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Preface

Welcome to RSS 2009!
This booklet contains information about Seattle, the technical and social program.
All papers are available from the conference Web page
http://www.roboticsconference.org/

Jeff Trinkle, Yoky Matsuoka, Dieter Fox, Rajesh Rao, Lydia Kavraki, Devin Balkcom, Jose A. Castellanos
and Scott M. Rose
Conference Information

Location

All technical sessions, including oral and poster presentations, workshops, and exhibits will take place at the University of Washington campus in Seattle. Located just north of downtown Seattle, the University of Washington campus occupies 684 acres bordering Lake Washington. Conference meeting facilities on campus are within comfortable walking distance of hotels, nearby restaurants, shops, and services. The main conference will be held in Guggenheim Hall. Registration, breaks, exhibits, and the poster reception will take place in the Paul Allen Center for Computer Science and Engineering. Dedicated in October 2003, the Paul Allen Center is attached to the Electrical Engineering Building on the University of Washington campus. The Sunday Workshops will be held in the Electrical Engineering Building (EEB). The Monday morning workshops will be in the Husky Union Building (HUB). A map of all conference locations is shown below.

On Tuesday, June 30, there will be two organized lab tours led by student volunteers departing from Guggenheim Hall at 12:20 pm. Participants are also welcome to visit these labs on their own during the 12:20 pm to 2:20 pm time period. More details can be found below under “Lab tours and demos”. 
Registration

The Conference Desk will be staffed for registration and information services in the atrium of the Paul Allen Center for Computer Science and Engineering according to the following schedule:

- Saturday, June 27  4:00pm to 6:00pm
- Sunday, June 28  8:00am to 5:00pm
- Monday, June 29   8:00am to 5:00pm
- Tuesday, June 30  8:00am to 4:00pm
- Wednesday, July 1 8:00am to 5:00pm

The conference registration fees are:

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<tr>
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<th>Early (before June 3)</th>
<th>Regular (after June 3)</th>
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<tr>
<td>Regular</td>
<td>$400</td>
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<td>Student</td>
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<td>Workshop only, Regular</td>
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<tr>
<td>Workshop only, Student</td>
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<td>$120</td>
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Both regular and student registration includes attendance to the main conference oral and poster sessions, as well as the workshops on Sunday June 28 and Monday June 29. In addition, it includes one hardcopy of the conference proceedings, and one ticket for the conference banquet on Tuesday June 30 evening at Kiana Lodge located on the Kitsap Peninsula (chartered harbor cruise included). Additional banquet tickets can be purchased for companions through the Regonline Registration System for $100.00 per adult and $35.00 per child. You can go to Regonline through the RSS website under Registration. The system remembers you by email address and the password you established when you registered.

Sponsors

The organizers of Robotics: Science and Systems gratefully acknowledge the following conference sponsors.

- The Boeing Company
- Willow Garage
- Naval Research Laboratory
- Google
- Intel
- Microsoft
- Springer
- iRobot

We would like to thank all conference sponsors as their support has allowed us to keep registration and workshop fees to a minimum, particularly for graduate students.
Workshop Locations

Sunday workshops will take place in the Electrical Engineering Building:

- W1 Bridging the gap between high-level discrete representations and low-level continuous behaviors: Room EEB 045
- W2 Good Experimental Methodology in Robotics: Room EEB 031
- W3 Understanding the human hand for advancing robotic manipulation: Room EEB 125
- W4 Regression in Robotics-Approaches, and Applications: Room EEB 105
- W5 Algorithmic Automation: Room EEB 037
- W6 Integrating Mobility and Manipulation: Room EEB 003
- Industry sponsored workshop. Introduction to Microsoft Robotics Developer Studio: Room EEB 003

Monday workshops will take place in the Husky Union Building Workshop:

- W1-HD Creative Manipulation: Examples using the WAM: Room HUB 209A
- W2-HD Aquatic Robots and Ocean Sampling: Room HUB 106B
- W3-HD Autonomous Flying vehicles. Fundamentals and Applications HUB 108
- W4-HD Protein Structure, Kinematics, and Motion Planning: Room HUB 200AB

Exhibits

Throughout Monday, Tuesday, and Wednesday, the Paul Allen Center for Computer Science and Engineering will host an array of exhibitors in the atrium. The current list of exhibitors includes:

- Aldebaran Robotics
- Boeing Company
- Microsoft Research

Poster Session and Reception

The poster session will take place on Monday June 29 from 6:30 pm to 9:30 pm in the atrium of the Paul Allen Center for Computer Science and Engineering. There will be a poster reception with heavy appetizers and a hosted bar.

If you are presenting a poster, please make sure the poster is ready by the time the poster session starts. The poster easels will be available for putting up your posters after 12 noon on Monday. Please take down your poster at the end of the session.
Lab Tours and Demos

On Tuesday, June 30, from 12:20 pm to 2:20 pm, six robotics labs at the University of Washington will hold an open house to illustrate the array of projects being pursued on campus. Two organized lab tours led by student volunteers will depart from Guggenheim Hall at 12:20 pm after the conference session. These tours will include visits to the six labs and demonstrations. Participants are also welcome to visit these labs on their own during the 12:20 pm to 2:20 pm time period. The six labs are as follows:

- Robotics and State Estimation Lab (PI: Dieter Fox), Room 491, Paul Allen Center for Computer Science and Engineering
- Neurobotics Lab (PI: Yoky Matsuoka), Room 407, Paul Allen Center for Computer Science and Engineering
- Humanoid Robotics and Brain-Computer Interface Lab (PI: Rajesh Rao), Room 286, Paul Allen Center for Computer Science and Engineering
- Nonlinear Dynamics and Control Lab (PI: Kristi Morgansen), Room 101, Aerospace Research Building (AERB)
- Self-Organizing Systems Lab (PI: Eric Klavins), Room B040 (sub basement), Electrical Engineering Building (EEB)
- Biorobotics Lab (PI: Blake Hannaford), Room 455, Electrical Engineering Building (EEB)

A campus map showing the locations of these labs is on the following page.
Banquet

On Tuesday, June 30, there will be a conference banquet at the historic Kiana Lodge. Buses will depart from campus at approximately 4:30 pm and take you to a chartered boat at the Seattle waterfront. Once on the boat, you will enjoy a harbor cruise on the way to the Kiana Lodge located on the Kitsap Peninsula. At the lodge, you will be served a traditional Northwest Salmon dinner (vegetarian alternative available). The return cruise features views of Seattle’s night time skyline from the waters of Elliott Bay. Buses will then transport you back to campus. This excursion is complimentary with full conference registration. Your badge will serve as your bus and boat ticket, so please ensure that you have your badge when boarding the bus. You will receive a banquet ticket with your registration packet. You may purchase additional banquet tickets for $100.00 per adult and $35.00 per child through the Regonline Registration System (access via the RSS website under Registration, and use the email address and the password you established when you registered).
Lodging and Dormitory Housing

The conference hotels are:

- University Inn, 4140 Roosevelt Way NE, Seattle, WA 98105 (206-632-5055; 800-733-3855)

- Watertown Hotel, 4242 Roosevelt Way NE, Seattle, WA 98105 (206-826-4242; 866-944-4242)

- Silver Cloud Inn-University District, 5036 25th Ave. NE, Seattle, WA 98105 (206-526-5200; 800-205-6940)

On-campus Univ. Washington Dormitory Housing is at McMahon Hall, a short walk from the conference meeting rooms (see campus locations map above).

Internet Access

Wireless internet access will be available while on campus through a shared temporary UWNetID#. You will find this number and instructions in your registration packet.

Lunch and Dinner Breaks

During all conference and workshop days, there will be no breakfast, lunch, or dinner (except for the banquet) provided by the conference. The conference will provide coffee and tea service during registration on Sunday morning. There will be morning and afternoon coffee breaks with snacks every day during the conference except for Tuesday when there will only be a morning break.

We therefore encourage all attendees to plan accordingly, taking into consideration the technical schedule of events. The Husky Union Building (HUB) is the closest location on campus for food and includes a limited variety of dining options. There is also a cafeteria at the conference dormitory housing (McMahon Hall). If you bought the on-campus dormitory housing package, you may use your debit meal card at either of the above two campus dining locations. University Way (“The Ave”), which is a 10-minute walk from the meeting rooms and on the western edge of campus, offers a much larger variety of restaurants, cafes, and bars. The University Village shopping complex on the northeast corner of campus is a slightly longer walk and offers more upscale dining options. A map showing the relative locations of the Ave and University Village can be found on the next page.

Useful websites:
http://www.udistrictchamber.org/BusinessLocator2.html#Dining
http://www.uvillage.com/dining.asp
Locations of Nearby Restaurants and Shops

University Way ("The Ave")  University Village

Paul Allen Center for Computer Science and Engineering
Transportation

Airport: Seattle-Tacoma International Airport is located approximately 20 miles south of the University of Washington. Taxis are readily available and cost about $45 to the airport from campus (Orange cab: 206-522-8800; Yellow cab: 206-622-6500). Shuttle Express (425-981-7000), which pools passengers, is a cheaper alternative (about $28) but factor in some extra time to get to the airport.

Getting around: Seattle has an excellent bus system. A large number of buses run through UW campus and along the outer boundaries, especially along University Ave and 15 Ave. These connect to almost all parts of the city (including the airport) and beyond. Plan your trip at: http://transit.metrokc.gov/

Other options are taxi, renting a car, biking, or roller-blading (along the Burke-Gilman Trail which runs through campus).

Parking: A car is not necessary for conference participants who will be staying in University area hotels. The recommended hotels are walking distance from the campus or provide a shuttle service. For participants who will be arriving by car, visitor parking is available in the Central Plaza Garage (entrance on 15th Ave on the east side of campus). Daily parking permits are available for $12 per day, payable at the entrance gates. Saturday and evening parking permits are available for $8 (evenings 4 pm - 9 pm and Saturdays 7 am-noon). You cannot purchase 24 hour parking permits.

About Seattle

Seattle is a city known for its scenic beauty, temperate climate, and abundant cultural/recreational opportunities. The Olympic Mountains to the west, Mount Rainier dominating the horizon to the south, and the Cascade Range to the east provide spectacular backdrops to the city’s waterfront, lakes and forested hills. Summer temperatures in Seattle are generally mild. The average maximum temperature in June is 69.4°F and the average minimum temperature is 51.3°F. Contrary to what you may have heard, rain is very rare in the summer (so hopefully you may stash away those umbrellas you may have brought!).

Detailed information about places of interest in and around Seattle can be found in the travel kit on the conference website: http://www.roboticsconference.org/TravelKit.pdf
Program Highlights

Location: Guggenheim Hall Room 220

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<th>Event</th>
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<tr>
<td>1:30-1:40</td>
<td>Welcome</td>
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<tr>
<td>1:40-3:40</td>
<td>Session 1. Chair: Gaurav Sukhatme</td>
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<td>1:40-2:40</td>
<td>Invited talk</td>
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<td>Michael Dickinson, Visually-Mediated Behaviors of the Fruit Fly</td>
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<td>2:40-3:10</td>
<td>Poster Spotlight I</td>
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<td>Poster 1-9</td>
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<td>3:10-3:40</td>
<td>Poster Spotlight II</td>
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<td>Poster 10-19</td>
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<td>3:40-4:00</td>
<td>Coffee Break</td>
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<td>4:00-6:00</td>
<td>Session 2. Chair: Tamim Asfour</td>
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<td>4:00-4:30</td>
<td>Oral 1</td>
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<td>Cooperative Manipulation and Transportation with Aerial Robots,</td>
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<td>Nathan Michael, Jonathan Fink, Vijay Kumar</td>
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<td>4:30-5:00</td>
<td>Oral 2</td>
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<td>Learning of 2D Grasping Strategies from Box-Based 3D Object</td>
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<td></td>
<td>Approximations, Sebastian Geidenstam, Kai Huebner, Daniel Banksell,</td>
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<td>Danica Kragic</td>
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<td>5:00-5:30</td>
<td>Oral 3</td>
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<td>LQR-Trees: Feedback Motion Planning on Sparse Randomized Trees,</td>
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<td>Russ Tedrake</td>
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<td>5:30-6:00</td>
<td>Oral 4</td>
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<td>Human Motion Database with a Binary Tree and Node Transition Graphs,</td>
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<td>Katsu Yamane, Yoshifumi Yamaguchi, Yoshihiko Nakamura</td>
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<td>6:00-6:30</td>
<td>Break</td>
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<td>6:30-9:30</td>
<td>Session 3: Poster Session</td>
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<td>Poster 1: Explicit Parametrizations of the Configuration Spaces of</td>
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<td></td>
<td>Anthropomorphic Multi-Linkage Systems, Li Han, Lee Rudolph</td>
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<td>Poster 2: Approximating Displacement with the Body Velocity Integral,</td>
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<td>Ross Hatton, Howie Choset</td>
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<td>Poster 3: Tactile Texture Recognition with a 3-Axial Force MEMS</td>
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<td>integrated Artificial Finger, Florian De Boissieu, Christelle Godin,</td>
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<td>Bernard Guilhamat, Christine Serviere, Dominique David, Daniel</td>
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<td>Poster 4: On the Complexity of the Set of Three-Finger Caging Grasps</td>
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<td>of Convex Polygons, Mostafa Vahedi, Frank van der Stappen</td>
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<td>Poster 5: On the Consistency of Multi-Robot Cooperative Localization,</td>
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<td>Guoquan Huang, Nikolas Trawny, Anastasios Mourikis, Stergios</td>
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<td>Roumeliotis</td>
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</table>
6:30-9:30  **Session 3: Poster Session (cont.)**

Poster 6: *Inner Sphere Trees for Proximity and Penetration Queries*, Rene Weller, Gabriel Zachmann

Poster 7: *Using the Distribution Theory to Simultaneously Calibrate the Sensors of a Mobile Robot*, Agostino Martinelli

Poster 8: *Planning Motion in Similar Environments*, Jyh-Ming Lien, Yanyan Lu

Poster 9: *Robust Visual Homing with Landmark Angles*, John Lim, Nick Barnes

Poster 10: *Rut Detection and Following for Autonomous Ground Vehicles*, Camilo Ordonez, Oscar Chuy, Emmanuel Collins


Poster 12: *Towards Cyclic Production Systems for Modular Robotics and Rapid Manufacturing*, Matt Moses, Hiroshi Yamaguchi, Greg Chirikjian


Poster 14: *Centralized Path Planning for Multiple Robots: Optimal Decoupling into Sequential Plans*, Jur van den Berg, Jack Snoeyink, Ming Lin, Dinesh Manocha

Poster 15: *Accurate Rough Terrain Estimation with Space-Carving Kernels*, Raia Hadsell, Drew Bagnell, Martial Hebert

Poster 16: *View-Based Maps*, Kurt Konolige, Michael Colander, James Bowman, Patrick Mihelich, JD Chen, Pascal Fua, Vincent Lepetit

Poster 17: *Generalized-ICP*, Aleksandr Segal, Dirk Haehnel, Sebastian Thrun

Poster 18: *3D Laser Scan Classification Using Web Data and Domain Adaptation*, Kevin Lai, Dieter Fox

Poster 19: *Adaptive Relative Bundle Adjustment*, Gabe Sibley, Christopher Mei, Ian Reid, Paul Newman

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**Tuesday, June 30, 2009**

8:30-10:30  **Session 4. Chair: John Leonard**

8:30-9:30  **Invited Talk**

John Delaney, *Next Generation Ocean Sciences: The Leading Edge of an Environmental Renaissance*

9:30-10:00  **Oral 5**

*Underwater Human-Robot Interaction via Biological Motion Identification*, Junaed Sattar, Gregory Dudek

10:00-10:30  **Oral 6**

*Robustness of the Unscented Kalman Filter for State and Parameter Estimation in an Elastic Transmission*, Edvard Naerum, H. Hawkeye King, Blake Hannaford

10:30-10:50  **Coffee Break**
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<tr>
<td>10:50-12:20</td>
<td><strong>Session 5. Chair: Tetsunari Inamura</strong></td>
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<td>10:50-11:20</td>
<td>Oral 7</td>
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<td><em>POMDPs for Robotic Tasks with Mixed Observability</em>, Sylvie Ong, David Hsu, Wee Sun Lee</td>
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<td>11:20-11:50</td>
<td>Oral 8</td>
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<td><em>Policy Search via the Signed Derivative</em>, J. Zico Kolter, Andrew Ng</td>
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<td>11:50-12:20</td>
<td>Oral 9</td>
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<td><em>Non-Parametric Learning to Aid Path Planning over Slopes</em>, Sisir Karumanchi, Thomas Allen, Tim Bailey, Steve Scheding</td>
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<tr>
<td>12:20-2:20</td>
<td>Lunch + Lab Tours</td>
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<td>2:20-4:20</td>
<td><strong>Session 6. Chair: Danica Kragic</strong></td>
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<td>2:20-3:20</td>
<td>Invited Talk</td>
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<td>Marc Ernst, <em>The Puzzle of Human Multisensory Perception: Optimal Integration for Action</em></td>
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<td>3:20-3:50</td>
<td>Oral 10</td>
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<td><em>Learning GP-BayesFilters via Gaussian Process Latent Variable Models</em>, Jonathan Ko, Dieter Fox</td>
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<td>3:50-4:20</td>
<td>Oral 11</td>
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<td><em>3D Relative Pose Estimation from Six Distances</em>, Nikolas Trawny, Xun Zhou, Stergios Roumeliotis</td>
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<td>4:20</td>
<td>Banquet Transportation via Bus and Ferry</td>
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<tr>
<td>8:30-10:30</td>
<td><strong>Session 7. Chair: Eric Klavins</strong></td>
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<td>8:30-9:30</td>
<td>Invited Talk</td>
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<td>John C. Doyle, <em>Rules of engagement: The architecture of robust, evolvable networks</em></td>
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<td>9:30-10:00</td>
<td>Oral 12</td>
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<td><em>An Ab-initio Tree-based Exploration to Enhance Sampling of Low-energy Protein Conformations</em>, Amarda Shehu</td>
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<td>10:00-10:30</td>
<td>Oral 13</td>
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<td><em>Cellular Muscle Actuators with Variable Resonant Frequencies</em>, Thomas Secord, Harry Asada</td>
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<td>10:30-10:50</td>
<td>Coffee Break</td>
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</tbody>
</table>
10:50-12:20  **Session 8. Chair: Hugh Durrant-Whyte**

10:50-11:20  **Oral 14**
*Positioning Unmanned Aerial Vehicles as Communication Relays for Surveillance Tasks*, Oleg Burdakov, Patrick Doherty, Kaj Holmberg, Jonas Kvarnstrom, Per-Magnus Olsson

11:20-11:50  **Oral 15**
*Efficient, Guaranteed Search with Multi-Agent Teams*, Geoffrey Hollinger, Athanasios Kehagias, Sanjiv Singh

11:50-12:20  **Oral 16**
*Time-Extended Multi-Robot Coordination for Domains with Precedence Constraints*, Edward Jones, Bernardine Dias, Anthony Stentz

12:20-1:45  **Lunch**

1:45-3:30  **Session 9. Chair: Blake Hannaford**

1:45-2:30  **Early Career Spotlight Talk**
*Haptography: Creating Authentic Haptic Feedback from Recordings of Real Interactions*, Katherine Kuchenbecker

2:30-3:00  **Oral 17**
*Bridging the gap between passivity and transparency*, Michel Franken, Stefano Stramigoli, Rob Reilink, Cristian Secchi, Alessandro Macchelli

3:00-3:30  **Oral 18**
*Feedback Control for Steering Needles Through 3D Deformable Tissue Using Helical Paths*, Kris Hauser, Ron Alterovitz, Nuttapong Chentanez, Allison Okamura, Ken Goldberg

3:30-3:50  **Coffee Break**

3:50-4:50  **Session 10. Chair: Jose Neira**

3:50-4:20  **Oral 19**
*Large Scale Graph-Based SLAM using Aerial Images as Prior Information*, Bastian Steder, Rainer Kummerle, Christian Dornhege, Alexander Kleiner, Giorgio Grisetti, Wolfram Burgard

4:20-4:50  **Oral 20**
*Highly Scalable Appearance-Only SLAM - FAB-MAP 2.0*, Mark Cummins, Paul Newman

4:50-5:00  **Award Presentation**

5:00-5:30  **Wrap Up, Discussion**

5:30  **Adjourn**
Invited talk: Michael Dickinson, *Visually-Mediated Behaviors of the Fruit Fly*

Abstract:
The fruit fly, Drosophila melanogaster, suffers a rather poor reputation as a pesky lab rat, better known for its rapid breeding chromosome number than for its behavioral repertoire. Independent of their utility as model genetic organisms, however, fruit flies are also noted as the result of an extraordinary evolutionary radiation. The genus Drosophila is one of the most species-rich genera in the animal kingdom. Fruit flies would be better termed fungus flies, as they make a living on fungus that grows on rotting plant and animal matter. As larvae, these animals grow quickly within yeast- and bacteria-rich rots; as adults, they navigate through their habitat guided by the sensory cues that signal the location of suitable sites for feeding, shelter, mating, and oviposition. The research in my laboratory focuses on the sensory ethology of fruit flies, treating these tiny insects not simply as convenient laboratory models, but as real animals that have evolved a successful life history pattern. The goal of this work is to try to deconstruct the animal’s behavior into a sequence of sensory-motor modules. Although these insects make use of many sensory modalities as they explore their environment, vision plays an essential role in nearly all aspects of their life history. My talk will focus on several visually-mediated components of behavior including take-off, navigation, predator avoidance, landing, and local exploration, as well as components of social behavior that ensue whenever two or more flies alight on the same piece of rotting fruit. Long distance search starts with take-off, a behavior that is less stereotyped than previously supposed. Hungry flies launch themselves smoothly in the presence of an attractive odor, and do so by carefully coordinating a gentle leg jump with the start of wing flapping. Flies escaping a looming threat, in contrast, jump with greater force - often before they have finished raising their wings. Although the escape takes place within tens of milliseconds, the animal computes the azimuthal position of the visual threat and jumps in the opposite direction. This directionality is achieved by careful placement of the legs prior to the jump - a rudimentary form of pre-motor planning. Once in the air, flies use a variety of visuomotor reflexes to navigate, including object fixation, velocity control, expansion avoidance, and rotatory optomotor equilibrium. My laboratory has attempted to characterize these different behaviors through a combination of free- and tethered-flight experiments. The results suggest that the gross flight behavior of flies - sequences of straight flight interspersed with rapid turns called body saccades - arises from the combination of these concurrently-running visuomotor modules. Fruit flies do not exhibit the complex mating chases exhibited by other species, but they still must fly toward safe landmarks while avoiding small targets that represent predators or other potentially harmful objects. Flies appear to make this behavioral choice - whether to fly toward an object or steer away from it - using a relatively simple visually-mediated algorithm. Fruit flies are attracted to long vertically-oriented objects (i.e. stripes), whereas they actively avoid objects that subtend a narrow vertical angle (i.e. spots). Once a fly lands - another behavior mediated in large part by visual reflexes - it uses an array of visuomotor behaviors to explore its local environs. Because fruit fly social behavior takes place on the ground, the visually-mediated behaviors that operate while walking and standing are even more varied and complicated than those that take place in the air. Using new technology to track the trajectories of individual flies as they explore and interact within large controlled arenas, my lab is beginning to identify and quantify these new suites of visuomotor behaviors. In summary, by systematically dissecting the entire life history of Drosophila, we hope to provide a richer view of the visual system’s role in behavior.

Schedule: see page 13.
Technical Session 2, Monday, June 29, 2009

Cooperative Manipulation and Transportation with Aerial Robots, Nathan Michael, Jonathan Fink, Vijay Kumar

Abstract:
In this paper we consider the problem of controlling multiple robots manipulating and transporting a payload in three dimensions via cables. We develop robot configurations that ensure static equilibrium of the payload at a desired pose while respecting constraints on the tension and provide analysis of payload stability for these configurations. We demonstrate our methods on a team of aerial robots via simulation and experimentation.

Schedule: see page 13.

Learning of 2D Grasping Strategies from Box-Based 3D Object Approximations, Sebastian Geidenstam, Kai Huebner, Daniel Banksell, Danica Kragic

Abstract:
In this paper, we bridge and extend the approaches of 3D shape approximation and 2D grasping strategies. We begin by applying a shape decomposition to an object, i.e. its extracted 3D point data, using a flexible hierarchy of minimum volume bounding boxes. From this representation, we use the projections of points onto each of the valid faces as a basis for finding planar grasps. These grasp hypotheses are evaluated using a set of 2D and 3D heuristic quality measures. Finally on this set of quality measures, we use a neural network to learn good grasps and the relevance of each quality measure for a good grasp. We test and evaluate the algorithm in the GraspIt! simulator.

Schedule: see page 13.

LQR-Trees: Feedback Motion Planning on Sparse Randomized Trees, Russ Tedrake

Abstract:
Recent advances in the direct computation of Lyapunov functions using convex optimization make it possible to efficiently evaluate regions of stability for smooth nonlinear systems. Here we present a feedback motion planning algorithm which uses these results to efficiently combine locally-valid linear quadratic regulator (LQR) controllers into a nonlinear feedback policy which probabilistically covers the reachable area of a (bounded) state space with a region of stability, certifying that all initial conditions that are capable of reaching the goal will stabilize to the goal. We demonstrate the performance of this systematic nonlinear feedback control design algorithm on the model underactuated systems and discuss the potential for the control of more complicated control problems like bipedal walking.

Schedule: see page 13.
**Human Motion Database with a Binary Tree and Node Transition Graphs**, Katsu Yamane, Yoshifumi Yamaguchi, Yoshihiko Nakamura

**Abstract:**
Database of human motion has been widely used for recognizing human motion and synthesizing humanoid motions. In this paper, we propose a data structure for storing and extracting human motion data and demonstrate that the database can be applied to the recognition and motion synthesis problems in robotics. We develop an efficient method for building a binary tree data structure from a set of continuous, multidimensional motion clips. Each node of the tree represents a statistical distribution of a set of human figure states extracted from the motion clips. We also identify the valid transitions among the nodes and construct node transition graphs. Similar states in different clips may be grouped into a single node, thereby allowing transitions between different behaviors. Using databases constructed from real human motion data, we demonstrate that the proposed data structure can be used for human motion recognition, state estimation and prediction, and robot motion planning.

**Schedule:** see page 13.

**Technical Session 3, Monday, June 29, 2009**

**Explicit Parametrizations of the Configuration Spaces of Anthropomorphic Multi-Linkage Systems**, Li Han, Lee Rudolph

**Abstract:**
Multi-fingered manipulation systems are important in the study of robotics. These are also challenging systems, in part because of the loop closure constraints required of several (virtual) loops each formed by two fingers and the grasped object. Most existing work describes system configurations using joint parameters, in which loop closure constraints are expressed by highly nonlinear equations. Such a formulation amounts to an implicit parametrization of the configuration space (CSpace) as a lower-dimensional semi-algebraic subset embedded in a higher-dimensional ambient joint parameter space. The non-zero difference between the two dimensions is the codimension of CSpace as seen in the given parametrization. In this paper, we point out that, quite generally, parametrizations leading to lower codimensional configuration spaces provide multi-faceted advantages over those producing higher codimensions. For two example manipulation systems 3-fingered hand and a planar star-manipulator with any number of fingers we present explicit parameterizations, which are effectively of codimension 0. We base these parametrizations on our recently developed construction trees of simplices (such as triangles and tetrahedra) for multi-object systems; such a tree gives simplex-based parameters on CSpace, in which loop closure constraints become simplex formation constraints (such as triangle inequalities and CayleyMenger determinant constraints). Both example systems are very difficult to deal with using joint angle parameters. Our results here further demonstrate the generality and effectiveness of the simplex-based approach.

**Schedule:** see page 13.
Approximating Displacement with the Body Velocity Integral, Ross Hatton, Howie Choset

Abstract:
In this paper, we present a technique for approximating the net displacement of a locomoting system over a gait without directly integrating its equations of motion. The approximation is based on a volume integral, which, among other benefits, is more open to optimization by algorithm or inspection than is the full displacement integral. Specifically, we develop the concept of a body velocity integral (BVI), which is computable over a gait as a volume integral via Stokes's theorem. We then demonstrate that, given an appropriate choice of coordinates, the BVI for a gait approximates the displacement of the system over that gait. This consideration of coordinate choice is a new approach to locomotion problems, and provides significantly improved results over past attempts to apply Stokes's theorem to gait analysis.

Schedule: see page 13.

Tactile Texture Recognition with a 3-Axial Force MEMS integrated Artificial Finger, Florian De Boissieu, Christelle Godin, Bernard Guilhamat, Christine Serviere, Dominique David, Daniel Baudois

Abstract:
Recently, several three-axial MEMS-based force sensors have been developed. This kind of force micro sensor is also called tactile sensor in literature for its similarities in size and sensitivity with human mechanoreceptors. Therefore, we believe these three-axial force sensors being able to analyse textures properties while sliding on a surface, as would do a person with his finger. In this paper, we present one of these sensors packaged as an artificial finger, with a hard structure for the bone and a soft rubber for the skin. Preliminary experiments show a good sensitivity of the finger, as its ability to sense the periodic structure of fabrics or to differentiate papers from fabrics calculating a friction coefficient. Its performance for discrimination of different surfaces is then estimated on fine textures of 10 kinds of paper. Supervised classification methods are tested on the data. They lead to an automatic classifier of the 10 papers showing good performances.

Schedule: see page 13.

On the Complexity of the Set of Three-Finger Caging Grasps of Convex Polygons, Mostafa Vahedi, Frank van der Stappen

Abstract:
We study three-finger caging grasps of convex polygons. A part is caged with a number of fingers when it is impossible to rigidly move the part to an arbitrary placement far from its initial placement without penetrating any finger. A convex polygon with n vertices and a placement of two fingers referred to as the base fingers are given. The caging region is the set of all placements of the third finger that together with the base fingers cage the polygon. We derive a novel formulation of caging in terms of visibility in three-dimensional space. We use this formulation to prove that the worst-case combinatorial complexity of the caging region is close to $O(n^3)$, which is a significant improvement of the previously known upper bound of $O(n^6)$. Moreover we provide an algorithm with a running time close to $O(n^3 \log n)$ that considerably improves the current best known algorithm, which runs in $O(n^6)$ time.

Schedule: see page 13.
On the Consistency of Multi-Robot Cooperative Localization, Guoquan Huang, Nikolas Trawny, Anastasios Mourikis, Stergios Roumeliotis

Abstract:
In this paper, we investigate the consistency of extended Kalman filter (EKF)-based cooperative localization (CL) from the perspective of observability. To the best of our knowledge, this is the first work that analytically shows that the error-state system model employed in the standard EKF-based CL always has an observable subspace of higher dimension than that of the actual nonlinear CL system. This results in unjustified reduction of the EKF covariance estimates in directions of the state space where no information is available, and thus leads to inconsistency. To address this problem, we adopt an observability-based methodology for designing consistent estimators and propose a novel Observability-Constrained (OC)-EKF. In contrast to the standard EKF-CL, the linearization points of the OC-EKF are selected so as to ensure that the dimension of the observable subspace remains the same as that of the original (nonlinear) system. The proposed OC-EKF has been tested in simulation and experimentally, and is shown to significantly outperform the standard EKF in terms of both accuracy and consistency.

Schedule: see page 13.

Inner Sphere Trees for Proximity and Penetration Queries, Rene Weller, Gabriel Zachmann

Abstract:
We present a novel geometric data structure for approximate collision detection at haptic rates between rigid objects. Our data structure, which we call inner sphere trees, supports different kinds of queries, namely, proximity queries and a new method for interpenetration computation, the penetration volume, which is related to the water displacement of the overlapping region and, thus, corresponds to a physically motivated force. The main idea is to bound objects from the inside with a set of non-overlapping spheres. Based on such sphere packings, a inner bounding volume hierarchy can be constructed. In order to do so, we propose to use an AI clustering algorithm, which we extend and adapt here. The results show performance at haptic rates both for proximity and penetration volume queries for models consisting of hundreds of thousands of polygons.

Schedule: see page 14.

Using the Distribution Theory to Simultaneously Calibrate the Sensors of a Mobile Robot, Agostino Martinelli

Abstract:
This paper introduces a simple and very efficient strategy to extrinsically calibrate a bearing sensor (e.g. a camera) mounted on a mobile robot and simultaneously estimate the parameters describing the systematic error of the robot odometry system. The paper provides two contributions. The first one is the analytical computation to derive the part of the system which is observable when the robot accomplishes circular trajectories. This computation consists in performing a local decomposition of the system, based on the theory of distributions. In this respect, this paper represents the first application of the distribution theory in the frame-work of mobile robotics. Then, starting from this decomposition, a method to efficiently estimate the
parameters describing both the extrinsic bearing sensor calibration and the odometry calibration is derived (second contribution). Simulations and experiments with the robot e-Puck equipped with encoder sensors and a camera validate the approach.

**Schedule:** see page 14.

*Planning Motion in Similar Environments, Jyh-Ming Lien, Yanyan Lu*

**Abstract:**
In this work, we investigate solutions to the following question: Given two motion planning problems W1 and W2 with the same robot and similar obstacles, can we reuse the computation from W1 to solve W2 more efficiently? While the answer to this question can find many practical applications, all current motion planners ignore the correspondences between similar environments. Our study shows that by carefully storing and reusing the computation we can gain significant efficiency.

**Schedule:** see page 14.

*Robust Visual Homing with Landmark Angles, John Lim, Nick Barnes*

**Abstract:**
This paper presents a novel approach to visual homing for robot navigation on the ground plane, using only the angles of landmark points. We focus on a robust approach, leading to successful homing even in real, dynamic environments where significant numbers of landmark points are wrong or missing. Three homing algorithms are presented, two are shown to be provably convergent, and the other shown to converge empirically. Results from simulations under noise and robot homing in real environments are provided.

**Schedule:** see page 14.

*Rut Detection and Following for Autonomous Ground Vehicles, Camilo Ordonez, Oscar Chuy, Emmanuel Collins*

**Abstract:**
Expert off road drivers have found through experience that ruts formed on soft terrains as a result of vehicular transit can be used to improve vehicle safety and performance. Rut following improves vehicle performance by reducing the energy wasted on compacting the ground as the vehicle traverses over the terrain. Furthermore, proper rut following can improve vehicle safety on turns and slopes by utilizing the extra lateral force provided by the ruts to reduce lateral slippage and guide the vehicle through its path. This paper presents a set of field experiments to show the relevance of rut following for autonomous ground vehicles and proposes a reactive based approach based on knowledge of the width of the tires and the vehicle body clearance to provide mobile robots with rut detection and following abilities. Experimental results on a Pioneer 3AT robot show that the proposed system was able to detect and follow S-shaped ruts, and ruts that are not directly in front or parallel to the robot.

**Schedule:** see page 14.
Unsupervised Discovery of Object Classes from Range Data using Latent Dirichlet Allocation, Felix Endres, Christian Plagemann, Cyrill Stachniss, Wolfram Burgard

Abstract:
Truly versatile robots operating in the real world have to be able to learn about objects and their properties autonomously, that is, without being provided with carefully engineered training data. This paper presents an approach that allows a robot to discover object classes in three-dimensional range data in an unsupervised fashion and without a-priori knowledge about the observed objects. Our approach builds on Latent Dirichlet Allocation (LDA), a recently proposed probabilistic method for discovering topics in text documents. We discuss feature extraction, hypothesis generation, and statistical modeling of objects in 3D range data as well as the novel application of LDA to this domain. Our approach has been implemented and evaluated on real data of complex objects. Practical experiments demonstrate, that our approach is able to learn object class models autonomously that are consistent with the true classifications provided by a human. It furthermore outperforms unsupervised method such as hierarchical clustering that operate on a distance metric.

Schedule: see page 14.

Towards Cyclic Production Systems for Modular Robotics and Rapid Manufacturing, Matt Moses, Hiroshi Yamaguchi, Greg Chirikjian

Abstract:
A cyclic fabrication system (CFS) is a network of materials, tools, and manufacturing processes that can produce all or most of its constituent components. This paper proposes an architecture for a robotic CFS based on modular components. The proposed system is intended to self-replicate via producing necessary components for replica devices. Some design challenges unique to self-replicating machines are discussed. Results from several proof-of-principle experiments are presented, including a manipulator designed to handle and assemble modules of the same type it is constructed from, a DC brush motor fabricated largely from raw materials, and basic manufacturing tools made with a simple CFS.

Schedule: see page 14.

Setpoint Regulation for Stochastically Interacting Robots, Nils Napp, Samuel Burden, Eric Klavins

Abstract:
We present an integral feedback controller that regulates the average copy number of a particular assembly in a system of stochastically interacting robots. The mathematical model for the stochastic system is a tunable reaction network, which makes this approach applicable to a large class of other systems, including ones that exhibit stochastic self assembly at various length scales. We prove that this controller works for a range of set-points, and how to compute this range. Finally, we demonstrate the approach on a physical testbed.

Schedule: see page 14.
Centralized Path Planning for Multiple Robots: Optimal Decoupling into Sequential Plans, Jur van den Berg, Jack Snoeyink, Ming Lin, Dinesh Manocha

Abstract:
We develop an algorithm to decouple a multi-robot path planning problem into subproblems whose solutions can be executed sequentially. Given an external path planner for general configuration spaces, our algorithm finds an execution sequence that minimizes the dimension of the highest-dimensional subproblem over all possible execution sequences. If the external planner is complete (at least up to this minimum dimension), then our algorithm is complete because it invokes the external planner only for spaces of dimension at most this minimum. Our algorithm can decouple and solve path planning problems with many robots, even with incomplete external planners. We show scenarios involving 16 to 65 robots, where our algorithm solves planning problems of dimension 32 to 130 using a PRM planner for at most eight dimensions.

Schedule: see page 14.

Accurate Rough Terrain Estimation with Space-Carving Kernels, Raia Hadsell, Drew Bagnell, Martial Hebert

Abstract:
Accurate terrain estimation is critical for autonomous offroad navigation. Reconstruction of a 3D surface allows rough and hilly ground to be represented, yielding faster driving and better planning and control. However, data from a 3D sensor samples the terrain unevenly, quickly becoming sparse at longer ranges and containing large voids because of occlusions and inclines. The proposed approach uses online kernel-based learning to estimate a continuous surface over the area of interest while providing upper and lower bounds on that surface. Unlike other approaches, visibility information is exploited to constrain the terrain surface and increase precision, and an efficient gradient-based optimization allows for realtime implementation.

Schedule: see page 14.

View-Based Maps, Kurt Konolige, Michael Colander, James Bowman, Patrick Mihelich, JD Chen, Pascal Fua, Vincent Lepetit

Abstract:
Robotic systems that can create and use visual maps in realtime have obvious advantages in many applications, from automatic driving to mobile manipulation in the home. In this paper we describe a mapping system based on retaining stereo views of the environment that are collected as the robot moves. Connections among the views are formed by consistent geometric matching of their features. Out-of-sequence matching is the key problem: how to find connections from the current view to other corresponding views in the map. Our approach uses a vocabulary tree to propose candidate views, and a strong geometric filter to eliminate false positives essentially, the robot continually re-recognizes where it is. We present experiments showing the utility of the approach on video data, including map building in large indoor and outdoor environments, map building without localization, and re-localization when lost.

Schedule: see page 14.
**Generalized-ICP**, Aleksandr Segal, Dirk Haehnel, Sebastian Thrun

**Abstract:**
In this paper we combine the Iterative Closest Point (ICP) and point-to-plane ICP algorithms into a single probabilistic framework. We then use this framework to model locally planar surface structure from both scans instead of just the model scan as is typically done with point-to-plane. This can be thought of as plane-to-plane. The new approach is tested with both simulated and real-world data and is shown to outperform both standard ICP and point-to-plane. Furthermore, the new approach is shown to be more robust to incorrect correspondences, and thus makes it easier to tune the maximum match distance parameter. In addition to the demonstrated performance improvement, the proposed framework allows for more expressive probabilistic models to be incorporated into the ICP framework. While maintaining the speed and simplicity of ICP, Generalized-ICP allows the addition of outlier terms, measurement noise, and other probabilistic techniques to increase robustness.

**Schedule:** see page 14.

**3D Laser Scan Classification Using Web Data and Domain Adaptation**, Kevin Lai, Dieter Fox

**Abstract:**
Over the last years, object recognition has become a more and more active field of research in robotics. An important problem in object recognition is the need for sufficient labeled training data to learn good classifiers. In this paper we show how to significantly reduce the need for manually labeled training data by leveraging data sets available on the World Wide Web. Specifically, we show how to use objects from Googles 3D Warehouse to train classifiers for 3D laser scans collected by a robot navigating through urban environments. In order to deal with the different characteristics of the web data and the real robot data, we additionally use a small set of labeled 3D laser scans and perform domain adaptation. Our experiments demonstrate that additional data taken from the 3D Warehouse along with our domain adaptation greatly improves the classification accuracy on real laser scans.

**Schedule:** see page 14.

**Adaptive Relative Bundle Adjustment**, Gabe Sibley, Christopher Mei, Ian Reid, Paul Newman

**Abstract:**
It is well known that bundle adjustment is the optimal non-linear least-squares formulation of the simultaneous localization and mapping problem, in that its maximum likelihood form matches the definition of the Cramer Rao Lower Bound. Unfortunately, computing the ML solution is often prohibitively expensive this is especially true during loop closures, which often necessitate adjusting all parameters in a loop. In this paper we note that it is precisely the choice of a single privileged coordinate frame that makes bundle adjustment costly, and that this expense can be avoided by adopting a completely relative approach. We derive a new relative bundle adjustment, which instead of optimizing in a single Euclidean space, works in a metric-space defined by a connected Riemannian manifold. Using an adaptive optimization strategy, we show experimentally that it is possible to solve for the full ML solution incrementally in constant time even at loop closure. Our system also operates online in real-time using stereo data, with fast appearance-based
loop closure detection. We show results for sequences of 23k frames over 1.08km that indicate the accuracy of the approach.

**Schedule:** see page 14.

**Technical Session 4, Tuesday, June 30, 2009**

**Invited Talk:** John Delaney, *Next Generation Ocean Sciences: The Leading Edge of an Environmental Renaissance*

**Abstract:**
Interactive, Internet-linked sensor-robotic networks are the next-generation approach to enabling long-term 24/7/365 surveillance of major, remote, or dangerous processes that are central to the habitability of our planet. Continuous, real-time information from the environment, specifically from within the ocean basins, will launch rapid growth in our understanding of the habitats and behavior of known and novel life forms, climate change, assessment and management of living and non-living marine resources, elements of homeland defense, erupting underwater volcanoes, major earthquake timing and intensity, and mitigation of natural disasters.

The Regional Component of the U.S. National Science Foundation’s ocean observatory program will be a leader in this approach. The observatory’s network of heavily instrumented fiber-optic/power cable will convert a major sector of the Juan de Fuca tectonic plate and its overlying ocean into an internationally accessible, interactive, real-time natural laboratory reaching hundreds of millions of users or viewers via the Internet.

Thousands of physical, chemical, and biological sensors distributed across the seafloor, throughout the ocean above, and within the seabed below, may be linked to partially or fully autonomous robotic platforms that are integrated into interactive networks connected by Internet to land-based users. The observatory is being designed to provide scientists, educators, policy makers, and the public with unprecedented levels of novel information about a broad host of natural and human-induced processes operating within the ocean basins.

Data management and visualization challenges include handling large volumes of multidisciplinary data streams; assimilating real-time data into models; and providing data discovery and visualization tools that enable collaborative discovery by groups of researchers.

**Schedule:** see page 14.

**Underwater Human-Robot Interaction via Biological Motion Identification**, Junaed Sattar, Gregory Dudek

**Abstract:**
We present an algorithm for underwater robots to visually detect and track human motion. Our objective is to enable human-robot interaction by allowing a robot to follow behind a human moving in (up to) six degrees of freedom. In particular, we have developed a system to allow a robot to detect, track and follow a scuba diver by using frequency domain detection of biological motion patterns. The motion of biological entities is characterized by combinations of periodic motions which are inherently distinctive. This is especially true of human swimmers. By using the frequency-space response of spatial signals over a number of
video frames, we attempt to identify signatures pertaining to biological motion. This technique is applied to track scuba divers in underwater domains, typically with the robot swimming behind the diver. The algorithm is able to detect a range of motions, which include motion directly away from or towards the camera. The motion of the diver relative to the vehicle is then tracked using an Unscented Kalman Filter (UKF), an approach for non-linear estimation. The efficiency of our approach makes it attractive for real-time application onboard our underwater vehicle, and in future applications we intend to track scuba divers real-time with the robot. The paper presents an algorithmic overview of our approach, together with experimental evaluation based on underwater video footage.

Schedule: see page 14.

Robustness of the Unscented Kalman Filter for State and Parameter Estimation in an Elastic Transmission, Edvard Naerum, H. Hawkeye King, Blake Hannaford

Abstract:
The Unscented Kalman Filter (UKF) was applied to state and parameter estimation of a one degree of freedom robot link with an elastic, cable-driven transmission. Only motor encoder and command torque data was used as input to the filter. The UKF was used offline for joint state and model-parameter estimation, and online for state estimation. This paper presents an analysis of the robustness of the UKF to unknown/unmodeled variation in inertia, cable tension and contact forces, using experimental data collected with the robot. Using model parameters found offline the UKF successfully estimated motor and link angles and velocities online. Although the transmission was very stiff, and hence the motor and link states almost equal, information about the individual states was obtained. Irrespective of variation from nominal conditions the UKF link angle estimate was better than using motor position as an approximation (i.e. inelastic transmission assumption). The angle estimates were particularly robust to variation in operating conditions, velocity estimates less so. A near-linear relationship between contact forces and estimation errors suggested that contact forces might be estimated using this error information.

Schedule: see page 14.
Technical Session 5, Tuesday, June 30, 2009

POMDPs for Robotic Tasks with Mixed Observability, Sylvie Ong, David Hsu, Wee Sun Lee

Abstract:
Partially observable Markov decision processes (POMDPs) provide a principled mathematical framework for motion planning of autonomous robots in uncertain and dynamic environments. They have been successfully applied to various robotic tasks, but a major challenge is to scale up POMDP algorithms for more complex robotic systems. Robotic systems often have mixed observability: even when a robot's state is not fully observable, some components of the state may still be fully observable. Exploiting this, we use a factored model to represent separately the fully and partially observable components of a robot's state and derive a compact lower-dimensional representation of its belief space. We then use this factored representation in conjunction with a point-based algorithm to compute approximate POMDP solutions. Separating fully and partially observable state components using a factored model opens up several opportunities to improve the efficiency of point-based POMDP algorithms. Experiments show that on standard test problems, our new algorithm is many times faster than a leading point-based POMDP algorithm.

Schedule: see page 15.

Policy Search via the Signed Derivative, J. Zico Kolter, Andrew Ng

Abstract:
We consider policy search for reinforcement learning: learning policy parameters, for some fixed policy class, that optimize performance of a system. In this paper, we propose a novel policy gradient method based on an approximation we call the Signed Derivative; the approximation is based on the intuition that it is often very easy to guess the direction in which control inputs affect future state variables, even if we do not have an accurate model of the system. The resulting algorithm is very simple, requires no model of the environment, and we show that it can outperform standard stochastic estimators of the gradient; indeed we show that Signed Derivative algorithm can in fact perform as well as the true (model-based) policy gradient, but without knowledge of the model. We evaluate the algorithms performance on both a simulated task and two realworld tasks driving an RC car along a specified trajectory, and jumping onto obstacles with a quadruped robot and in all cases achieve good performance after very little training.

Schedule: see page 15.

Non-Parametric Learning to Aid Path Planning over Slopes, Sisir Karumanchi, Thomas Allen, Tim Bailey, Steve Scheding

Abstract:
This paper addresses the problem of closing the loop from perception to action selection for unmanned ground vehicles, with a focus on navigating slopes. A new non-parametric learning technique is presented to generate a mobility representation where maximum feasible speed is used as a criterion to classify the world. The inputs to the algorithm are terrain gradients derived from an elevation map and past observations.
of wheel slip. It is argued that such a representation can aid in path planning with improved selection of vehicle heading and operating velocity in off-road slopes. Results of mobility map generation and its benefits to path planning are shown.

Schedule: see page 15.

Technical Session 5, Tuesday, June 30, 2009

Invited Talk: Marc Ernst, *The Puzzle of Human Multisensory Perception: Optimal Integration for Action*

Abstract:
We use all our senses to construct a reliable percept representing the world with which we interact. The view we take in the Independent Max-Planck Research Group for Human Multisensory Perception and Action is that in many aspects of behaviour, motor actions and multisensory processing are inseparably linked and therefore have to be studied in a closed action/perception loop. We believe that human perception and action is tailored to the statistics of the natural environment and when the environment changes our perceptions will follow these changes through the process of adaptation minimizing potential costs during interaction. In the neural processing such statistics will represent itself in probability distributions. We follow Hermann von Helmholtz in our belief that human perception is a problem of inference, for which the sensory data are often not sufficient to uniquely determine the percept. Thus, prior knowledge has to be used to constrain the process of inference from ambiguous sensory signals. A principled way to describe the combination of prior knowledge with sensory data in a probabilistic way is the Bayesian Framework. Therefore, we regularly use this Bayesian Framework to construct ”ideal observer models” models that use the available information in the most optimal way, provided some task and cost function. These models can then be used as a benchmark against which human performance can be tested. To do so in the Multisensory Perception and Action Group we use quantitative psychophysical and neuropsychological methods together with Virtual Reality techniques. Quantitative psychophysical methods are important to best determine the relevant perceptual parameters minimizing uncertainty and unknowns. Virtual Reality is important because it provides us with a tool to precisely control the perceptual situation that are investigated, while at the same time it allows for a degree of interaction, which is necessary for studying the action/perception loop. Often, however, today's Virtual Reality techniques and Human-Computer Interaction devices are not sufficiently developed to be readily used in the study of human perception and action. Therefore, some of our work concentrates on the development of human-machine interfaces. In this talk I will provide some overview of how humans use multisensory information in an optimal way in order to guide actions.

Schedule: see page 15.

*Learning GP-BayesFilters via Gaussian Process Latent Variable Models*, Jonathan Ko, Dieter Fox

Abstract:
GP-BayesFilters are a general framework for integrating Gaussian process prediction and observation models into Bayesian filtering techniques, including particle filters and extended and unscented Kalman filters.
GP-BayesFilters learn nonparametric filter models from training data containing sequences of control inputs, observations, and ground truth states. The need for ground truth states limits the applicability of GP-BayesFilters to systems for which the ground truth can be estimated without prohibitive overhead. In this paper we introduce GPBF-LEARN, a framework for training GP-BayesFilters without any ground truth states. Our approach extends Gaussian Process Latent Variable Models to the setting of dynamical robotics systems. We show how weak labels for the ground truth states can be incorporated into the GPBF-LEARN framework. The approach is evaluated using a difficult tracking task, namely tracking a slotcar based on IMU measurements only.

Schedule: see page 15.

3D Relative Pose Estimation from Six Distances, Nikolas Trawny, Xun Zhou, Stergios Roumeliotis

Abstract:
In this paper, we present three fast, hybrid numerical algebraic methods to solve polynomial systems in floating point representation, based on the eigendecomposition of a so-called multiplication matrix. In particular, these methods run using standard double precision, use only linear algebra packages, and are easy to implement. We provide the proof that these methods do indeed produce valid multiplication matrices, and show their relationship. As a specific application, we use our algorithms to compute the 3D relative translation and orientation between two robots, based on known egomotion and six robot-to-robot distance measurements. Equivalently, the same system of equations arises when solving the forward kinematics of the general Stewart-Gough mechanism. Our methods can find all 40 solutions, trading off speed (0.08s to 1.5s, depending on the choice of method) for accuracy.

Schedule: see page 15.

Technical Session 7, Wednesday, July 1, 2009

Invited Talk: John C. Doyle, Rules of engagement: The architecture of robust, evolvable networks

Abstract:
Biological systems are robust and evolvable in the face of even large changes in environment and system components, yet can simultaneously be extremely fragile to small perturbations. Such universally robust yet fragile (RYF) complexity is found wherever we look. The amazing evolution of microbes into humans (robustness of lineages on long timescales) is punctuated by mass extinctions (extreme fragility). Diabetes, obesity, cancer, and autoimmune diseases are side-effects of biological control and compensatory mechanisms so robust as to normally go unnoticed. RYF complexity is not confined to biology. The complexity of technology is exploding around us, but in ways that remain largely hidden. Modern institutions and technologies facilitate robustness and accelerate evolution, but enable catastrophes on a scale unimaginable without them (from network and market crashes to war, epidemics, and global warming). Understanding RYF means understanding architecture the most universal, high-level, persistent elements of organization and protocols. Protocols define how diverse modules interact, and architecture defines how sets of protocols are organized.
Insights into the architectural and organizational principles of networked systems can be drawn from three converging research themes. 1) With molecular biology’s description of components and growing attention to systems biology, the organizational principles of biological networks are becoming increasingly apparent. Biologists are articulating richly detailed explanations of biological complexity, robustness, and evolvability that point to universal principles. 2) Advanced technology’s complexity is now approaching biology’s. While the components differ, there is striking convergence at the network level of architecture and the role of layering, protocols, and feedback control in structuring complex multiscale modularity. New theories of the Internet and related networking technologies have led to test and deployment of new protocols for high performance networking. 3) A new mathematical framework for the study of complex networks suggests that this apparent network-level evolutionary convergence within/between biology/technology is not accidental, but follows necessarily from the universal system requirements to be efficient, adaptive, evolvable, and robust to perturbations in their environment and component parts.

**Schedule:** see page 15.

*An Ab-initio Tree-based Exploration to Enhance Sampling of Low-energy Protein Conformations*, Amarda Shehu

**Abstract:**
This paper proposes a robotics-inspired method to enhance sampling of native-like protein conformations when employing only amino-acid sequence. Computing such conformations, essential to associate structural and functional information with gene sequences, is challenging due to the high-dimensionality and the rugged energy surface of the protein conformational space. The contribution of this work is a novel two-layered method to enhance the sampling of geometrically-distinct lowenergy conformations at a coarse-grained level of detail. The method grows a tree in conformational space reconciling two goals: (i) guiding the tree towards lower energies and (ii) not oversampling geometrically-similar conformations. Discretizations of the energy surface and a low-dimensional projection space are employed to select more often for expansion low-energy conformations in under-explored regions of the conformational space. The tree is expanded with low-energy conformations through a Metropolis Monte Carlo framework that uses a move set of physical fragment configurations. Testing on sequences of seven small-to-medium structurally-diverse proteins shows that the method rapidly samples native-like conformations in a few hours on a single CPU. Analysis shows that computed conformations are good candidates for further detailed energetic refinements by larger studies in protein engineering and design.

**Schedule:** see page 15.

*Cellular Muscle Actuators with Variable Resonant Frequencies*, Thomas Secord, Harry Asada

**Abstract:**
This paper presents the design and analysis of a novel variable stiffness and variable resonance actuator based on a cellular arrangement of piezoelectric devices. The cellular muscle actuator design concept is presented followed by a general dynamic model for establishing the theoretical bounds on achievable resonant frequencies. A model that is specific to the proposed design is then formulated to include the effects of parasitic dynamics. The resonance characteristics of a three cell prototype system are identified experimentally. The theoretical model and experimental results agree over a large frequency range and illustrate the variable
Abstract:
When unmanned aerial vehicles (UAVs) are used to survey distant targets, it is important to transmit sensor information back to a base station. As this communication often requires high uninterrupted bandwidth, the surveying UAV often needs a free line-of-sight to the base station, which can be problematic in urban or mountainous areas. Communication ranges may also be limited, especially for smaller UAVs. Though both problems can be solved through the use of relay chains consisting of one or more intermediate relay UAVs, this leads to a new problem: Where should relays be placed for optimum performance? We present two new algorithms capable of generating such relay chains, one being a dual ascent algorithm and the other a modification of the Bellman-Ford algorithm. As the priorities between the number of steps in the relay chain and the cost of the chain may vary, we calculate chains of different lengths and costs and let the ground operator choose between them. Several different formulations for edge costs are presented. In our test cases, both algorithms are substantially faster than an optimized version of the original Bellman-Ford algorithm, which is used for comparison.
Time-Extended Multi-Robot Coordination for Domains with Precedence Constraints, Edward Jones Berardine Dias, Anthony Stentz

Abstract:
Many applications require teams of robots to cooperatively execute complex tasks. Among these domains are those where successful coordination solutions must respect constraints that occur on the intra-path level. This work focuses on multi-agent coordination for disaster response with intra-path constraints, a compelling application that is not well addressed by current coordination methods. In this domain a group of fire trucks agents attempt to address a number of fires spread throughout a city in the wake of a large-scale disaster. The disaster has also caused many city roads to be blocked by impassable debris, which can be cleared by bulldozer robots. A high-quality coordination solution must determine not only a task allocation but also what routes the fire trucks should take given the intra-path precedence constraints and which bulldozers should be assigned to clear debris along those routes. This work presents two methods for generating time-extended coordination solutions where more than one task is assigned to each agent for domains with intra-path constraints. While a number of approaches have employed time-extended coordination for domains with independent tasks, few approaches have used time-extended coordination in domains where agents schedules are interdependent at the path planning level. Our first approach uses tiered auctions and two heuristic techniques, clustering and opportunistic path planning, to perform a bounded search of possible time-extended schedules and allocations. Our second method uses a centralized, non-heuristic, genetic algorithm-based approach that provides higher quality solutions but at substantially greater computational cost. We compare our time-extended approaches with a range of single task allocation approaches in a simulated disaster response domain.

Schedule: see page 16.

Technical Session 9, Wednesday, July 1, 2009

Early Career Spotlight Talk: Haptography: Creating Authentic Haptic Feedback from Recordings of Real Interactions, Katherine Kuchenbecker

Schedule: see page 16.

Bridging the gap between passivity and transparency, Michel Franken, Stefano Stramigioli, Rob Reilink, Cristian Secchi, Alessandro Macchelli

Abstract:
In this paper a structure will be given which in a remarkably simple way offers a solution to the implementation of different telemanipulation schemes for discrete time varying delays by preserving passivity and allowing the highest transparency possible. This is achieved by splitting the communication channel in two separate ones, one for the energy balance which will ensure passivity and one for the haptic information between master and slave and which will address transparency. The authors believe that this structure is the most general up to date which preserves passivity under discrete time varying delays allowing different control schemes to address transparency.


Feedback Control for Steering Needles Through 3D Deformable Tissue Using Helical Paths, Kris Hauser, Ron Alterovitz, Nuttapong Chentanez, Allison Okamura, Ken Goldberg

Abstract:
Bevel-tip steerable needles are a promising new technology for improving accuracy and accessibility in minimally invasive medical procedures. As yet, 3D needle steering has not been demonstrated in the presence of tissue deformation and uncertainty, despite the application of progressively more sophisticated planning algorithms. This paper presents a feedback controller that steers a needle along 3D helical paths, and varies the helix radius to correct for perturbations. It achieves high accuracy for targets sufficiently far from the needle insertion point; this is counterintuitive because the system is highly underactuated and not locally controllable. The controller uses a model predictive control framework that chooses a needle twist rate such that the predicted helical trajectory minimizes the distance to the target. Fast branch and bound techniques enable execution at kilohertz rates on a 2GHz PC. We evaluate the controller under a variety of simulated perturbations, including imaging noise, needle deflections, and curvature estimation errors. We also test the controller in a 3D finite element simulator that incorporates deformation in the tissue as well as the needle. In deformable tissue examples, the controller reduced targeting error by up to 88% compared to open-loop execution.

Technical Session 10, Wednesday, July 1, 2009

Large Scale Graph-Based SLAM using Aerial Images as Prior Information, Bastian Steder, Rainer Kummerle, Christian Dornhege, Alexander Kleiner, Giorgio Grisetti, Wolfram Burgard

Abstract:
To effectively navigate in their environments and accurately reach their target locations, mobile robots require a globally consistent map of the environment. The problem of learning a map with a mobile robot has been intensively studied in the past and is usually referred to as the simultaneous localization and mapping (SLAM) problem. However, existing solutions to the SLAM problem typically rely on loop-closures to obtain global consistency and do not exploit prior information even if it is available. In this paper, we present a novel SLAM approach that achieves global consistency by utilizing publicly accessible aerial photographs as prior information. Our approach inserts correspondences found between three-dimensional laser range scans and the aerial image as constraints into a graph-based formulation of the SLAM problem. We evaluate our algorithm based on large real-world datasets acquired in a mixed in- and outdoor environment by comparing the global accuracy with state-of-the-art SLAM approaches and GPS. The experimental results demonstrate that the maps acquired with our method show increased global consistency.
Abstract:
We describe a new formulation of appearance-only SLAM suitable for very large scale navigation. The system navigates in the space of appearance, assigning each new observation to either a new or previously visited location, without reference to metric position. The system is demonstrated performing reliable online appearance mapping and loop closure detection over a 1,000km trajectory, with mean filter update times of 14 ms. The 1,000km experiment is more than an order of magnitude larger than any previously reported result. The scalability of the system is achieved by defining a sparse approximation to the FAB-MAP model suitable for implementation using an inverted index. Our formulation of the problem is fully probabilistic and naturally incorporates robustness against perceptual aliasing. The 1,000km data set comprising almost a terabyte of omni-directional and stereo imagery is available for use, and we hope that it will serve as a benchmark for future systems.

Schedule: see page 16.
Workshops

W1: Bridging the Gap between High-Level Discrete Representations and Low-Level Continuous Behaviors

Schedule and Location:
Full-day workshop, Sunday, June 28, 2009
9:00 am - 5:30 pm
Electrical Engineering Building (Room EEB 045), University of Washington campus, Seattle, Washington.

Organizers:
Dana Kulic’, Department of Mechano-Informatics, University of Tokyo
Jan Peters, Max Planck Institute of Biological Cybernetics
Pieter Abbeel, Dept of Electrical Engineering and Computer Science, UC Berkeley

Description:
Recently, robotics researchers have been investigating the modeling of human and robot behavior in terms of motion primitives. This research direction, based on biological and neuroscience findings, posits that human behavior is composed of motor primitive units, which can be acquired by a robot through imitation learning or practice. Motion primitives offer an approach for discretizing continuous behavior, representing a "bottom-up" approach for organizing robot behavior. On the other hand, in AI and planning fields, there has been a longstanding area of research in planning and acting in the discrete domain, or through modeling changes in the world as an instantaneous change in discrete state. This approach can be thought of as a "top-down" approach for organizing robot behavior. In this workshop, we propose to bring together researchers from both areas to discuss approaches for "bridging the gap" and combining continuous domain approaches with discrete representations.

The aim of the workshop is to bring together researchers working on motion primitives as a way of discretizing continuous behavior, and discuss ways in which these approaches can be extended through hierarchical organization and combined with planning and other discrete domain approaches. Specific themes of the workshop include: motion primitive representations and task abstractions; learning and parsing sequences and plans of motion primitives; imitation learning and learning from observation based on motion primitives; hierarchical reinforcement learning; apprenticeship learning of composed tasks; hybrid task control; hierarchical organization of behaviors; learning operator conditions for primitives; plan recognition; plan generation and modification.

The workshop will include talks by a number of the top researchers in the field, who will articulate current approaches and the progress to date. A key goal of the workshop is to provide a venue to allow discussion on how current approaches may be combined to integrate the capability for acting in the continuous domain while reasoning in the discrete domain.

The workshop is supported by the Technical Committee on Robot Learning of the IEEE Robotics and Automation Society.
W2: Good Experimental Methodology in Robotics

Schedule and Location:
Full-day workshop, Sunday, June 28, 2009
9:00 am - 5:30 pm
Electrical Engineering Building (Room EEB 031), University of Washington campus, Seattle, Washington.

Organizers:
John Hallam, University of Southern Denmark
Angel P. del Pobil, Robotic Intelligence Laboratory, Universitat Jaume I, Spain
Fabio Bonsignorio, Heron Robots, Italy

Description:
As the complexity of current robotic and embodied intelligent systems grows, it is more and more necessary to define proper experimental approaches and benchmarking procedures. The Special interest group on Good Experimental Methodology was formed by EURON in response to a wide perception evidenced by some 90 responses to an email call for interest that roboticists could do much better at performing and, particularly, reporting experimental work. A major output of the Special Interest Group is a set of guidelines for good experimental (reporting) practice, which we believe supports the communitys wish to produce better experimental work. Equally significant is a series of workshops on Benchmarking and Good Experimental Methodology held at major Robotics conferences. Good experimental work is not novel in robotics: there are many good experimental scientists in our community. However, uniformly good experimental work and reporting has not yet been achieved. The evidence of community interest in the topic mentioned above suggests that the community is willing to take steps to improve in this area. Thus we propose to take the work of good experimental robotics groups and use it to illustrate high-quality experimental work and reporting, using the workshop format to draw out the strengths (and weaknesses) of presented work and encourage sharing and adoption of good practices.
W3: Understanding the Human Hand for Advancing Robotic Manipulation

Schedule and Location:
Full-day workshop, Sunday, June 28, 2009
9:00 am - 5:30 pm
Electrical Engineering Building (Room EEB 125), University of Washington campus, Seattle, Washington.

Organizers:
Ravi Balasubramanian, University of Washington
Yoky Matsuoka, University of Washington

Description:
Recent advances in the human sciences have energized the field of robotics toward personal assistants and brain machine interface. There is an increased interest to solve the robotic manipulation question: Can we build robotic hands that can accomplish our daily manipulation tasks? The human hand is adept at many diverse tasks in varied contexts, including power and precision grasping, twisting, and tapping. But we still do not know what features of the human hand enable such capability. For example, do biomechanical features like the complex tendon-hood, synergistic muscle actuation, and bone shapes make the difference? Or is it the neural coding of movement? Importantly for robotics, we need to understand what features should be included in future robotic hands. This workshop is a forum for researchers to discuss manipulation viewed in light of the human hands features and hopes to push the state of the art of the robotic hand. We expect that the workshop will bring together researchers from diverse areas such as robotics, biomechanics, neuroscience, and anthropologists.
W4: Regression in Robotics - Approaches, and Applications

Schedule and Location:
Full-day workshop, Sunday, June 28, 2009
9:00 am - 5:30 pm
Electrical Engineering Building (Room EEB 105), University of Washington campus, Seattle, Washington.

Organizers:
Christian Plagemann, Stanford University
Jo-Anne Ting, University of Southern California
Sethu Vijayakumar, University of Edinburgh

Description:
Function approximation from noisy data is a central task in robot learning. Relevant problems include sensor modelling, manipulation, control, and many others. A large number of function approximation methods have been proposed from statistics, machine learning and control system theory to address robotics-related issues such as online updates, active sampling, high dimensionality, non-homogeneous noise and missing features. However, with minimal communication and collaboration between communities, work is sometimes reproduced or re-discovered, making research progress challenging.

Our goal is to draw researchers from the different communities of robotics, control systems theory and machine learning into a discussion of the relevant problems in function approximation to be learned in robotics. We would like to develop a common understanding of the benefits and drawbacks of different function approximation approaches and to derive practical guidelines for selecting a suitable approach to a given problem.

In addition, we would like to discuss two key points of criticism in current robot learning research. First, data-driven machine learning methods do, in fact, not necessarily outperform models designed by human experts and we would like to explore what function approximation problems in robotics really have to be learned. Second, function approximation/regression methods are typically evaluated using different metrics and data sets, making standardized comparisons challenging.
W5: Algorithmic Automation

Schedule and Location:
Full-day workshop, Sunday, June 28, 2009
9:00 am - 5:30 pm
Electrical Engineering Building (Room EEB 037), University of Washington campus, Seattle, Washington.

Organizers:
Ken Goldberg, UC Berkeley
Vijay Kumar, University of Pennsylvania
Todd Murphey, Northwestern University
Frank van der Stappen, Utrecht University

Description:
Our goal is to bring together researchers and students to present "algorithmic" approaches to automation and discuss open research questions that can benefit the quality and productivity of manufacturing. Algorithms are a fundamental component of automation systems: they control or reason about motion and perception in the physical world. They receive input from noisy sensors, consider geometric and physical constraints, and perform repetitive operations using imprecise actuators. Unfortunately, automation for manufacturing today is where computer technology was in the early 1960's, a patchwork of ad-hoc solutions lacking a rigorous scientific methodology. Computer aided design (CAD) has progressed a long way toward elegant modelling of mechanical parts and behavior. What’s needed is a framework for the systematic design of automated manufacturing systems that handle these parts. Automation is amenable to formal specification, analysis, and synthesis. The abstraction of these operations and resulting analysis can facilitate improving the integrity, reliability, interoperability, and maintainability of manufacturing systems.
W6: Integrating Mobility and Manipulation

Schedule and Location:
Full-day workshop, Sunday, June 28, 2009
9:00 am - 5:30 pm
Electrical Engineering Building (Room EEB 003), University of Washington campus, Seattle, Washington.

Organizers:
Brian Gerkey, Willow Garage
Kurt Konolige, Willow Garage
Odest Chadwicke Jenkins, Brown University
Robert Platt, NASA JSC
Neo Ee Sian, AIST

Description:
The goal of this full-day workshop is to gather and discuss state of the art research in mobile manipulation. We emphasize mobile and manipulation: we will explore the problems that arise and the solutions that are developed when working with robots that move freely through, and manipulate objects in, human-centered environments. These problems must be solved to develop applications in real-world settings in health care, flexible factories, and domestic chores. We are especially interested in autonomous systems that integrate robust sensing and actuation to perform tasks in cluttered and uncertain environments, but we also welcome new ideas on teleoperation and mixed-mode systems. Empirical results showing integrated systems with physical hardware are preferred, even if preliminary.
Industry-Sponsored Workshop: Introduction to Microsoft Robotics Developer Studio

Schedule and Location:
Sunday, June 28, 2009
6:30pm - 8:30pm
Electrical Engineering Building (Room EEB 003), University of Washington campus, Seattle, Washington.

Organizers:
Trevor Taylor, Microsoft
Stewart Tansley, Microsoft

Description:
Microsoft Robotics Developer Studio (RDS) is a general-purpose software platform for developing applications that require a high level of concurrency in a distributed environment, especially typical of robotics. It has been designed so that it can easily interface with a wide variety of hardware devices. The architecture uses a lightweight service-oriented approach that scales well, enabling very high messaging throughput.

This lecture-style tutorial provides an overview of RDS and its various components supplemented by numerous live demonstrations. The tutorial is based on the latest version of RDS 2008, released in November 2008.
W1-HD: Creative Manipulation: Examples using the WAM

Schedule and Location:
Half-day workshops, Monday, June 29, 2009
8:30am-12:00pm
Husky Union Building (Room HUB 209A), University of Washington campus, Seattle, Washington.

Organizers:
William T. Townsend, Barrett Technology
Yoky Matsuoka, University of Washington

Description:
This workshop is intended to foster the sharing of various algorithmic approaches to the open Whole-Arm Manipulator (WAM) platform. Several users will present their recent research on the WAM platform including videos clips, novel algorithmic implementations, and current challenges. The Whole-Arm Manipulator is one of the most open, soft manipulation systems available for advanced robotics research and pHRI (physical human-robot interaction). It was designed specifically for robotics researchers and allows users unprecedented access to realtime joint torques so they can apply novel computed-torque algorithms. It also supports high-level control of Cartesian trajectories and force/torques. Different research teams from a dozen countries have used the WAM platform in unique and innovative ways. We invite all people interested in dexterous manipulation, mobile manipulation, and human-interactive robotics to join us.
**W2-HD: Aquatic Robots and Ocean Sampling**

**Schedule and Location:**
Half-day workshops, Monday, June 29, 2009
8:30am-12:00pm
Husky Union Building (Room HUB 106B), University of Washington campus, Seattle, Washington.

**Organizers:**
Gaurav Sukhatme, University of Southern California
Kanna Rajan, Monterey Bay Aquarium Research Institute

**Description:**
This half day workshop at RSS 2009 will bring together researchers in several disciplines: aquatic robotics (both underwater and surface systems), communications science and technology, physical oceanography, biological oceanography, and marine microbiology. The primary goal of the workshop is to make bridges between these communities by sharing recent advances and discussing future needs. The workshop features technical talks by experts in the areas of underwater robotic systems, autonomous surface vehicles, networked and multi-robot systems in the aquatic domain, as well experts in physical and biological oceanography, and aspects of marine microbiology.
W3-HD: Autonomous Flying Vehicles: Fundamentals and Applications

Schedule and Location:
Half-day workshops, Monday, June 29, 2009
8:30am-12:00pm
Husky Union Building (Room HUB 108), University of Washington campus, Seattle, Washington.

Organizers:
Srikanth Saripalli, Arizona State University
Pieter Abbeel, UC Berkeley

Description:
Unmanned Aerial Vehicles (UAVs) by nature are complex dynamical systems that present several challenges in design, dynamics, estimation, guidance and control. Various researchers have worked on problems ranging from design and control of UAVs to obstacle avoidance, path planning. Because of the diverse nature of research involved in developing UAVs, there is not much interaction between various researchers. For example, obstacle avoidance and path planning algorithms differ significantly depending on whether the UAV is a fixed wing aircraft or a rotorcraft. Similarly control algorithms for a fixed wing vehicle are vastly different from those of an Airship. Multi-UAV control and coordination aspects pose a completely different set of problems. The objective of the workshop is to bring together several experts in different disciplines interested in this problem, but who normally do not interact with each other.
W4-HD: Protein Structure, Kinematics, and Motion Planning

Schedule and Location:
Half-day workshops, Monday, June 29, 2009
8:30am-12:00pm
Husky Union Building (Room HUB 200AB), University of Washington campus, Seattle, Washington.

Organizers:
Lydia Tapia, Texas A&M
Nancy Amato, Texas A&M
Mark Moll, Rice University

Description:
Proteins play an essential role in many biochemical processes. They can catalyze biochemical reactions, have structural or mechanical functions, and undergo critical conformational changes that affect their functionality. This workshop will explore the many connections between robotics and protein modelling and will feature speakers who work in robotics and computational structural biology. We will focus this exploration through three concepts vital to the simulation of proteins: structure, kinematics, and motions. These concepts have been addressed with techniques from robotics. For example, protein motions have been explored through techniques from robotic motion planning. Speakers will talk about their current research, and they will ensure that the biological topics can be well understood, even by non-experts.
## Conference Organizers

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   The arguments to the dvips command will ensure that all fonts are embedded in the PDF file produced by ps2pdf.
Checking the PDF file: Before you submit your file, please open it in Acrobat Reader. In the menu “File” under “Document Properties” you can find information about “Fonts.” Your document should only contain Type-1 fonts. If you followed the instructions above, but your documents contains other types of fonts, they may have been included as part of figures. Please ensure that your submission only contains Type-1 fonts. If you experience difficulties creating PDF files that comply with this requirement, please send email to jacaste@unizar.es prior to the deadline.

5. Submission: Please submit your paper by August 1, 2009 using the link

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We are looking forward to receiving your final submission!

Author Checklist

- Revised paper uploaded via the conference submission software
- Author agreement form signed and mailed to Jose A. Castellanos via physical mail.
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Please note: We reserve the right not to publish accepted papers should not all information be received by August 1, 2009. We will also exclude papers that violate our formatting guidelines.

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Robotics: Science and Systems 2010

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