common situations that employ rescue robots are mining accidents, urban disasters, hostage situations, and explosions.
- The benefits of rescue robots to these operations include reduced personnel requirements, reduced fatigue, and access to otherwise unreachable areas.

http://en.wikipedia.org/wiki/Rescue_robot

Lecture material

- ***Rescue Robots and Systems in Japan***, F. Matsuno, S. Tadokoro: Proceedings of Robio2004, Shenyang, China, 22-26 Aug. pp.12-20.
- ***The Impact of Autonomy and Reasoning on Social Roles for Robotics,*** Matthew T. Long, Robin R. Murphy, Journal of Artificial Intelligence Research, 2006, pp.1-10.
- ***Human-Robot Interactions during the Robot-assisted Urban Search and Rescue Response at the World Trade Center***, J. Casper, MS Thesis, Computer Science and Engineering, USF, April, 2002.
- ***A Novel Reconfigurable Robot for Urban Search and Rescue,*** H.X. Zhang, W. Wang, Z.C. Deng, G.H. Zong, International Journal of Advanced Robotic Systems, Vol.3 No.4, pp.359-366, 2006.

Web links on search and rescue robots

- **IEEE Robotics and Automation Society(RAS)**
  - http://www.ncsu.edu/IEEE-RAS
- **European Robotics research Network (EURON)**
  - http://www.euron.org/
- **International Rescue System Institute**
  - http://www.rescuesystem.org
- **Center for Robot Assisted Search and Rescue**
  - http://crasar.csee.usf.edu/rescuerobots/history.htm

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Reasons for designing rescue robots

- The history of human development has always been a struggle with natural disasters such as earthquakes, storms and floods.
- Recently the number of disasters by accidents or terrorism has evidently been increasing, such as the explosion in Madrid 2004.
- Civil search and rescue is a domain that involves a great amount of human labor; and it is quite dangerous and laborious in a hostile environment.

Reasons for designing rescue robots

- **A lot of examples using robots for rescue purposes recently**
  - In Japan, some prototypes aiming to mitigate the damages and decrease the number of victims during accidents and disasters were achieved at the International Rescue System Institute.

http://www.rescuesystem.org/tmp/NEW/en/robot.htm

Reasons for designing rescue robots

- **A lot of examples using robots for rescue purposes recently**
  - Another good example is the use of robots for the search and detection operation in the collapsed World Trade Center in September 2001.
  - Meanwhile in Europe, security robotics has become an important part of the 7th Framework Programme.

http://www.rescuesystem.org/tmp/NEW/en/robot.htm

Brief introduction on research background

Urban Search and Rescue

- Emergency rescue involves threats to the lives of survivors and rescuers
- For robots to be effective they have to work cooperatively with rescuers and intimately with survivors
- Range of tasks requires several scales of robot, e.g. building triage (large), buried survivor seeking (small)
- Scope for dual-use technology

RUROBOTS
Cognitive Science at Work
NARRC

Urban Search & Rescue: Technology Innovations

- Robot-Robot Cooperation
  - Multi-robot mapping and localisation in a (very) dynamic environment
  - Cooperative / networked, dynamically positioned communication links
- Human-Robot Cooperation
  - Human-robot cooperative tasks, e.g. non-exoskeleton force amplifier
  - Safe overlapping workspace working with high-force, autonomous machine
- Multi-sensor Data Fusion
  - Vision / Audio / Bio-sensor victim / survivor identification
- System Architectures supporting cooperative working
  - Design-time & real-time modularity
  - Task sharing between controlled and non-controlled agents

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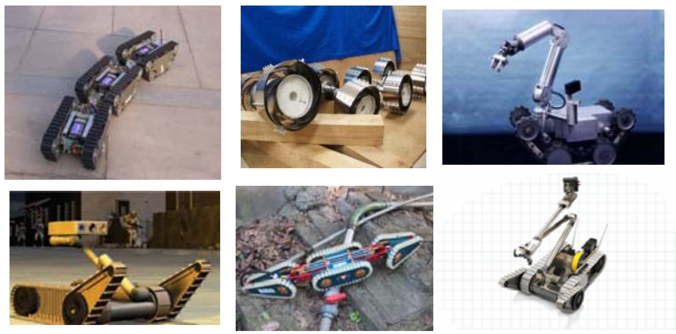
Urban search and rescue



Our prototype – JL-I

- JL-I consists of three uniform modules.
- 35 centimetres long, 25 centimetres wide and 15 centimetres high.
- Two powered tracks, a serial mechanism, a parallel mechanism, and a docking mechanism.
- Changing its posture by pitching, yawing and rotating.

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http://www.irobot.com/sp.cfm?pageid=150

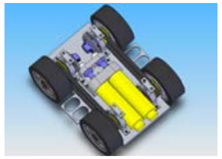
Wheeled robots- John Deere R-Gator

- A versatile and rugged platform capable of taking on a wide variety of critical unmanned missions, such as a perimeter guard, unmanned scout, “point man,” supply carrier and more.
- Combining the field-proven technologies, navigation and obstacle detection technologies jointly developed for critical missions.
- Offering the chance to evaluate unmanned vehicle technology advantages in numerous operational scenarios.
- In autonomous mode, numerous sensors to detect obstacles and guide the vehicle. With a single switch, the operator can transition to manual mode and drive the vehicle like a car.

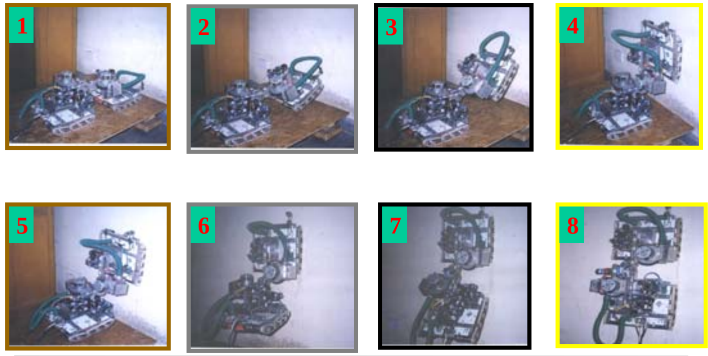
http://www.irobot.com/sp.cfm?pageid=141

A miniature wall-climbing platform

- **The second version**
  - We improved several aspects of the first version for in 2005-2006.
  - Much lighter and smaller
  - Sensors and wireless interface
  - Controlled in two different ways



Further prototype



Chain-tracked robots – OmniTread

- Use of pneumatic bellows for joint actuation. Bellows are powerful, naturally compliant, and take up minimal space.
- Maximal coverage of all sides of all segments with extra wide moving tracks.
- Unique pneumatic control method allows simultaneous proportional control of stiffness and joint angles.
- The "drive shaft spine" is powered by a single electric motor in the center segment. The spine runs through the center of all segments and provides torque to all tracks.

http://www.engin.umich.edu/research/mrl/00MoRob_6.html

Source: Prof. Christian Schindelhauer, http://cone.informatik.uni-freiburg.de/teaching/vorlesung/informatik-III-w07/index.html, Germany

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Literature

- Hirose, S.; et al., 1990
- Klaassen, B.; et al., 1999
- Yim, M.; et al., 2001
- Sahin, E.; et al., 2004
- Granosik, G.; et al., 2005
- Wang, T.M.; et al., 2005

- Relatively simple docking and pose-adjusting mechanisms
- Heavy weight and limited flexibility
- Working environment and limited locomotion capability

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Intelligent Robotics

A Novel Reconfigurable Robot for Urban Search and Rescue

Lecturer

Houxiang Zhang

TAMS, Department of Informatics
University of Hamburg, Germany

@Tams/hzhang

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Basic functions of rescue robots

- Locomotion capability
- Sensory perception
- Knowledge representation
- Planning
- Autonomy
- Collaboration

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Basic functions of rescue robots

- Locomotion capability
- Sensory perception
  - The robots have to sense what is in their environment in order to navigate in it, detect hazards, and identify goals. Sensor fusion is an important capability, as no single sensor will be able to identify or classify all aspects of the concerned area. These different goals are represented by a collection of different sensory signatures.
- Knowledge representation
- Planning
- Autonomy
- Cooperation

Basic functions of rescue robots

- Locomotion capability
- Sensory perception
- Knowledge representation
  - Knowledge representation is the next level. It encompasses the robot' s ability to model the world, using both a prior information and newly acquired information. Ideally, this would provide humans with a map of the environment they have explored. The environment that the robots operate in is three-dimensional, hence they should reason in and be able to map in three dimensions.
- Planning
- Autonomy
- Cooperation

Basic functions of rescue robots

- Locomotion capability
- Sensory perception
- Knowledge representation
- Planning
- Autonomy
  - The robots are designed to operate with humans. The level of interaction may vary significantly, depending on the robot's design and capabilities, or on the circumstances. Pure tele-operation is not a desirable mode for the robot's operation. The human should provide the robot with high level commands, such as "go to the room on the left" rather than joystick the robot in that direction.
- Cooperation

Basic functions of rescue robots

- Locomotion capability
- Sensory perception
- Knowledge representation
- Planning
- Autonomy
- Cooperation
  - Usually the complicated task is based on the cooperation in a team, such as a rescue and search implementation. The given targets will be assigned separately. Every robot should communicate with the others and perform distributed activities.

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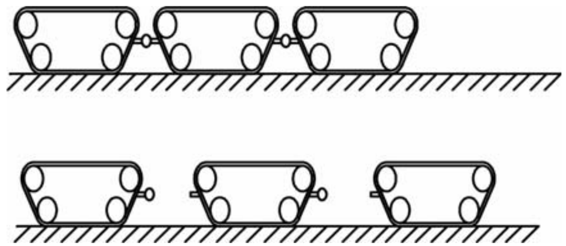
Our design idea

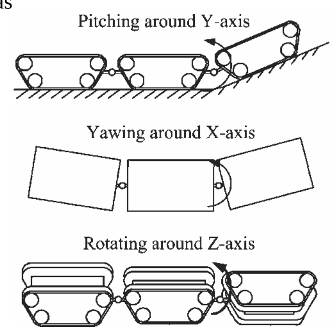
- What is the reconfigurable robot?
  - Reconfigurable robots consist of many modules which are able to change the way they are connected.
  - The modular approach enables mobile robots the reconfiguration capability which is very essential in such tasks which are difficult for a fixed-shape robot.

Overview – prototype design



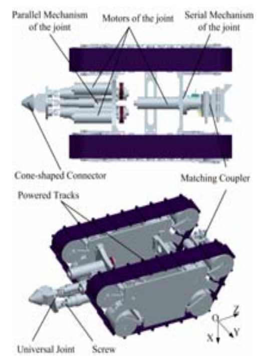
Overview – prototype design

- JL-I with three uniform modules was developed.
- Changing its posture by pitching, yawing and rotating.



JL-I mechanical realization

- 35 centimetres long, 25 centimetres wide and 15 centimetres high.
- Two powered tracks, a serial mechanism, a parallel mechanism, and a docking mechanism.
- It weighs approximately 7 kg including the batteries.



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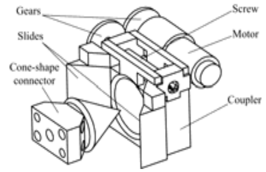
Overview-- a novel prototype

- Flexibility due to its uniform modules and special connection joints .
- Each module is an entire robot system that can perform distributed activities.
- Three DOF active spherical joints between two modules and the docking mechanism enable the adjacent robot to adopt optimized configurations to negotiate difficult terrain.

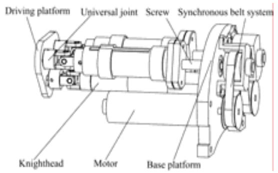
The docking mechanism

- A cone-shaped connector at the front and a matching coupler at the back.
- The sliders and the coupler with a matching funnel guide the connector to mate with the cavity and enable the modules to self-align with lateral and directional offsets.
- The locking mechanism including two sliders propelled by a motor-driven screw.
- After locking, two mating planes between the sliders and the coupler constrain the movement.

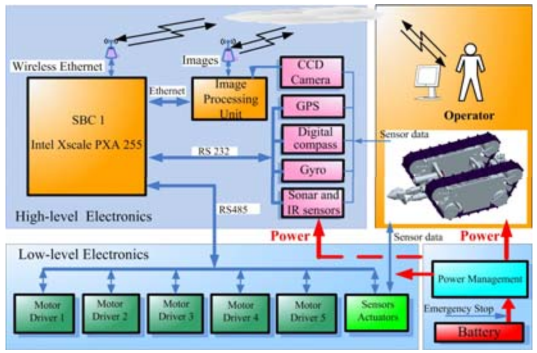


The serial and parallel mechanisms

- Two reasons for using the serial and parallel mechanisms
  - Firstly, the JL-I robot can be made lightweight and dexterous while allowing for a larger payload.
  - Secondly, the advantages of the high rigidity of a parallel mechanism and the extended workspace of a serial mechanism can be combined, thus improving the flexibility of the robotic system.
- The serial mechanism can rotate 360° around the Z axis, actuated by a geared minimotor(3.5 Nm at a speed of 30 rpm).



Control system



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Technical Aspects of Multimodal System
Dept. Informatics, Faculty of Mathematics, Informatics and Natural Sciences
University of Hamburg

Locomotion capability

- The robot should have a flexible mobility in the rugged terrain to get to every point in the working space.
- The robot has to handle uncertainties and cross narrow openings by reconfiguring its structure.
- The robot designed in this paper is capable of necessary actions that can be required in real situations, e.g. crossing obstacles such as steps and roadblocks, self-recovery.

Technical Aspects of Multimodal System
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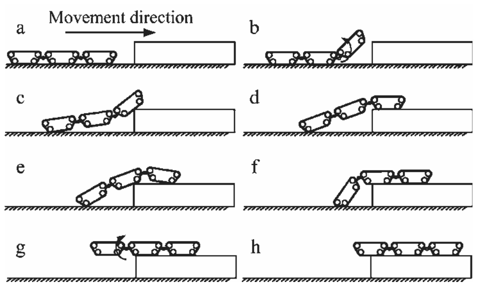
Required locomotion capabilities

- Crossing a step



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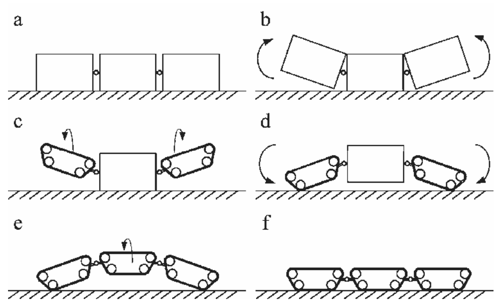
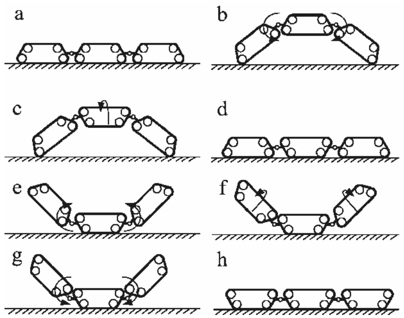
Required locomotion capabilities

- 90° self-recovery



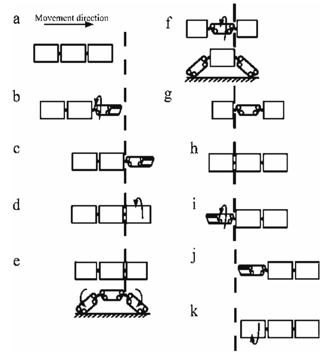
Required locomotion capabilities

- 180° self-recovery



Required locomotion capabilities

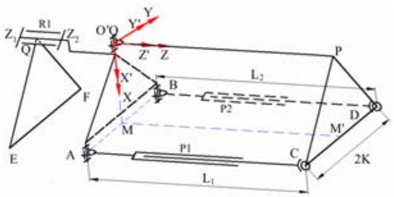
- Crossing a narrow fence



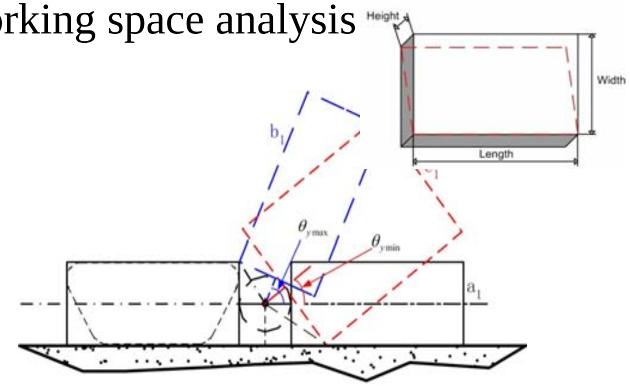
DOF analysis

- Three Hooker joints at points *O*, *A*, and *B*; two linear movement joints at links *AC* and *BD*; one rotating joint along the axis Z_1Z_2 and two spherical joints at *C* and *D*.
- According to equation (1), the DOF can be concluded. Where m means the DOF; n means the movable links of the active joint. There are seven links totally.

$$m = 6(n - g - 1) + \sum_{i=1}^{g} f_i = 3$$

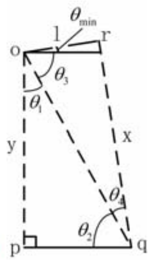


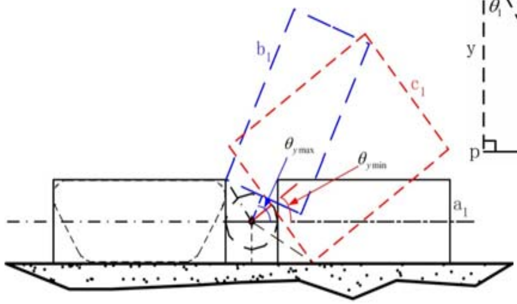
Working space analysis



Working space for the pitching movement from the lateral view .

Working space analysis





Working space for the pitching movement from the lateral view .

Working space analysis

$$\theta_{y\max} = 180 - 2arctg\frac{y}{l}$$

$$\theta_{y\min} = \arccos\frac{y}{\sqrt{l^2+x^2}} - \arccos\frac{x}{\sqrt{l^2+x^2}}$$

$$\begin{cases} x = \sqrt{Height^2 + Width^2} \\ y = Height/2 \end{cases}$$

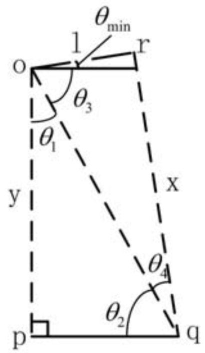
l is the length of the equivalent connecting joint of JL-I

$y = 75mm$

$l = 35mm$

$width = 250mm$

$height = 150mm$



Working space analysis

$$\theta_y \in [-180 - 2arctg\frac{y}{l},\ \ -\arccos\frac{y}{\sqrt{l^2+x^2}} - \arccos\frac{x}{\sqrt{l^2+x^2}}] \cup$$
$$[+\arccos\frac{y}{\sqrt{l^2+x^2}} - \arccos\frac{x}{\sqrt{l^2+x^2}},\ \ +180 - 2arctg\frac{y}{l}]$$

$$\begin{cases} \theta_x \in [-32°,\ \ -8°] \cup [+8.0°,\ \ +32.0°] \\ \theta_y \in [-50°,\ \ -24°] \cup [+24°,\ \ +50°] \end{cases} \longrightarrow \begin{cases} \theta_x \in [0°,\ \ \pm 50.0°] \\ \theta_y \in [0°,\ \ \pm 50.0°] \end{cases}$$

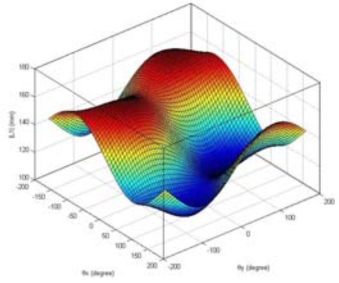
Inverse kinematics analysis

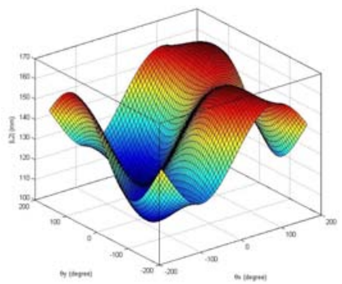
- $\theta = [\ \theta x,\ \ \theta y,\ \ \theta z]$
- $q = [L_1, L_2,\ \ \theta z]$
- Named $T_{L1}=L_1^{1/2}$, $T_{L2}=L_2^{1/2}$
- $q = [\ T_{L1}^{1/2}, T_{L2}^{1/2},\ \ \theta z]$

$$\begin{aligned} L_1^2 = &(K(c\theta_y c\theta_z + s\theta_x s\theta_y s\theta_z) - \\ &K(-s\theta_z c\theta_y + s\theta_x s\theta_y c\theta_z) + \\ &Lc\theta_x s\theta_y - Kc\theta_z - Ks\theta_z)^2 + \\ &(K(c\theta_x s\theta_z) - K(c\theta_x c\theta_z) - Ls\theta_x - Ks\theta_z + Kc\theta_z)^2 + \\ &(K(-s\theta_y c\theta_z + s\theta_x c\theta_y s\theta_z) - \\ &K(s\theta_y s\theta_z + s\theta_x c\theta_y c\theta_z) + Lc\theta_x c\theta_y)^2 \end{aligned}$$

$$\begin{aligned} {L_2}^2 = &(K(c\theta_y c\theta_z + s\theta_x s\theta_y s\theta_z) + \\ &K(-s\theta_z c\theta_y + s\theta_x s\theta_y c\theta_z) + \\ &Lc\theta_x s\theta_y - Kc\theta_Z + Ks\theta_Z)^2 + \\ &(K(c\theta_x s\theta_z) + K(c\theta_x c\theta_z) - Ls\theta_x - Ks\theta_z - Kc\theta_z)^2 \\ &+ (K(-s\theta_Y c\theta_Z + s\theta_X c\theta_Y s\theta_Z) + \\ &K(s\theta_Y s\theta_Z + s\theta_X c\theta_Y c\theta_Z) + Lc\theta_x c\theta_y)^2 \end{aligned}$$

Kinematics analysis





Kinematics analysis

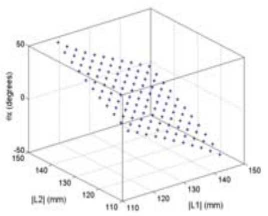
$$L_1^2 = (K(c\theta_y c\theta_z + s\theta_x s\theta_y s\theta_z) - K(-s\theta_z c\theta_y + s\theta_x s\theta_y c\theta_z) + Lc\theta_x s\theta_y - Kc\theta_z - Ks\theta_z)^2 + (K(c\theta_x s\theta_z) - K(c\theta_x c\theta_z) - Ls\theta_x - Ks\theta_z + Kc\theta_z)^2 + (K(-s\theta_y c\theta_z + s\theta_x c\theta_y s\theta_z) - K(s\theta_y s\theta_z + s\theta_x c\theta_y c\theta_z) + Lc\theta_x c\theta_y)^2$$

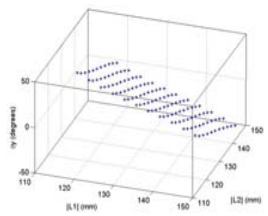
$$L_2{}^2 = (K(c\theta_y c\theta_z + s\theta_x s\theta_y s\theta_z) + K(-s\theta_z c\theta_y + s\theta_x s\theta_y c\theta_z) + Lc\theta_x s\theta_y - Kc\theta_Z + Ks\theta_Z)^2 + (K(c\theta_x s\theta_z) + K(c\theta_x c\theta_z) - Ls\theta_x - Ks\theta_z - Kc\theta_z)^2 + (K(-s\theta_Y c\theta_Z + s\theta_X c\theta_Y s\theta_Z) + K(s\theta_Y s\theta_Z + s\theta_X c\theta_Y c\theta_Z) + Lc\theta_x c\theta_y)^2$$

$$\begin{cases} d_1 = \| L_1 \|^2 - \| L_2 \|^2 = 4Ks\theta_x(Ks\theta_y - L) \\ d_2 = \| L_1 \|^2 + \| L_2 \|^2 = 8K^2 + 2L^2 - 4KLs\theta_y c\theta_x - 4K^2 c\theta_y - 4K^2 c\theta_x \end{cases}$$

$$J = \begin{bmatrix} \frac{d(d_1)}{d\theta_x} & \frac{d(d_1)}{d\theta_y} \\ \frac{d(d_2)}{d\theta_x} & \frac{d(d_2)}{d\theta_y} \end{bmatrix} = \begin{bmatrix} 4Kc\theta_x(Ks\theta_y - L) & 4K^2 s\theta_x c\theta_y \\ 4KLs\theta_x s\theta_y + 4K^2 s\theta_x & -4KLc\theta_x c\theta_y + 4K^2 s\theta_y \end{bmatrix}$$

Kinematics analysis





Outline of today's lecture

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- Review of urban search and rescue robots
  - Brief introduction to research background
  - Several famous prototypes
  - Challenging issues
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  - A novel rescue robot
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On-site experiments

- Docking process
- Crossing a step
- 90° self-recovery
- 180° self-recovery
- Crossing a narrow fence

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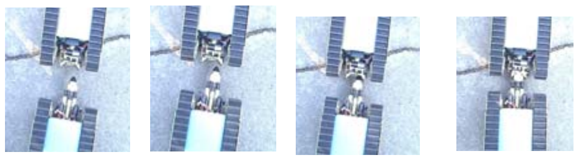
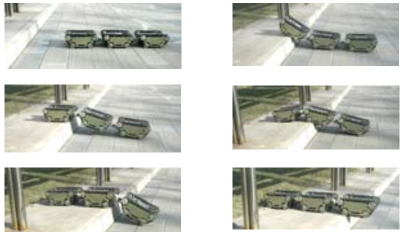


On-site experiments

- Crossing a step



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On-site experiments

- 90° self-recovery

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On-site experiments

- 180° self-recovery

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Experiment data

Posture adjustment angle around X-axis:	±45°
Posture adjustment angle around Y-axis:	±45°
Posture adjustment angle around Z-axis:	0~360°
Maximum lateral docking offset:	±30 mm
Maximum directional docking offset:	±45°
Maximum height of steps to cross:	280 mm
Maximum length of ditches to cross:	500 mm
Minimum width of the fence to cross:	200 mm
Maximum slope angle to climb:	40°
Self-recovering ability:	0~180°
Maximum moving velocity:	180 mm/s
Maximum unchangeable working time:	4 hours

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Conclusions

- It proposes a robot named JL-I which is based on a module reconfiguration concept.
- A kinematics model of reconfiguration between two modules is given. Furthermore, the movements can be anticipated according to the joints' driving outputs.
- Experimental tests have shown that the JL-I can implement a series of various reconfigurations such as 90° recovery, 180° recovery, and crossing steps.

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Future work

- Further analysis on working capabilities
- Dynamics analysis is on the way
- Some new related experiments will be presented soon

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Related publications

- H.X. Zhang, S.Y. Chen, W. Wang, J.W. Zhang, G.H. Zong, "Runtime Reconfiguration of a Modular Mobile Robot with Serial and Parallel Mechanisms", 2007 IEEE/RSJ International Conference on Intelligent Robots and Systems, IROS 2007, San Diego, U.S.A, Oct.29-Nov.02, 2007, pp.2999-3004.
- H.X. Zhang, Z.C. Deng, W. Wang, J.W. Zhang, G.H. Zong: Locomotion Capabilities of a Novel Reconfigurable Robot with 3 DOF Active Joints for Rugged Terrain, IROS 2006, Beijing, China, Oct.10-15, pp.5588 - 5593, 2006
- H.X. Zhang, W. Wang, Z.C. Deng, J.W. Zhang, G.H. Zong: A Novel Reconfigurable Robot for Urban Search and Rescue, International Journal of Advanced Robotic Systems, Vol.3 No.4, pp.359-366, 2006.
- H.X. Zhang, W. Wang, Z.C. Deng, J. W. Zhang: A Reconfigurable Robot with Serial and Parallel Mechanisms, CLAWAR 2006, Brussels, Belgium, September 12-14, pp.716-721, 2006.
- …

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Thanks for your attention!

Any questions?