Tianjin University
Research Seminar

Mobile Robots for Missions in Dynamical Natural Environments

XiaoQi Chen (陈小奇), PhD, Assoc Prof
Director, Mechatronics Engineering
Email: xqchen@canterbury.ac.nz

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New Zealand is located in the South Pacific between the Pacific Ocean and the Tasman Sea, between latitude 35 and 45 degrees south.
Liveable Place

• In 1996, Christchurch was acknowledged as the outstanding garden city from 620 international entries.

• In 1997, Christchurch was judged Overall Winner of Major Cities in the Nations in Bloom International Competition to become 'Garden City of the World'!

“I think every person..... dreams of finding some enchanted place of beautiful mountains and breathtaking coastlines, clear lakes and amazing wildlife. Most people give up on it because they never get to New Zealand”

Mr. Bill Clinton – Former US President
Gala Dinner, Christchurch, NZ 2000
Agenda

- Overview of Mechatronics@UC
- Underwater Robot
- Wall Climbing Robot using Non-Contact Adhesion
- Invasion of Mobile Robots
- Conclusions
Who are involved

- **Supervising Team:**
  - Assoc Prof XiaoQi Chen (Director for Mechatronics) - robotics, mechatronic systems
  - Prof J Geoff Chase - dynamics and control, bioengineering, structural
  - Dr Wenhui Wang - robotics, bio-mechatronics
  - Dr Stefanie Gutschmidt - dynamics and vibration
  - Dept of Electrical Engineering, Computer Science, MacDiarmid, HITLab, Bioengineering Centre

- **Technical Support**
  - Mechatronics and electronics technicians: Rodney Elliot, Julian Murphy, Julian Philips,
  - Mechanical workshop

- **Postgraduates**
  - James Pinchin, PhD - Low-cost GPS based attitude solution using multiple software based receivers.
  - Patrick Wolm, MEng – Dynamic stability control of front wheel drive wheelchairs.
  - Scott Green, PhD - Human Robot Collaboration Utilising Augmented Reality
  - Ali Ghanbari, PhD – MEMS actuation and precision micromanipulation.
  - Mostafa Nayyerloo, PhD, – Structural health monitoring
  - Chris Hardie, MEng – biologically inspired robots
  - Matthew Keir, PhD – Head motion tracking, graduated in 2008

- **Visiting Researchers / Fellows**
  - Prof Richard King, Oregon Institute of Technology, Jun 2006 – Mar 2007
  - Prof Clarence de Silva, University of British Colombia, 1-31 August 2008
  - Australian DEST Endeavour Fellowship, Mr Ben Horan, Aug – Dec 2008. Haptics technology

- **Interns**
  - Julien Dufeu, Institut Francais de Mecanique Avancee (IFMA), 2007. Modelling of wall climbing device
  - Matthias Wagner, the University of Munich, 2007. Design of wall climbing robot.
  - Harald Zophoniasson, ENISE, France, 2008. High-precision motorised stage

- **Industrial Collaborators**
  - Geospatial Research Centre, Dynamic Controls Limited, Industrial Research Limited (IRL), Commtest, etc.
**Mechatronics@UC**

**Bio-mechatronics**
- Assistive devices for rehabilitation
- Bio-micromanipulation – cell injection

**Mobile Robotics**
- Unmanned aerial vehicle, micro air vehicle
- Underwater vehicle for bio-security inspection
- Wall-climb robot for tank welding

**Instrumentation and Automation**
- Manufacturing
- Structural control
- Energy harvesting
- Bio-scaffolding

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*Burwood Academy of Independent Living*

*[Industrial Research LAB]*

*cell injection*

*[NIWA Taihororo Nukurangi]*

*[HITLabNZ]*

*Geospatial Research Centre*
SMART: Self-compliance, Multi-tasking, Adaptive-planning, Re-configurable, Teaching-free

- Part Loading
- Airfoil Measurement
- Distortion Compensation
- Blended Airfoil
- Auto Blending
- Path Generation

Video Clip
Digital Image-Based Elasto-Tomography

The DIET system is broken down into 4 fundamental steps: (1) Actuation → (2) Image Capture → (3) Motion Tracking and measurement → (4) Tissue stiffness reconstruction

1. A woman’s breast is vibrated by an actuator and imaged with high-resolution digital cameras.

2. Spatially calibrated digital cameras combined with a motion sensor measures the surface motion of the breast.

3. Finite Element method converts the measured breast surface motion into a 3-D stiffness distribution, where regions of high stiffness suggest cancer.
Microrobotic Cell Injection

Video: cell preparation

Video: cell injection

Biomimetics -
Force measurement of C. elegans in motion

Variable Resistance Rehabilitation Device

Video Clip

Provisional Patent (2008)
Integrated Flight Dynamics Model

- The input of aircraft geometry instead of aerodynamic coefficients greatly simplified aircraft model development
  - No wind tunnel testing is required
  - Effects on changing aircraft geometry can be seen immediately
  - Much better repeatability

FDM Validation with On-Board Instruments

- Equipment used
  - 2.4 meter wing-span gas powered RC plane
  - GPS base station
  - Inertia navigation system
  - Servo pulse acquisition device
  - Wind speed sensor
  - Data logger
  - Wind tunnel

Underwater Robots for Shallow Water Applications

Canterbury UUV - Biosecurity

For shallow waters, up to 20m depth

foreign invaders hiding in the sea chest

Video: QEII Pool Test
Hull design

PVC storm water pipe

A cylinder has favourable geometry for both pressure (no obvious stress concentrations) and dynamic reasons (minimum drag).
<table>
<thead>
<tr>
<th>Surge - u</th>
<th>Sway - y</th>
<th>Heave - z</th>
</tr>
</thead>
<tbody>
<tr>
<td>Roll - p</td>
<td>Pitch - q</td>
<td>Yaw - r</td>
</tr>
</tbody>
</table>

**Dive scooter**
- Vol: 12V
- Max. F: 5kg
- Depth: 20m
- Price: US$60
Thrusting

\[ y = 0.4517x - 2.4057 \]

Drag force:
\[ F_{\text{drag}} = \frac{1}{2} \cdot \rho \cdot v^2 \cdot c_d \cdot S \]

Ansys modeling and simulation
Max. velocity: 1.4m/s
Vehicle design and electronics

Video: QEII Pool Test

- Cable and canister seals
- Mother board
- Power supply
- RoboteQ motor controller
- Sliding mechanism
- Temperature sensor
- Webcam
- IMU
- Pressure sensor-depth

UC UNIVERSITY OF CANTERBURY
Te Whare Wānanga o Wairaha
CHIEFCHURCH NEW ZEALAND

Back
A Novel Wall Climbing Robot using Non-Contact Adhesion

Robotic research at the University of Canterbury has climbed new heights with the development of a wall-climbing robot.

The robot has been developed by a team of researchers lead by Associate Professor XiaoQi Chen in the University’s Mechanical Engineering department.

- **Motivation**
- **The Bernoulli Effect**
- **Design Considerations**
- **Performance**

The Problem – Tank Welding

- Adhere Vertically
- Track a Seam to +/-0.5mm
- Produce Welds to Industry Standard
- Perform at twice the Existing Weld Rate
Wall Climbing Welding Robot using Vacuum Suction

- Motors and Gearbox
- Chassis
- Weld Torch
- Steering
Motivation

Adhesion | Surface Conditions
---|---
Magnetic | Ferromagnetic
Vacuum | Smooth, Non-permeable
Microfibre | Clean

Adhesion effect independent of materials and surface conditions is desirable
Challenge

Develop a Wall Climbing robot insensible to surface conditions
Adhesion device using air pressure to create attraction force
The Bernoulli Effect

Assumptions to simplify equations:
Laminar, steady, frictionless flow, viscous effects are neglected, incompressible fluid, only forces acting are pressure and weight

\[ \frac{v^2}{2} + \frac{p}{\rho} + gh = \text{const} \]

Bernoulli equation:

\[ \frac{v_1^2}{2} + \frac{p_1}{\rho} + gh_1 = \frac{v_2^2}{2} + \frac{p_2}{\rho} + gh_2 \]

The Bernoulli Effect (Bernoulli’s Principle):

\[ \rho \frac{v^2}{2} + p = \text{const} \]

The pressure decreases with a simultaneously increasing velocity
Design Considerations

Existing Devices

- Very small attraction force

NCT device

- Heavy
- High flow rate

More efficient lightweight device is needed
The Final Bernoulli Pad

Material: Aluminium
Number of parts: 2
Undercut: 0.5mm
Nozzle gap: 0.10mm
Diameter: 45mm
Height: 18mm
Total weight: 19g
Attraction forces for different surfaces

<table>
<thead>
<tr>
<th>Pressure / bar</th>
<th>Force / N</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td></td>
</tr>
<tr>
<td>3.5</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td></td>
</tr>
<tr>
<td>4.5</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td></td>
</tr>
</tbody>
</table>

- Glass
- Polyethylene board (plastic)
- Flake board (wood)
- Corrugated board
- Styrofoam
- Rough wood
- Cloth
- Air cushion foil
- Foam plastic
- Sandpaper S600
- Sandpaper S240
- Sandpaper S40
Illustration of passing a 10mm gap

- Centre of the Bernoulli Pad
- Edge radius
- Ramp for undercut
- Pin
- 10 mm gap

Distance / mm vs Force / N graph with data points:

<table>
<thead>
<tr>
<th>Distance / mm</th>
<th>Force / N</th>
</tr>
</thead>
<tbody>
<tr>
<td>-40</td>
<td>6.5</td>
</tr>
<tr>
<td>-35</td>
<td>6</td>
</tr>
<tr>
<td>-30</td>
<td>5.5</td>
</tr>
<tr>
<td>-25</td>
<td>5</td>
</tr>
<tr>
<td>-20</td>
<td>4.5</td>
</tr>
<tr>
<td>-15</td>
<td>4</td>
</tr>
<tr>
<td>-10</td>
<td>3.5</td>
</tr>
<tr>
<td>0</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td></td>
</tr>
<tr>
<td>15</td>
<td></td>
</tr>
<tr>
<td>20</td>
<td></td>
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<td>25</td>
<td></td>
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<tr>
<td>30</td>
<td></td>
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<tr>
<td>35</td>
<td></td>
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<tr>
<td>40</td>
<td></td>
</tr>
<tr>
<td>45</td>
<td></td>
</tr>
<tr>
<td>50</td>
<td></td>
</tr>
</tbody>
</table>
The Prototype Robot

Parts:

1. Plastic as main body
2. Bernoulli Pads
1. Aluminium suspension beam
2. Servo drive trains
2. Aluminium wheels with high friction tires (friction coefficient 0.74 on glass)
Total weight: 234g
Max attraction force (at 5 bar): 12N

Additional weight that can be lifted (on a wall as on a ceiling): 500g

The robot is able to transverse the gaps on the wall.

High manoeuvrability in every direction, and on different surfaces.

Video: Climbing different surfaces and ceiling
Invasion of Mobile Robots
A short history of robots

- **1921** - The term "robot" was first used in a play called "R.U.R." or "Rossum's Universal Robots" by the Czech writer Karel Capek. The plot was simple: man makes robot then robot kills man!
- **1941** - Science fiction writer Isaac Asimov first used the word "robotics" to describe the technology of robots and predicted the rise of a powerful robot industry.
- **1956** - George Devol and Joseph Engelberger formed the world's first robot company.
- **1961** - The first industrial robot was deployed in a General Motors automobile factory in New Jersey. It was called UNIMATE.
- **1963** - The first artificial robotic arm to be controlled by a computer was designed. The Rancho Arm was designed as a tool for the handicapped and it's six joints gave it the flexibility of a human arm.
- **1968** - The octopus-like Tentacle Arm was developed by Marvin Minsky.
- **1969** - The Stanford Arm was the first electrically powered, computer-controlled robot arm.
- **1970** - Shakey was introduced as the first mobile robot controlled by artificial intelligence. It was produced by SRI International.
- **1974** - A robotic arm (the Silver Arm) that performed small-parts assembly using feedback from touch and pressure sensors was designed.
- **1979** - The Stanford Cart crossed a chair-filled room without human assistance.
Explosion of Mobile Robotics

- Unmanned Aerial Vehicle, flying robots
- Unmanned Underwater Robots
- Climbing and walking robots, rescue robots
- Animal-inspired robots: pets, cockroach, gecko, fish
- Humanoid robots
- Agricultural robots: plough, sowing, harvesting
Into Hospital
Into Fields

- Global positioning system (GPS) to autonomously navigate agricultural machineries on the field
- Imaging sensors recognise crops, fruits, plants, etc
Into Sea

- Oceanographic exploration, environmental monitoring, surveying, undersea operations, and military mission.
- Scientists often use these underwater vehicles to map the ocean floor, conduct fish counts, and monitor pollution.
Into Our Homes
- Members of family?

- Free us from home chores: vacuuming floor, mowing lawn.
- Robot butler.
- Robot assistant for elderly, handicapped.
- Patrolling, security.
Functional model of generalised robots

- Intellectual (information processing and decision making)
- Actuation
- Energy
- Sensory
- Motivational
- Statue
- Communication
- Environment (workspace, natural, other subjects)
- Mobility

UC
Comparison of functional modules between robots and human beings

<table>
<thead>
<tr>
<th>Functional Blocks</th>
<th>Human Beings</th>
<th>Robots</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intellectual</td>
<td>Brain</td>
<td>Microprocessor (computer hardware and software)</td>
</tr>
<tr>
<td>Statue</td>
<td>Skeleton</td>
<td>Mechanical frame (airframe, chassis, hull).</td>
</tr>
<tr>
<td>Motivational</td>
<td>Limbs</td>
<td>Wheels, legs, tracks, propellers, grippers, etc.</td>
</tr>
<tr>
<td>Actuation</td>
<td>Muscles</td>
<td>Hydraulic, electric, pneumatic, piezoelectric, electrostatic actuators; artificial muscles.</td>
</tr>
<tr>
<td>Sensory (perception)</td>
<td>Eyes, ears, skin</td>
<td>Cameras, optic sensors, sonar, sound, infra-red light, magnetic fields, radiation, etc.</td>
</tr>
<tr>
<td>Communication</td>
<td>Speech, gesture</td>
<td>Data, image/video, sound</td>
</tr>
<tr>
<td>Energy</td>
<td>Food / energy storage</td>
<td>Power source / energy storage.</td>
</tr>
</tbody>
</table>
## Comparison of lifting capacity between robots and human

<table>
<thead>
<tr>
<th></th>
<th>Self weight (Kg)</th>
<th>Lifting capacity (Kg)</th>
<th>Lifting-to-weight ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>ABB IRB 2000</td>
<td>350</td>
<td>10</td>
<td>0.03</td>
</tr>
<tr>
<td>Honda Asimo</td>
<td>52</td>
<td>1 (for two hands)</td>
<td>0.02</td>
</tr>
<tr>
<td>2008 Olympic Women</td>
<td>53</td>
<td>126 (clean &amp; jerk)</td>
<td>2.4</td>
</tr>
<tr>
<td>53 Kg Weightlifting Gold</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A person having</td>
<td>52</td>
<td>20</td>
<td>0.4</td>
</tr>
<tr>
<td>similar weight to Asimo</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Conclusion

- Technologies are maturing to tackle complex process automation
  - Machining under uncertain conditions
  - Additive manufacturing
  - Welding, etc.
- Future automation moves towards
  - Connectivity
  - Modularity
  - Portability / interchangeability
    (Microsoft expends into robotics)
- Emerging research areas in robotics
  - Service robotics
  - Biologically inspired robots
  - Human machine interface technology: augmented reality, brain-computer interface
Service Robots – a disruptive technology


- Robots have the potential to replace humans in a variety of applications with far-reaching implications.
- The use of unmanned systems for terrorist activities could emerge because the availability of commercial civil robot platforms will increase significantly.
- Unmanned military systems with a much greater level of autonomy and closely related/synergistic technologies (e.g. human augmentation systems) could enhance the performance of soldiers.
- The development and implementation of robots for elder-care applications, and the development of human-augmentation technologies, mean that robots could be working alongside humans in looking after and rehabilitating people. A change in domestic and social responsibilities and a change in domestic employment requirements could adversely affect lower income service-oriented workers.
Can mobile robotics emulate the impact of PC?