PERFORMANCE METRICS
FOR
INTELLIGENT SYSTEMS WORKSHOP

Courtyard Gaithersburg Washingtonian Center, Gaithersburg, Maryland USA
August 28 - 30, 2007

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FOREWORD

The 2007 Performance Metrics for Intelligent Systems (PerMIS) Workshop was held at the Courtyard Gaithersburg Washingtonian Center from August 28–30. This seventh installment of PerMIS started in 2000 targeted at defining measures and methodologies of evaluating performance of intelligent systems, and focused on applications of performance measures to practical problems in commercial, industrial, homeland security, and military applications. The cardinal theme of this year's workshop was *the interplay between autonomy and intelligence*, i.e. how does autonomy influence intelligence and vice versa.

Defining and measuring aspects of a system:

- The level of autonomy
- Human-robot interaction
- Collaboration

Evaluating components within intelligent system

- Sensing and perception
- Knowledge representation, world models, ontologies
- Planning and control
- Learning and adaption
- Reasoning

Infrastructural support for performance evaluation

- Testbeds and competitions for intercomparisons
- Instrumentation and other measurement tools
- Simulation and modeling support

Technology readiness measures for intelligent systems

Applied performance measures in various domains, e.g.,

- Intelligent transportation systems
- Emergency response robots (search and rescue, bomb disposal)
- Homeland security systems
- De-mining robots
- Defense robotics
- Hazardous environments (e.g., nuclear remediation)
- Industrial and manufacturing systems
- Space/Aerial robotics
- Medical Robotics & Assistive devices

This year's exciting program consisted of four plenary addresses, one featured presentation, four special sessions, and two panel discussions. In addition to these, there were five general technical sessions. All of these presentations addressed, in one way or another, performance metrics, evaluation, and analysis of intelligent systems in diverse domains ranging from space robotics to manufacturing, from mobile robotic systems to human machine interaction, to name a few.

PerMIS'07 was sponsored by NIST with technical co-sponsorship of the IEEE Washington Section Robotics and Automation Society Chapter and in-cooperation with the Association for Computing Machinery (ACM) Special Interest Group on Artificial Intelligence (SIGART). We also acknowledge the financial support of the IEEE Washington Section.

There were several firsts to this year's workshop. The proceedings of PerMIS'07 are being indexed by INSPEC, Ei Compendex, ACM's Digital Library, and are released, as in previous years, as a NIST Special Publication. These indexing services will enable the presented work to reach a wider audience for increased references and citations. Springer Publishers hosted a booth on the last two days of the workshop during which time some of the displayed books were raffled off. We thank Springer for their participation and hope that this is the beginning of many years of their support.

We would like to thank all members of the PerMIS'07 Program Committee, and the reviewers for contributing to the success of the workshop. Most importantly, we thank all authors for their valuable submissions and the attendees for their participation. We sincerely hope that you enjoyed the presentations and ensuing discussions, while forging new relationships and renewing old ones. It was our great pleasure to host all the attendees.

See you next year!

Raj Madhavan
Program Chair

Elena Messina
General Chair

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PROGRAM COMMITTEE

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E. Tunstel (Jet Propulsion Lab. USA)

PLENARY SPEAKER

Prof. Maria Gini

University of Minnesota, USA

Methodology for Experimental Research in Multi-robot Systems with Case Studies

Tue. 08:30

ABSTRACT

Fully repeatable and controllable experiments are essential to enable a precise comparison of multi-robot systems. Using different case studies, we describe a general methodology for conducting experimental activities for multi-robot systems. This is a first step toward the goal of fostering the practice of replicating experiments in order to compare different methods and assess their strengths and weaknesses.

In the first case study, we examine the problem of building a geometrical map of an indoor environment using multiple robots. The map is built by integrating partial maps made of segments without using any odometry information. We show how to improve the repeatability and controllability of the experimental results and how to compare different mapping systems.

We then present a case study of auction-based methods for the allocation of tasks to a group of robots. The robots operate in a 2D environment for which they each have a map. Tasks are locations in the map that must be visited by one robot. Robots bid to obtain tasks, but unexpected obstacles and other delays may prevent a robot from completing its allocated tasks. We show how to compare our experimental results with other published auction-based methods.

BIOGRAPHY

Maria Gini is a Professor at the Department of Computer Science and Engineering of the University of Minnesota. Before joining the University of Minnesota, she was a Research Associate at the Politecnico of Milan, Italy, and a Visiting Research Associate at Stanford University. Her work has included motion planning for robot arms, navigation of mobile robots around moving obstacles, unsupervised learning of complex behaviors, coordinated behaviors among multiple robots, and autonomous economic agents. She has coauthored over 200 technical papers. She is currently the chair of ACM Special Interest Group on Artificial Intelligence (SIGART), a member of the Association for the Advancement of Artificial Intelligence (AAAI) Executive Council and of the board of the International Foundation of Autonomous Agents and Multi-Agent Systems. She is on the editorial board of numerous journals, including Autonomous Robots, the Journal of Autonomous Agents & Multi-Agent Systems, Electronic Commerce Research and Applications, Integrated Computer-Aided Engineering, and Web Intelligence and Agent Systems.

PLENARY SPEAKER

Dr. Eric Krotkov

Griffin Technologies, USA

Measuring Ground Robot Performance

Tue. 14:00

ABSTRACT

This talk first describes several approaches to measure the performance of ground robots. It is easy enough to measure quantities such as speed and reliability. It is more challenging to define metrics for perception, planning, and autonomy. The talk then presents selected results of applying the approaches to systems developed by several Government programs.

BIOGRAPHY

Dr. Krotkov is the President of Griffin Technologies, a consulting and software firm specializing in robotics and machine perception. Before founding Griffin, he worked in industry as an executive in a medical imaging technology start-up, in government as a program manager at DARPA, and in academia as a faculty member of the Robotics Institute at Carnegie Mellon University. Dr. Krotkov earned his Ph.D. degree in Computer and Information Science in 1987 from the University of Pennsylvania, for pioneering work in active computer vision.

PLENARY SPEAKER

Prof. Illah Nourbakhsh

Carnegie Mellon University, USA

Formalizing Educational Human-Robot Collaboration

Wed. 08:30

ABSTRACT

Designing human-robot collaboration systems is an inherently multidisciplinary endeavor aimed at providing humans with rich, effective and satisfying interactions. Over the past ten years, my laboratory has focused on educational collaboration, wherein the purpose of the interaction is to provide measurable learning for humans through exploration and discovery. We propose that the creation of a successful human-robot collaboration system requires innovation in several areas: robot morphology; robot behavior; social perception; interaction design; human cognitive models and evaluation of educational effectiveness. Our iterative process for collaboration design extends evaluation techniques from the informal learning field together with underlying technical advances in robotics. This talk describes our research methodology, technical contributions and experimental outcomes for three fielded robot systems that push on developing a generalizable, formal approach to educational human-robot collaboration. For the past several months, our group has been laying the groundwork for large-scale dissemination of our technology and curricular instruments.

I will describe the robot “community” we wish to help spawn, and the ingredients that may help to catalyze a broad form of technologically empowered community, including the Telepresence Robot Kit and the Global Connection Project.

BIOGRAPHY

Illah R. Nourbakhsh is an Associate Professor of Robotics and head of the Robotics Masters Program in The Robotics Institute at Carnegie Mellon University. He was on leave for the 2004 calendar year and was at NASA/Ames Research Center serving as Robotics Group lead. He received his Ph.D. in computer science from Stanford University in 1996. He is co-founder of the Toy Robots Initiative at The Robotics Institute, director of the Center for Innovative Robotics and director of the Community Robotics, Education and Technology Empowerment (CREATE) lab. He is also co-PI of the Global Connection Project, home of the Gigapan project. He is also co-PI of the Robot 250 city-wide art+robotics fusion program in Pittsburgh. His current research projects include educational and social robotics and community robotics. His past research has included protein structure prediction under the GENOME project, software reuse, interleaving planning and execution and planning and scheduling algorithms, as well as mobile robot navigation. At the Jet Propulsion Laboratory he was a member of the New Millenium Rapid Prototyping Team for the design of autonomous spacecraft. He is a founder and chief scientist of Blue Pumpkin Software, Inc., which was acquired by Witness Systems, Inc. Illah recently co-authored the MIT Press textbook, Introduction to Autonomous Mobile Robots.

PLENARY SPEAKER

Dr. Alex Zelinsky

CSIRO ICT Centre, Australia

Building Autonomous Systems of High Performance, Reliability and Integrity

Thu. 08:30

ABSTRACT

Commercial applications for the everyday deployment of autonomous systems based on robotic and intelligent systems technologies require the highest levels of performance, reliability and integrity. The general public expects intelligent machines to be fully operational 100% of the time. People expect autonomous technologies to operate at higher levels of performance and safety than people themselves exhibit. For example smart car technologies are expected to cause ZERO accidents while human errors kill more 150,000 people on our roads every year! This talk will describe the design principles that have been developed over of the last 10 years through exhaustive trial and error testing to underpin autonomous systems that are suitable for real-world deployment. Currently, it is not yet possible to realise an autonomous system that doesn't fail periodically. Even if the mean rate between failures is days or weeks, a single failure could have catastrophic consequences. The approach we have adopted to address this situation has been to build-in monitoring systems that continually check all key system parameters and variables. If the monitored parameters move outside tightly defined bounds the system will safely shutdown, and alert the human supervisor. The failure conditions are logged and then further testing and debugging is performed. The value and appropriateness of our approach will be shown by a number of real-world studies. We will show that how it is possible to design computer vision systems for human-machine applications can operate with over 99% reliability, in all lighting conditions, for all types of users irrespective of age, race or visual appearance. These systems have been used in automotive and sports applications. We have also show how this approach has been used to design field robotic systems that have deployed in automobile safety systems and 24/7 mining applications.

BIOGRAPHY

Dr. Alex Zelinsky is a well-known scientist, specialising in robotics and computer vision and is widely recognised as an innovator in human-machine interaction. Dr. Zelinsky is currently Group Executive, Information and Communication Sciences and Technology, and Director, CSIRO Information Communication Technology (ICT) Centre. Before joining CSIRO in July 2004, Dr. Zelinsky was CEO of Seeing Machines, a company dedicated to the commercialisation of computer vision systems. Dr. Zelinsky co-founded Seeing Machines in June 2000, the company is now publicly listed on the London Stock Exchange. The technology commercialised by Seeing Machines was developed at the Australian National University where Dr. Zelinsky was Professor and Head of the Department of Systems Engineering (1996 -2000). Prior to joining the Australian National University, Dr. Zelinsky worked as an academic at the University Wollongong (1984-1991) and as a research scientist in the Electrotechnical Laboratory, Japan (1992-1995). Dr. Zelinsky is an active member of the robotics community and has served on the editorial boards of the International Journal of Robotics Research and IEEE Robotics and Automation Magazine, he also founded the Field & Services Robotics conference series. Dr. Zelinsky's contributions have been recognised by awards in Australia and internationally. These include the Australian Engineering Excellence Awards, US R&D magazine Top 100 Award and Technology Pioneer at the World Economic Forum.

FEATURED PRESENTATION

Dr. Vladimir Lumelsky

NASA-Goddard Space Center, USA

Human-Robot Interaction in Physical Proximity: Issues and Prospects

Wed. 14:00

ABSTRACT

After spectacular successes, in 1970s-1980s, in the use of robotics in highly structured environments - e.g. automotive assembly, welding, and painting lines - the penetration of "serious" robots (those large and powerful enough to be harmful) into new applications has slowed down markedly. User manuals of most robot arm manipulators warn that under no circumstance can people enter the workspace of an operating robot. The reason is simple - due to intended use these robots are strong enough to endanger a human, yet their sensing and intelligence is "too dumb" to be trusted for human safety. In the roboticists' parlance, today's robots are not designed to operate in unstructured environments, that is settings not created specifically for the robot's operation. It is not the function the robot is built for that is the problem - it is the robot's interaction with its environment. The problem is lesser with robot rovers but quite pronounced with arm manipulators.

The way to break this barrier is to design robots fully capable of operating in an unstructured environment, in places where things are unpredictable and must be perceived and decided upon on the fly. This is a new terrain - the required hardware and intelligence are to be more complex and sophisticated than what we know today. In this talk we will review related technical and scientific issues.

BIOGRAPHY

Dr. Vladimir Lumelsky is the head of the Laboratory of Robotics for Unstructured Environments at NASA-Goddard Space Center, and is Adjunct Professor of Computer Science at the University of Maryland-College Park. The long-term goal of the laboratory is to develop robots capable of operating in the uncertain and changing settings likely to arise in future NASA missions. This work builds upon Dr. Lumelsky's work on large sensitive robot skin systems prior to joining NASA in 2004, as a professor at Yale University and later at the University of Wisconsin-Madison (where he was The Consolidated Papers Professor of Engineering). Dr. Lumelsky is the author of three books and over 200 professional papers covering the areas of robotics, computational intelligence, human-machine interaction, human spatial reasoning, massive sensor arrays, bio-engineering, control theory, kinematics, pattern recognition, and industrial automation. He has held a variety of positions in both the public and private sectors: he was Program Director at the National Science Foundation, and has led large technical projects, including development of a universal industrial robot controller at General Electric (GE Research Center), and a joint robot skin development effort with Hitachi Corporation. Dr. Lumelsky also has held temporary positions at the Science University of Tokyo (Japan), Weizmann Institute (Israel) and US South Pole Station, Antarctica. He is the founding Editor-in-Chief of the IEEE Sensors Journal, and has served on editorial boards of other professional journals. He has been guest editor of special issues at professional journals; served on the Administrative Committees of IEEE Robotics Society and Sensors Council; chaired technical committees and working groups; and chaired and co-chaired major international conferences, workshops and special sessions. Dr. Lumelsky has served as a technical expert in legal cases, including multinational litigation. He frequently gives talks at US and foreign universities, government groups, think tanks, and in industry. He is a member of several professional societies, and is a Fellow of IEEE.

08:15	**Welcome & Overview**
08:30	**Plenary Presentation:** **Maria Gini** ***Methodology for Experimental Research in Multi-robot Systems with Case Studies***
09:30	**Coffee Break**
10:00	**TUE-AM1 Mobile Robot Performance Evaluation I** ***Chairs: C. Schlenoff & M. Childers*** • Evaluation of Navigation of an Autonomous Mobile Robot [N. Muñoz, J. Valencia, N. Londoño] • Assessing the Impact of Bi-directional Information Flow in UGV Operation: A Pilot Study [M. Childers, B. Bodt, S. Hill, R. Dean, W. Dodson, L. Sutton] • A Common Operator Control Unit Color Scheme for Mobile Robots [M. Shneier, R. Bostelman, J. Albus, W. Shackleford, T. Chang, T. Hong] • How DoD's TRA Process Could be Applied to Intelligent Systems Development [D. Sparrow, S. Cazares] • A Brief History of PRIDE [Z. Kootbally, C. Schlenoff, R. Madhavan]
12:30	**Lunch on your own**
14:00	**Plenary Presentation:** **Eric Krotkov** ***Measuring Ground Robot Performance***
15:00	**Coffee Break**
15:30	**TUE-PM1 Mobile Robot Performance Evaluation II** ***Chairs: S. Balakirsky & C. Lundberg*** • Assessment of Man-portable Robots for Law Enforcement Agencies [C. Lundberg, H. Christensen] • Performance Metrics and Evaluation of a Path Planner based on Genetic Algorithms [G. Giardini, T. Kalmar-Nagy] • The Evolution of Performance Metrics in the RoboCup Rescue Virtual Robot Competition [S. Balakirsky, C. Scrapper, S. Carpin] • Robot Simulation Physics Validation [C. Pepper, S. Balakirsky, C. Scrapper] • Design and Validation of a Whegs Robot in USARSim [B. Taylor, S. Balakirsky, E. Messina, R. Quinn]
18:30	**Reception**

Note: Please click on the paper title to view it in pdf.

08:15	**Welcome & Overview**
08:30	**Plenary Presentation:** **Maria Gini** ***Methodology for Experimental Research in Multi-robot Systems with Case Studies***
09:30	**Coffee Break**
10:00	**TUE-AM2 Special Session I: Autonomy Levels for Unmanned Systems** ***Organizer: Hui-Min Huang (NIST)*** • Autonomy Levels for Unmanned Systems (ALFUS) Framework: Safety and Application Issues [H-M. Huang] • Evaluation of Autonomy in Recent Ground Vehicles Using the Autonomy Levels for Unmanned Systems (ALFUS) Framework [G. McWilliams, M. Brown, R. Lamm, C. Guerra, P. Avery, K. Kozak, B. Surampudi] • A Methodology for Testing Unmanned Vehicle Behavior and Autonomy [D. Gertman, C. McFarland, T. Klein, A. Gertman, D. Bruemmer] • Standardizing Measurements of Autonomy in the Artificially Intelligent [A. Hudson, L. Reeker]
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14:00	**Plenary Presentation:** **Eric Krotkov** ***Measuring Ground Robot Performance***
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15:30	**TUE-PM2 Special Session II: Human Robot Interface Issues** ***Organizers: Salvatore Schipani & Brian Antonishek (NIST)*** • Maze Hypothesis Development in Assessing Robot Performance During Teleoperation [S. Schipani, E. Messina] • Human System Performance Metrics for Evaluation of Mixed-Initiative Heterogeneous Autonomous Systems [L. Billman, M. Steinberg] • Concepts of Operations for Robot-Assisted Emergency Response and Implications for Human-Robot Interaction [J. Scholtz, B. Antonishek, B. Stanton, C. Schlenoff] • Multimodal Displays to Enhance Human Robot Interaction On-the-Move* [E. Haas, C. Stachowiak]
18:30	**Reception**

*A multi-modal information system will be demonstrated.

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08:15	Overview
08:30	**Plenary Presentation:** **Illah Nourbakhsh** ***Formalizing Educational Human-Robot Collaboration***
09:30	Coffee Break
10:00	**WED-AM1 Autonomy Vs Intelligence** ***Chairs: J. Gunderson & J. Evans*** • Autonomy (What's it Good for?) [J. Gunderson, L. Gunderson] • Definitions and Measures of Intelligence in Deep Blue and the Army XUV [J. Evans] • Automotive Turing Test [S. Kalik, D. Prokhorov] • Autonomous Robots with Both Body and Behavior Self-Knowledge [B. Gordon] • A Cognitive-based Agent Architecture for Autonomous Situation Analysis [G. Berg-Cross, W-T. Fu, A. Kwon]
12:30	Lunch on your own
14:00	**Featured Presentation:** **Vladimir Lumelsky** ***Human-Robot Interaction in Physical Proximity: Issues and Prospects***
15:00	Coffee Break
15:30	**WED-PM1 Human Machine Interaction** ***Chairs: N. Dagalakis & A. Steinfeld*** • Evaluation of an Integrated Multi-Task Machine Learning System with Humans in the Loop [A. Steinfeld, S. Bennett, K. Cunningham, M. Lahut, P-A. Quinones, D. Wexler, D. Siewiorek, J. Hayes, P. Cohen, J. Fitzgerald, O. Hansson, M. Pool, M. Drummond] • Survey Measures for Evaluation of Cognitive Assistants [A. Steinfeld, P-A. Quinones, J. Zimmerman, S. Bennett, D. Siewiorek] • Development of Tools for Measuring the Performance of Computer Assisted Orthopaedic Hip Surgery Systems [N. Dagalakis, Y. Kim, D. Sawyer, C. Shakarji] • Haptic Feedback System for Robot-Assisted Surgery [J. Desai, G. Tholey, C. Kennedy]
19:30	Banquet

Note: Please click on the paper title to view it in pdf.

08:15	**Overview**
08:30	**Plenary Presentation:** **Illah Nourbakhsh** ***Formalizing Educational Human-Robot Collaboration***
09:30	**Coffee Break**
10:00	**WED-AM2 Panel Discussion I: Can the Development of Intelligent Robots be Benchmarked? Concepts and Issues from Epigenetic Robotics *(Moderator: Gary Berg-Cross, EM & I)*** • Douglas Blank, Bryn Mawr College • James Marshall, Sarah Lawrence College • Lisa Meeden, Swarthmore College • Charles Kemp, Georgia Tech. • Chad Jenkins, Brown University
12:30	**Lunch on your own**
14:00	**Featured Presentation:** **Vladimir Lumelsky** ***Human-Robot Interaction in Physical Proximity: Issues and Prospects***
15:00	**Coffee Break**
15:30	**WED-PM2 Special Session III: Space/Aerial Robotics** ***Organizer: Edward Tunstel (JPL)*** • Prototype Rover Field Testing and Planetary Surface Operations [E. Tunstel] • Planning to Fail - Reliability as a Design Parameter for Planetary Rover Missions [S. Stancliff, J. Dolan, A. Trebi-Ollennu] • A Decision Space Compression Approach for Model Based Parallel Computing Processes [R. Bonneau, G. Ramseyer] • Physically-Proximal Human-Robot Collaboration for Air and Space Applications [E. Atkins]
19:30	**Banquet (Adam Jacoff, NIST)**

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08:15	**Overview**
08:30	**Plenary Presentation:** **Alex Zelinsky** ***Building Autonomous Systems of High Performance, Reliability and Integrity***
09:30	**Coffee Break**
10:00	**THU-AM1 Performance Assessment of Algorithms** ***Chairs: R. Lakaemper & S. Spetka*** • Analyzing the Performance of Distributed Algorithms [R. Lass, E. Sultanik, W. Regli] • An Agent Structure for Evaluating MAS Performance [C. Dimou, A. Symeonidis, P. Mitkas] • Information Management for High Performance Autonomous Intelligent Systems [S. Spetka, S. Tucker, G. Ramseyer, R. Linderman] • Efficient Monte Carlo Computation of Fisher Information Matrix using Prior Information [S. Das, J. Spall, R. Ghanem] • Performance of 6D LuM and FFS SLAM -- An Example for Comparison using Grid and Pose Based Evaluation Methods [R. Lakaemper, A. Nuchter, N. Adluru, L. Latecki]
12:30	**Lunch on your own**
14:00	**THU-PM Panel Discussion II: (Re-)Establishing or Increasing Collaborative Links Between Artificial Intelligence and Intelligent Systems** ***(Moderator: Brent Gordon, NASA-Goddard)*** • James Albus, Senior Fellow, Intelligent Systems Division, NIST • Ella Atkins, Associate Professor, University of Michigan • Henrik Christensen, Director, Center for Robotics and Intelligent Machines, Georgia Tech. • Larry Reeker, Computer Scientist, Information Technology Laboratory, NIST
15:30	**Coffee Break**
16:00	**Adjourn**

Note: Please click on the paper title to view it in pdf.

08:15	**Overview**
08:30	**Plenary Presentation:** **Alex Zelinsky** ***Building Autonomous Systems of High Performance, Reliability and Integrity***
09:30	**Coffee Break**
10:00	**THU-AM2 Special Session IV: Smart Assembly Systems** ***Organizers: Robert Tilove (GM) & John Slotwinski (NIST)*** • Smart Assembly: Industry Needs and Challenges [J. Slotwinski, R. Tilove] • Science based Information Metrology for Engineering Informatics [S. Rachuri] • Evaluating Manufacturing Control Language Standards: An Implementer's View [T. Kramer] • Interoperability Testing for Shop-Floor Inspection [F. Proctor, W. Rippey, J. Horst, J. Falco, T. Kramer] • A Virtual Environment-Based Training Systems for Mechanical Assembly Operations [M. Schwartz, S. Gupta, D. Anand, R. Kavetsky]
12:30	**Lunch on your own**
14:00	**THU-PM Panel Discussion II: (Re-)Establishing or Increasing Collaborative Links Between Artificial Intelligence and Intelligent Systems** ***(Moderator: Brent Gordon, NASA-Goddard)*** • James Albus, Senior Fellow, Intelligent Systems Division, NIST • Ella Atkins, Associate Professor, University of Michigan • Henrik Christensen, Director, Center for Robotics and Intelligent Machines, Georgia Tech. • Larry Reeker, Computer Scientist, Information Technology Laboratory, NIST
15:30	**Coffee Break**
16:00	**Adjourn**

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