20 years of Microrobotics: progress, challenges, and future directions.
A Full Day Workshop at IROS 2011, San Francisco, CA

Workshop SW4, September 25, 2011
Website: http://www.uta.edu/ee/ngs/IROS2011/IROS2011MicroNanoWorkshop.htm

Workshop Organizers:

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Micro and Nano Robotics is an emerging area with a tremendous potential to revolutionize manufacturing of nanostructures, nanosensors, and nanoactuators, and to enable new applications in medicine.

IROS 2011 will feature a series of special symposia to celebrate the achievements of the last fifty years of robotics and to articulate a vision for the future of the field. Special symposia will consist of 90 minute sessions consisting of invited talks and invited papers, with presentations either in the conventional format or during a multimedia session.

We organized a full day workshop with themes based on 4 main applications areas, and under the main theme: 20 years of Microrobotics: progress, challenges, and future directions**.** This workshop is held in conjunction with the Symposium on Microrobotics consisting of four invited sessions and organized by Sylvain Martel and David Cappelleri. The format will include *twenty one 15 minute presentations* by both junior and senior roboticists, from all three continents (Europe, Asia, North America). The purpose of the talks is to give a more general overview, going beyond the paper submissions to the invited Microrobotics sessions. After the workshop, we will collect and publish select slides from the workshop participants.

Final Workshop Program

Workshop Starts at 8:30 am
Motivation and Objectives - Organizers

Session 1: Micro assembly/manipulation for manufacturing at small scales 8:45-10:15 am
Robotics at small scales shares common similarities with its macro scale counterpart, however, there are also many differences which make robotic manufacturing methods more challenging and less robust. This session explores past breakthroughs, limitations, challenges and future directions in micro manipulation and assembly at small scales.

Invited Talks (18 minutes each), confirmed speakers:
- Philippe Lutz, Femto-St, France
- Dan Popa, UT Arlington, USA
- Ville Liimatainen/Quan Zhou, Aalto University, Finland

- David Capelleri, Stevens Inst. of Technology, USA
- Karl F. Bohringer, Univ. of Washington, USA

Session 2: Nano manipulation / Nano assembly 10:30am-12:00 pm
Robotics at nano scales small scales shares common similarities with its micro scale counterpart, however, there are also many differences due to significantly different physics at these scales. This session explores past breakthroughs, limitations, challenges and future directions in nano manipulation at small scales.

Invited talks (18 minutes each), confirmed speakers:
- Stephane Regnier, Pierre and Marie Curie University, France
- Ari Requicha, USC, USA
- Christian Dahmen/Sergej Fatikow, Univ. of Oldenburg, Germany
- Toshio Fukuda, Univ. of Nagoya, Japan
- Lixin Dong, Michigan State University, USA.

Session 3: Micro and Nano robotics in medicine and life sciences 1:15pm-3:00 pm
Micro and nano robots hold tremendous promise for healthcare applications of the future, given their ability to reach parts of the body previously unaccessible to surgeons, or their ability to manipulate living matter at the cellular level. This session will explore progress to date and future challenges in the design, characterization, fabrication, and use of micro and nano robots in healthcare.

Invited talks (18 minutes each), confirmed speakers:
- Fumihito Arai, Nagoya University, Japan
- Dimitris Felekis/Bradley Nelson, ETHZ, Switzerland
- Arianna Menciassi, Scuola Superiore Sant'Anna, Italy
- Sylvain Martel, Polytechnic of Montreal, Canada
- Antoine Ferreira, ENSI, Bourges, France
- Tatsuo Arai, Osaka University, Japan

Session 4: Autonomous robotics at micro and nano scales 3:15pm-4:45pm
Autonomous microrobots are expected to play an increasingly important role in medicine, manufacturing, and remote sensing. The challenges in autonomous microrobotics include severe constraints in the design, fabrication and packaging these these tiny entities. Equally important are algorithms and deployment schemes for large numbers of micro and nano robots that are scalable and efficient in utilizing limited energy, sensing, computational and communication resources available. This session will explore progress to date and future challenges in mobile microrobotics.

Invited talks (18 minutes each), confirmed speakers:
-Sarah Bergbreiter, University of Maryland, USA
-Ashis Banerjee, MIT/S.K Gupta, Univ. of Maryland, USA
-Ron Fearing, UC. Berkeley, USA
-Metin Sitti, CMU, USA
-Igor Paprotny, UC Berkeley/Bruce Donald, Duke Univ., USA

4:45 pm: Conclusions and Summary - Participants
Workshop ends at 5:00pm.

Speaker biographies and talk titles are attached.

SW-4-4-3: Biomimetic Millirobots

Prof. Ron Fearing, University of California Berkeley, San Francisco, USA

Abstract

Decimeter to centimeter-scale robots will create the opportunity to manipulate, sense, and explore a wide range of environments with greatly reduced cost and expanded capabilities. In many applications, the capability of millirobots depends on three factors: 1) intelligence, 2) mobility, and 3) multiplicity. For intelligent macroscale robots, one can almost say that planning, sensing, computation, and control capabilities are available off-the-shelf. However, at the centimeter and smaller scale, we are finding more cases where intelligent behavior does not depend on explicit algorithms, but arises from the intrinsic mechanics. The study of small animals such as flies and lizards has lead to ``implicit intelligence" principles which can be applied to biomimetic millirobots. There remain significant challenges for millirobots in creating all-terrain mobility, and low production costs for multiplicity. However, there are advantages to this size scale for novel low-cost fabrication methods.

Speaker Biography

Ronald Fearing is a professor in the Dept. of Electrical Engineering and Computer Sciences at Univ. of California, Berkeley, which he joined in Jan. 1988. He was Vice-Chair for Undergraduate Matters from 2000-2006. His current research interests are in milli-robotics, including flying and crawling milli-robots, parallel nano-grasping (gecko adhesion), micro-assembly, and rapid prototyping. He has worked in tactile sensing, teletaction, and dextrous manipulation. He has a PhD from Stanford in EE (1988) and SB and SM in EECS from MIT (1983). He received the Presidential Young Investigator Award in 1991, and is the co-inventor on 12 US patents.

SW-4-3-2: Automated quantification of growth mechanics of living plant cells in situ using microrobotics

Dimitris Felekis, Bradley J. Nelson, ETH Zurich, Switzerland

Abstract

Microrobotic systems and methods have been reported for cell injection, mechanical characterization and handling of mouse oocytes and embryos, zebrafish embryos, HeLa cells, and stem cells, ex vivo. In addition, the biomechanics of biological organisms such as Drosophila melanogaster and Caenorhabditis elegans have been investigated with the aid of microrobotics. As molecular biology shifts toward understanding the mechanics of growth of individual living and growing cells as a unit and as a part of an organ or tissue, the need arises to characterize mechanical properties at the cellular level in situ. The challenge for microroboticists is to develop systems capable of identifying the changing morphology of a cell and the effect this change has on the growth of its host organ. It is also important to accurately quantify the mechanical properties of key structural elements of cells for input to mathematical models of growth. In this talk the achievements of our past work on microrobotics for life sciences will be presented. Our current research in developing automated microrobotic systems capable of measuring the membrane stiffness of individual plant cells is discussed as well as the challenges we have encountered so far.

Speaker Biography

Dimitris Felekis (S'09) received the Diploma degree in Mechanical Engineering from University of Thessaly, Volos, Greece in 2005 and the M.S. degree in Automation and Robotics from the National Technical University of Athens, Athens, Greece in 2007. In 2009 he joined the Swiss federal Institute of Technology (ETH) Zurich, Zurich, Switzerland where he is currently working toward the Ph. D. degree in the Institute of Robotics and Intelligent Systems, focusing on the development of microrobotic systems for studying the growth mechanics of living plant cells in situ.

Bradley J. Nelson (M'90–SM'06) received the B.S.M.E. degree from the University of Illinois at Urbana–Champaign, Urbana, in 1984, the M.S.M.E. degree from the University of Minnesota, Minneapolis, in 1987, and the Ph.D. degree in robotics from the School of Computer Science, Carnegie Mellon University, Pittsburgh, PA, in 1995.
He was an Engineer with Honeywell and Motorola and served as a U.S. Peace Corps Volunteer in Botswana, Africa. He became an Assistant Professor at the University of Illinois, Chicago, in 1995, and an Associate Professor at the University of Minnesota in 1998. Since 2002, he has been a Professor at the Institute of Robotics and Intelligent Systems, Swiss Federal Institute of Technology (ETH) Zurich, Zurich, Switzerland. His most recent scientific contributions have been in the areas of microrobotics, biomicrorobotics, and nanorobotics, including efforts in robotic micromanipulation, microassembly,

microelectromechanical systems (sensors and actuators), mechanical manipulation of biological cells and tissue, and nanoelectromechanical systems. He has also contributed to the fields of visual servoing, force control, sensor integration, and Web-based control and programming of robots. Dr. Nelson has been a member of several editorial boards, including the IEEE TRANSACTIONS ON ROBOTICS, the IEEE TRANSACTIONS ON NANOTECHNOLOGY, and the IEEE Robotics and Automation Magazine

SW-4-4-5: Microassembly through Global Control Selective Response (GCSR) : Controlling Many Robots Through a Single, Global Control Signal

Dr. Igor Paprotny, University of California Berkeley, USA

Prof. Bruce Donald, Duke University, USA

Abstract

Engineering microrobots to respond differently to various parts of a global control signal allows us to independently control many microrobots. Such "designed differentiation" is at the heart of the concept we call Global Control Selective Response (GCSR). In this talk, we show how GCSR can be applied to controlling a group of microrobots to assemble into planar shapes, and discuss how GCSR can be used to control future multi-microrobotic systems and applications.

Speaker Biography

Dr. Igor Paprotny is currently a scientist at the Berkeley Sensor & Actuator Center (BSAC) at U.C. Berkeley where he is involved in applying MEMS technologies to distributed self-powered microsensors for the Smart Grid, microrobotics, and pollution monitoring using air microfluidics. He received his Ph. D. in Computer Science from Dartmouth College while part time in-residence at the Department of Computer Science at Duke University. He has over 3 years of professional experience in the semiconductor industry where he was involved in designing automated material handling systems for semiconductor factories. His research interests include MEMS Smart Grid sensors and energy scavengers, MEMS micro- and nano-robotic systems, air microfluidics, as well as applications of MEMS to alternative computing paradigms.

Professor Bruce Donald is the William and Sue Gross Professor of Computer Science at Duke University, and Professor of Biochemistry in the Duke University Medical Center. He was a professor in the Computer Science Department at Cornell University from 1987-1998. Donald received a B.A. from Yale University, and a Ph.D. from MIT. He has been a National Science Foundation Presidential Young Investigator, and was awarded a Guggenheim Fellowship for his work on algorithms for structural proteomics. Donald is a Fellow of the ACM and a Fellow of the IEEE.

SW-4-3-3: Targeted therapy at small scales: possible approaches and challenges ahead

Prof. Arianna Menciassi, Scuola Superiore San'Anna, Italy

Abstract

The main issues when approaching diagnosis and therapy at the milli and micro scale are: 1) reaching the target area, that normally is remote and with small size, and 2) bringing therapeutic solutions to the selected target area. With traditional size approaches, the target area is reached by motorized tools, cable actuated instrumentation, or catheter-like structure piloted directly by the operator. This direct-drive approach is generally not feasible in the micro scale: miniature robots with embedded diagnostic and therapeutic tools are still at an early stage of development, mainly due to the bottleneck of adequate actuation technologies. On the other hand, technologies for minimally invasive therapy and diagnosis evolved dramatically in the last decade, thus generating new paradigms for, e.g., radio or US-based therapy with an increased precision of targeting than before. In addition, the problem of reaching remote regions of the human body and there delivering therapy has been approached by exploiting actuation techniques that are different from motors and cable-drive solutions, and that are based, e.g.. on “wireless” magnetic forces. Starting from the above considerations, this talk will discuss the combination of external robotic strategies and micro-nano-technologies, in order to smoothly passing from systemic therapy to targeted therapy, and thus approaching both the issues of targeting and therapeutics delivery. In particular, the speaker will illustrate a preliminary platform for vascular plaque targeting, based on magnetic dragging and ultrasound tracking. Different solutions for plaque treatment will be proposed: a strategy to magnetize the plaque and collecting plaque debris magnetically, and a promising solution for mechanical attack of the plaque by focused ultrasound, that can be precisely delivered and locally enhanced to the target.

Speaker Biography

Arianna Menciassi (M’01) is Associate Professor of biomedical robotics at the Scuola Superiore Sant’Anna (SSSA, Pisa, Italy). She received the Master Degree in Physics (with Honors) from the University of Pisa in 1995 and the PhD in Bioengineering from the SSSA in 1999. The main results of the PhD activity were awarded with the Best Manipulation Paper Award at ICRA’2001. She teaches at the SSSA and at the University of Pisa (Master Degree in Bioengineering). Her main research interests are in the fields of surgical robotics, biomedical micro- and nano-robotics, micromechatronics. She is working on several European projects and international projects for the development of miniature robotic solutions for medical and surgical applications. In the year 2007, jointly with the team working on capsule endoscopy at the SSSA, she was awarded with the Well-Tech Award 2007 (Milano, Italy). In the same year, she was awarded with the Gonfalone d’Argento of the Tuscany region, as one of the best ten young talented researchers of the region. Since the year 2009, she has been affiliated member of the Italian Institute of Technology (IIT, Genova, Italy) and she collaborates with the IIT Center of MicroBioRobotics@SSSA on selected topics related to smart materials and robotic technologies in the microdomain.

SW-4-4-4: Autonomous Magnetic and Bacteria Actuated Mobile Micro-Robots

Prof. Metin Sitti, Carnegie Mellon University, Pittsburgh, USA

Abstract

Miniature mobile robots have the unique capability of accessing to small spaces and scales directly. Due to their small size and small-scale physics and dynamics, they could be agile and portable, and could be inexpensive and in large numbers if they are mass-produced. Miniature robots would have potential future applications in health-care, mobile sensor networks, desktop micro-manufacturing, environmental monitoring, and inspection. In this presentation, miniature mobile robots with tens or hundreds of micrometer overall sizes and various locomotion capabilities are presented. Going down to tens or hundreds of micron scale robots, significant challenges are on-board actuation and power sources. Two alternative approaches are proposed in this talk to solve this challenge. First, external powering and actuation methods are used to move permanent magnet micro-robotic bodies using a stick-slip dynamics, spinning or rolling based surface locomotion on planar surfaces in air or in liquid in 2-D. Vision-based automatic control schemes can individually control single- or teams of micro-robots and these robots can manipulate and assemble micro-parts with or without contact in liquid. Controlled assembly and disassembly of such multiple magnetic micro-robots are also investigated and demonstrated towards reconfigurable micro-robotic systems in 2-D. As the next approach, a hybrid (biotic/abiotic) actuation principle is used to propel micron scale robotic bodies in liquid by harvesting the flagellar propulsion of attached bacteria and the chemical energy in the environment. Highly stochastic swimming locomotion of these S. marcescens bacteria attached micro-objects can be stopped and resumed repeatedly using chemical switching. Their 3-D motion can be steered using controlled chemical gradients in the liquid medium. Stochastic dynamics and control of such bacteria propelled micro-objects are demonstrated by simulations and experiments.

Speaker Biography

Metin Sitti received the PhD degree in electrical engineering from University of Tokyo, Japan, in 1999. He was a research scientist at University of California at Berkeley during 1999-2002. He is currently a professor in the Department of Mechanical Engineering and Robotics Institute at Carnegie Mellon. His research interests include micro/nano-robotics, bio-inspired miniature robots and materials, and micro/nano-manipulation. He received the SPIE Nanoengineering Pioneer Award in 2011. He was nominated for the World Technology Award related to health care and medicine in 2009. He has been appointed as the Adamson Career Faculty Fellow in 2007. He received the National Science Foundation CAREER award in 2005. He was elected as the Distinguished Lecturer of the IEEE Robotics and Automation Soceity for 2006-2008. He has many best paper and best video awards in major robotics and nanotechnology conferences. He was the Vice President of the Technical Activities in the IEEE Nanotechnology Council for 2008-2010, and he is the co-editor-in-chief of Journal of Micro/Nano-Mechatronics and an associate editor for the IEEE Trans. on Robotics and ACS Applied Materials and

Interfaces.

SW-4-3-6: Micro Manipulation and Its Challenging Bio Application

Prof. Tatsuo Arai, Osaka University

Abstract

We have been developing micro manipulation system capable of handling, assembling, and fabricating micro objects with the size ranging from 1um to 100um. In our nearly 20 year R&D history we have been designing and building dexterous two fingered micro hands, sophisticated sensing facilities including micro vision systems, micro force sensors, and usable interfaces. Our major interest is the application in the bio fields, e.g. manipulating and characterizing single cell, providing nice tools for skillful complicated tasks required in bio experiments and developments. The various utilities and the attractive applications will be demonstrated in the presentation.

With the recent advancements in the tissue bio science we have proposed and launched new national project called “Hyper Bio Assembler for 3D Cellular Innovation” where we are aiming to develop and study construction of in-vitro 3D tissue by applying micro robotics technology. The project has just started in August this year and will continue for 5 years. We have organized a consortium including 9 research groups from robotics, biology, and medical. The budget is totally Y1.2B supported by MEXT. The key issues are 1) measuring and characterizing cells in high speed to select and separate useful ones for active functionalized tissue, 2) assembling and fabricating 3D cellular system by applying micro manipulation and fluidic technologies, and 3) analyzing and evaluating functional expressions of cellular system. Through measuring cell/cellular system and controlling the interaction between cellular system and its environment we would try to achieve truly active 3D tissue in vitro as a world first achievement. The project summary will be introduced briefly.

Speaker Biography

Tatsuo ARAI was born in 1952 in Tokyo. He received B.S. M.S. and PhD degrees from the University of Tokyo in 1975, 1977, and 1986 respectively. He joined the Mechanical Engineering Laboratory, AIST, MITI (now METI) in 1977, and was engaged in research and development of new arm design and control, mobile robot, teleoperation, and micro robotics. He stayed at MIT as a visiting scientist in 1986-1987. He moved to Osaka University in 1997 and since then he has been a full professor at the Department of Systems Innovation, Graduate School of Engineering Science. His current research topics are mechanism design including parallel mechanisms, legged working robot, micro robotics for bio applications, humanoid robot, haptic interface, and network robotics. He has published more than 300 journal and conference papers on robotics and automation, 6 books, and has 37 patents including foreign 8. He is a member of IEEE, International Association of Automation and Robotics in Construction (IAARC), Robotic Society of Japan (RSJ), Society of Instrumentation and Control Engineers, Japan Society of Mechanical Engineers (JSME), and other societies. He is currently an Editor-in-Chief of Journal of Robotics and Mechatronics. He served as Vice President of IAARC, Chair of Robotics and

Mechatronics Division of JSME, a Director of RSJ, Chair of the Technical Advisory Committee of the Destruction of Abandoned Chemical Weapon of the Cabinet Office.

SW-4-3-4: Micro- and nanorobots navigating in the blood vessels for targeted applications: progress, challenges and future directions

Prof. Sylvain Martel, École Polytechnique de Montréal (EPM), Montréal, Canada

Abstract

In recent years, medical robotics have evolved from interventions being performed by large robots outside the patient to smaller untethered versions such as the camera pills capable of travelling through the digestive track. More recently, nanotechnology and robotics were combined to develop new interventional platforms designed to navigate therapeutic carriers capable of targeting regions in the human body such as tumors only accessible through smaller diameter blood vessels. These new navigable therapeutic agents could play a major role in cancer therapy by enhancing therapeutic efficacy by delivering an improved concentration of the drug at the targeted area while decreasing systemic side effects compared to modern interventions such as chemotherapy. The talk will provide an overview of recent progress in this field, identify some of the major challenges and conclude with some potential future directions.

Speaker Biography

Sylvain Martel received the Ph.D. degree in Electrical Engineering from McGill University, Institute of Biomedical Engineering, Montréal, Canada, in 1997. Following postdoctoral studies at the Massachusetts Institute of Technology (MIT), he was appointed Research Scientist at the BioInstrumentation Laboratory, Department of Mechanical Engineering at MIT. From Feb. 2001 to Sept. 2004, he had dual appointments at MIT and as Assistant Professor in the Department of Electrical and Computer Engineering, and the Institute of Biomedical Engineering at École Polytechnique de Montréal (EPM), Campus of the University of Montréal, Montréal, Canada. He is currently Professor in the Department of Computer and Software Engineering, and the Institute of Biomedical Engineering, and Director of the NanoRobotics Laboratory at EPM that he founded in 2002. Dr. Martel holds the Canada Research Chair (CRC) in Micro/Nanosystem Development, Fabrication and Validation since 2001 and he is a Fellow of the Canadian Academy of Engineering. In the medical field alone, he pioneered several innovative technologies such as the first parallel computing platform for remote surgeries, direct cardiac mapping systems designed to investigate the cause of sudden cardiac deaths, and new brain implants for decoding neuronal activities in the motor cortex. Presently, Dr. Martel is leading an interdisciplinary team involved in the development of new types of therapeutic agents and interventional platforms for cancer therapy.

SW-4-4-1: Toward the first leaps for jumping microrobots: Integrating mobility, mechanisms, and motors at small scales

Prof. Sarah Bergbreiter, University of Maryland

Abstract

The idea of microrobots crawling around like ants has excited the robotics and microsystems communities for over 20 years.

While ants can move at speeds over 40 body lengths/s on surfaces from picnic tables to grassy lawns, the only microrobots that have walked so far have done so on polished silicon wafers at speeds well under 1 body length/s. This talk will discuss some of the mechanisms and motors we have designed and fabricated to enable robot mobility at the insect size scale. Mechanisms utilize new microfabrication processes to incorporate materials with widely varying moduli and functionality for more complexity in smaller packages. Motors are designed to provide significant improvements in force density, efficiency and robustness over previous microactuators. Results include a 4mm jumping mechanism that can be launched approximately 35 cm straight up as well as a 300mg robot that jumps 8 cm with on-board power, sensing, actuation and control.

Speaker Biography

Sarah Bergbreiter joined the University of Maryland, College Park in 2008 as an Assistant Professor of Mechanical Engineering, with a joint appointment in the Institute for Systems Research. She received her B.S.E. degree in electrical engineering from Princeton University in 1999. After a short introduction to the challenges of sensor networks at a small startup company, she received the M.S. and Ph.D. degrees from the University of California, Berkeley in 2004 and 2007 with a focus on microrobotics. She received the DARPA Young Faculty Award in 2008 and the NSF CAREER Award in 2011 for her research on engineering robotic systems down to sub-millimeter size scales. She also received the Best Conference Paper Award at IEEE ICRA 2010 on her work incorporating new materials into microrobotics.

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SW-4-4-2: Multi-Particle Path Planning using Optical Tweezers

Dr. Ashish Banerjee, M.I.T, USA,

Prof. Satyandra K. Gupta, University of Maryland, USA

Abstract

Optical tweezers have emerged as one of the most promising non-contact manipulation techniques at the small scales; they can successfully trap and transport objects in fluid media. In other words, they can be viewed as miniature robots made out of focused light beams. Autonomous operation requires path planning, which is challenging due to the stochastic Brownian motion of the objects, noise in the imaging based measurements, and the need for fast control update rates.

We develop an approximate partially observable Markov decision process (POMDP) algorithm to compute near-optimal trap locations and velocities that minimize the expected transport time of individual dielectric particles by including collision avoidance and recovery steps. This algorithm is incorporated within a decoupled and prioritized framework to move multiple particles simultaneously, where we use an iterative bipartite graph matching algorithm to optimally assign goal locations to target particles. We demonstrate our approach using 2 micron diameter amorphous silica beads in a holographic tweezer set-up.

Successful runs show that the planner is customizable and can transport specific particles efficiently by either circumventing or trapping other freely diffusing particles. We also show the usefulness of heuristic planning algorithms in arranging biological cells uniformly within nets kept in microfluidic chambers.

I conclude by highlighting the potential impact and challenges of automating multi-cell studies. We believe that path planning will play a significant role in manipulating cells by trapping them indirectly using particles arranged in gripper-like configurations that avoid damage due to direct laser exposure.

Speaker Biography

Ashis Gopal Banerjee is a Postdoctoral Associate in the Computer Science and Artificial Intelligence Laboratory at Massachusetts Institute of Technology. He completed his Ph.D. in Mechanical Engineering at the University of Maryland, College Park, in 2009. Prior to that, he obtained his Master?s Degree in Mechanical Engineering at the University of Maryland in 2006 and Bachelor?s Degree in Manufacturing Science and Engineering at the Indian Institute of Technology, Kharagpur, in 2004. He received the 2009 Best Dissertation Award from the Department of Mechanical Engineering and the 2009 George Harhalakis Outstanding Systems Engineering Graduate Student Award at the University of Maryland. He is a member of the IEEE Robotics and Automation Society Technical Committee on

Micro/Nano Robotics and Automation as well as Algorithms for Planning and Control of Robot Motion.

SW-4-2-2: Automatic nanomanipulation and self-organizing nanorobot swarms

Prof. Aristides A.G. Requicha, University of Southern California, USA

Abstract

I will discuss two major results that flow from the work at the USC Laboratory for Molecular Robotics. Both are related to the fundamental issue of building spatial shapes with nanoscale components. The first is a system that uses an Atomic Force Microscope to manipulate nanoparticles with sizes on the order of 10 nm, and constructs spatial patterns automatically, without user intervention. The second is a global-to-local compiler and simulation system that shows how to coordinate a swarm of reactive, stateless nanorobots so as to build an arbitrary shape (approximated by a polygon) in the plane. The swarm organizes itself and is capable of self-repair and (to a limited extent) self-reproduction.

Speaker Biography

Aristides A. G. Requicha was born in Monte Estoril, Portugal. He received the Engenheiro Electrotécnico degree from the Instituto Superior Técnico, Lisbon, Portugal, and the Ph.D. in Electrical Engineering from the University of Rochester. He was a college and high school Valedictorian. He is a member of the National Academy of Engineering, and is a Fellow of the IEEE, the ACM and the AAAS. Requicha is listed in the ISI Web of Knowledge as a highly cited researcher for the decades 1980-1999. He received the USC Senior Research Award; the first-ever Pierre Bezier Award at the ACM Solid and Physical Modeling Symposium; the Pioneer in Robotics and Automation Award from the IEEE Robotics and Automation Society; and the Distinguished Service Award from the IEEE Nanotechnology Council (NTC). He is currently a Distinguished Lecturer of the NTC. Requicha is a Professor of Computer Science and Electrical Engineering and the Gordon Marshall Chair at USC, was the founding director of the Laboratory for Molecular Robotics, and was the Editor- in-Chief of the IEEE Transactions on Nanotechnology until recently.

SW-4-3-1: On-chip Robotics in Medicine and Life Sciences

Prof. Fumihito Arai, Nagoya University, Japan

Abstract

We have studied on robotic technology on a microfluidic chip. Our concept is based on micro-nano robots or tools being put in the microchannel, where they are actuated and manipulated for works such as sensing, handling, and surgery. In this talk, our recent research works on On-chip Robotics will provide allowing for: i) Precise positioning method of magnetically driven microtool (MMT) and high-speed cell enucleation using dual-arm MMT and ii) Active enrichment of influenza virus using insulated dielectrophoresis (DEP), and transport of single virus to a specific cell by optical tweezers. Further more, technical issues and future direction for applications in medicine and life sciences will be discussed.

Speaker Biography

Fumihito Arai received the Master of Eng. degree from the Tokyo Univ. of Science in 1988. He joined Nagoya University, Japan in 1989 as Research Associate. He received Dr. of Eng. from Nagoya University in 1993. Since 1998, he was Associate Professor of Department of Micro System Eng., Nagoya University. Since 2005, he is Professor of Department of Bioengineering and Robotics, Tohoku University. Since 2010, he is Professor of Nagoya University, mainly engaging in the research fields of micro- and nano-robotics and its application to the micro- and nano-assembly and cell manipulation, bio-automation systems, medical robotic systems, Micro and Nano Electro Mechanical Systems, intelligent robotic systems.

SW-4-3-5: Current Modeling and Control Challenges in Medical Nanorobotics

Prof. Antoine Ferreira, Ecole Nationale Supérieure d'Ingénieurs de Bourges

Abstract

This study presents the first steps of design, modeling, simulation and development of a drug delivery microrobotic system (consisting of nanoActuators and nanoSensors) for the propulsion and navigation of ferromagnetic microcapsules in the cardiovascular system controlled by a clinical Magnetic Resonance Imaging (MRI). Engineered micro-/nano-devices may be successful vehicles for transporting, delivering and targeting drugs. The integration of ferromagnetic particles allows potential MR-tracking and automatic delivery of the biocarriers through induced forces generated by magnetic gradients. MRI systems offer a level of flexibility, provide concentration and tracking information, real-time interventional capabilities and are already widespread in hospitals. Automatic delivery of these biocarriers to specific regions of the tumor through the lymphatic vessels is of special interest at early cancer diagnostics.

In this presentation we present first, the nanocapsule design constituted of molecular elements that can function as sensors, actuators, drug delivery mechanisms; magnetic components for achieving navigation inside the human body and carbon nanotube-based nanostructures. Second, we present computational studies on controlled navigable micro/nanocapsules which are steered by magnetic gradients generated by the MRI system. The navigation modeling was studied for future development of nanocapsules designed to perform minimally invasive interventions in remote sites accessible through the human cardiovascular system (from aorta-to-capillary networks). Third, different modeling methodologies and simulations have been developed for robust control in-vivo navigation in the cardiovascular system. Finally, some micro/nanofabrication technologies (magnetic carbon nanotube-based nanocapsules and novel polymer micelle nanocarrier, based on watersoluble amphiphilic block copolymers are presented.

Speaker Biography

Antoine Ferreira (M'04) received the M.S. and Ph.D. degrees in electrical and electronics engineering from the University of Franche-Comté, Besancon, France, in 1993 and 1996, respectively. In 1997, he was a Visiting Researcher in the ElectroTechnical Laboratory, Tsukuba, Japan. He is currently a Professor of robotics engineering at the Laboratoire PRISME, Ecole Nationale Supérieure d'Ingénieurs de Bourges, Bourges, France. He is an author of three books on micro- and nanorobotics and more than 140 journal and conference papers and book contributions. His research interests include the design, modeling, and control of micro and nanorobotic systems using active materials, micro- and nanomanipulation systems, biological nanosystems, and bionanorobotics. Dr. Ferreira was the Guest Editor for different special issues of the IEEE/ASME Transactions on Mechatronics in 2009, International Journal of Robotics Research in 2009, and the IEEE Nanotechnology Magazine in 2008.

He is actually associate editor in Reviews in Advanced Sciences and Engineering.

SW-4-2-1: Development of a Flexible Robotic System for Micro/Nano Manipulation and Haptic Teleoperation

Prof. Stephane Regnier, Pierre and Marie Curie University, France

Abstract

A flexible robotic system developed for multiscale manipulation from nanoscale to microscale is presented. This system is based on the principle of atomic force microscopy and comprises two individually functionalized cantilevers. After reconfiguration, the robotic system could be used for pick-and-place manipulation from nanoscale to the scale of several micrometers, as well as parallel imaging/nanomanipulation. Flexibilities and manipulation capabilities of the developed system were validated by pick-and-place manipulation of microspheres and silicon nanowires to build 3-D micro/nanoscale structures in ambient conditions. Moreover, the capability of parallel nanomanipulation is certified by high-efficiency fabrication of a 2-D pattern with nanoparticles. Complicated micro/nanoscale manipulation and teleoperated 3-D microassembly of spherical objects with haptic feedback will be presented

Speaker Biography

Stéphane Régnier received the Ph.D. degree in mechanical engineering and robotics from the University Pierre and Marie Curie, Paris, France, in 1996. He is full Professor at the Institute of Intelligent Systems and Robotics (ISIR), University Pierre and Marie Curie. Currently, he is Head of the ISIR micromanipulation team since 2001. His research interests include micro and nanomanipulation, teleoperation and haptic feedback at the nanoscale, micromechatronics, and biological cell characterization

SW-4-1-5: Heterogeneous microsystem integration with self-assembly

Prof. Karl F. Bohringer, University of Washington, USA

Abstract

Self-assembly is the spontaneous and reversible organization of components into ordered structures, representing an alternative to the conventional manufacture of systems made of components from milli to nano scales. First commercial applications of self-assembly have appeared in recent years, for example in the fabrication of radio frequency identification (RFID) tags. However, the full impact of this new approach towards hetero system integration will only be realized once self-assembly can be programmed on demand. This presentation gives an overview of several projects that aim at programmable self-assembly. A key concept is the "programmable surface" – an interface whose properties can be controlled with high spatial and temporal resolution. Several crucial topics are discussed: real time control of interfacial properties; optimization of binding site designs; and algorithms for the modeling and control of self-assembly. Promising novel manufacturing methods are emerging that combine the precision and reproducibility of semiconductor fabrication with the scalability and parallelism of stochastic self-assembly and with the specificity and programmability of biochemical processes.

Speaker Biography

Karl Böhringer is Professor of Electrical Engineering and Bioengineering at the University of Washington, Seattle. He received both his M.S. and Ph.D. degrees in Computer Science from Cornell University and his Diplom-Informatiker degree from the University of Karlsruhe, Germany. He was a visiting scholar at the Stanford Robotics Lab and Transducer Lab and a postdoctoral researcher at the University of California, Berkeley, before joining the faculty at the University of Washington. He received an NSF postdoctoral associateship in 1997, an NSF CAREER award in 1999, and was an NSF New Century Scholar in 2000. His work was featured among the Top 100 Science Stories in Discover Magazine's 2002 "Year in Science". In 2004, he received the IEEE Robotics and Automation Society Academic Early Career Award and a sabbatical fellowship from the Japan Society for the Promotion of Science (JSPS). Since 2010, he holds the John M. Fluke Distinguished Chair in Engineering at the University of Washington. He is a member of the editorial board of the ASME/IEEE Journal of Microelectromechanical Systems and the IEEE Transactions on Automation Science and Engineering. He was co-chair of the 2011 IEEE International Conference on Microelectromechanical Systems.

SW-4-1-4: Manipulation and assembly at small scales: Investigations on the Peg-In-the-Hole Task and Micro-scale Caging.

Prof. David Cappelleri, Stevens Institute of Technology, USA

Abstract

Micro and meso-scale systems technology is poised to be an extremely strong economic driver in this century. Market estimations predict large quantities of products involving this technology within the next decade and more specifically, meso and micro-scale assembly shows enormous potential in a vast range of industrial applications. In this talk, I will describe a test-bed for planar micro and meso-scale manipulation tasks and a framework for planning based on quasi-static models of mechanical systems with intermittent frictional contacts. I will show how planar peg-in-the-hole assembly tasks can be designed using randomized motion planning techniques with quasi-static manipulation models and a systematic approach to incorporating uncertainty into planning such tasks with frictional contacts. I will then introduces the concept of caging micromanipulation, inspired by its macro-scale counterpart, for use in automated open loop microassembly tasks. Guidelines to determine configurations for up to four coordinated micromanipulators to form caging grasps for transporting micro-scale planar, polygonal parts will be presented. Finally, I will show how the micro-caging transport primitive can be combined with rotational and one-sided-pushing motion primitives to carry out a representative microassembly task.

Speaker Biography

David J. Cappelleri is an Assistant Professor in the Department of Mechanical Engineering, Stevens Institute of Technology, Hoboken, NJ USA. His research interests include multi-scale robotic manipulation and assembly tasks, mobile micro/nano robotics, bio-nano robotics, mechatronics, robotic system integration, medical robotics and devices, MEMS device design and fabrication, micro/nano aerial vehicles, and automation for the life sciences. Prof. Cappelleri is a recipient of the Harvey N. Davis Distinguished Assistant Professor Teaching Award in 2010 and the Association for Lab Automation (ALA) Young Scientist Award for his paper at IEEE CASE 2009. He is an elected member of the IEEE Robotics and Automation Society Technical Committee on Micro/Nano Robotics and Automation, American Society of Mechanical Engineers (ASME) Design Engineering Division Mechanisms & Robotics Committee, and the ASME Design Engineering Division Micro/Nano-Systems Technical Committee. Dr. Cappelleri received the B.S. and M.S. degrees in Mechanical Engineering from Villanova University, and The Pennsylvania State University, and a Ph.D. from the University of Pennsylvania in Mechanical Engineering and Applied Mechanics.

SW-4-1-1: Micro-assembly of Reconfigurable Free Space Micro-optical benches

Prof. Philippe Lutz, Universite de France-Comte and FEMTO-ST Institute, Besancon, France

Abstract

The integration of MEMS (Micro-Electro-Mechanical Systems) and MOEMS (Micro-Opto Electro-Mechanical Systems) technology in commercial products is growing especially in the field of telecommunication and sensor technologies. Heterogeneous microparts produced from various fabrication processes are frequently used to fabricate complex 3D microstructures through microparts robotic micro-assembly. The presented work focusses on the assembly of reconfigurable free space micro-optical benches. These MOEMS has been designed to be assembled and reconfigured. We have studied the assembly performances for these sytems. Future challenges linking microfabrication process and assembly will be discussed.

Speaker Biography

Philippe LUTZ joined the University of Franche-Comté, Besançon, as Professor in 2002. He is currently the head of the research group “Automated Systems for Micromanipulation and Micro-assembly” of the AS2M department of FEMTO-ST. He is the Director of the PhD graduate school of Engineering science and microsystems. His research activities are focussed on the design and the control of MicroMechatronic Systems. P. Lutz received several awards of IEEE, is author of over 60 refereed publications, serves as associate editor for the IEEE Transaction on Automation Science and Engineering (T-ASE) and and is an active member in the IEEE Robotics and Automation Society (RAS) Committee on Micro-Nano Robotics. He received the Engineer degree from the National School of Mechanics and Microtechnology (ENSMM) in 1990 and the Ph.D. Degree of the University of Franche-Comté in Automation and Computer Science in 1994. He was Associate Professor in the INSA of Strasbourg since 1994 until 2002.

SW-4-1-3: Fusion of Robotic Microassembly and Self-assembly

Dr. Quan Zhou and Ville Liimatainen, Aalto University, Helsinki, Finland

Abstract

Microassembly at high precision and high speed is a challenging task due to the scaling down. This talk discusses our view on tackling the problem using hybrid microassembly technology that combines robotic microassembly and self-assembly. Firstly, the criteria of microassembly, namely precision, efficiency, yield, and capability, will be discussed. Then we discuss the hybrid microassembly technology in a unified view of robotic microassembly and self-assembly, breaking down to the different techniques composing the processes. Implementations of hybrid microassembly technology will be discussed, including chip stacking, 3D microassembly, mist-induced self-alignment, and assembly of RFID tags. Future challenges and potential technical paths will also be discussed.

Speaker Biography

Dr. Quan Zhou received the M.Sc degree and Dr. Tech. degree in Automation Technology, both from Tampere University of Technology, Tampere, Finland. He is an adjunct professor at the Department of Automation and Systems Technology, School of Electrical Engineering, Aalto University, Finland, leading the Micro- and Nanorobotics research team. Since 1995, he has worked in over 20 research projects related to micro- and nanorobotics. The current goal of his research is to bring microrobotics and self-assembly together. He is also actively working on mobile microrobots and micro- and nanomechatronic systems, and their industry and biomedical applications. Currently he is the coordinator of EU FP7 project FAB2ASM.

SW-4-1-2: Lean Robotic Micromanufacturing

Prof. Dan Popa, University of Texas, Arlington, USA

Abstract

This research aims to create a systematic approach to micromanufacturing that guarantees high yield as well as reliable operation for the resulting microsystems. During the last decade, we have abstracted a micromanufacturing methodology combining design for automated assembly, design for reliability, and advanced assembly and packaging processes at the micro scale. Parts of the methodology have been demonstrated in manufacturing of microsystems such as S&a;A fuze packaging and a gas chemical sensor. In past work, two microrobotic systems, the “M3” and the “μ3”, have been configured to carry out microassembly tasks with parts between 10μm and 1mm in size. The “μ3” consists of three robotic manipulators with a total of 19 DoF. Compliant part and socket designs snap-fit 2½D Si MEMS parts onto the substrate. To ensure 99%+ assembly yields, we formulated a set of workspace configuration rules (Resolution Repeatability Accuracy – R.R.A) for selecting between using fixtures, positioners, or active sensors, a quantitative assemblability criterion (High Yield Assembly Condition – H.Y.A.C.), and a Complexity Index (C.I.) for making yield maximization control and planning decisions in the workcell. In current work and future, we extend our approach - Lean Robotic Micromanufacturing (LRM) - and demonstrate it in reconfigurable automated cell-product design cycles to include microassembly, packaging, and testing operations. We present results aimed at abstracting the next generation design for micromanufacturing software tools in order to maximize the yield of robotic micromanufacturing with respect to established criteria, while minimizing manufacturing system costs within acceptable production time constraints. We also present results aimed at configuring the next generation microrobotic system at the wafer-scale - the N3.

Speaker Biography

Dan Popa is presently an Associate Professor with the Electrical Engineering Department at The University of Texas at Arlington, and Head of the Next Generation Systems (NGS) research group. He received a BA in Engineering, Mathematics and Computer Science and a MS in Engineering, both from Dartmouth College where he was a Montgomery Scholar from 1990 to 1993. He received a PhD in Electrical Engineering from Rensselaer Polytechnic Institute (RPI) in 1998, focusing on control of nonholonomic systems and robots. He then joined the Center for Automation Technologies at RPI, where he held the rank of Senior Research Scientist until 2004. Between 2004 and 2010, Dr. Popa was an Assistant Professor with the Automation and Robotics Research Institute (ARRI) at UT Arlington, and a founding member of the Navy-funded Texas Microfactory Initiative. Dr. Popa has a broad experience base, including the modeling, simulation and control of microsystems, the design of multiscale assembly architectures, the control and deployment of microrobots, the development of new systems level processes for hermetic sealing, wafer bonding, and 3D wafer integration. Dr. Popa is the recipient of several prestigious awards as a member of IEEE, ASME and the author of over 100 refereed publications. He also serves as an associate editor for the IEEE Transaction on Automation Science and Engineering (T-ASE), and is an active member in the IEEE Robotics and

Automation Society (RAS) Committee on Micro-Nano Robotics, the ASME Committee on Micro-Nano Systems (MNS), and the IEEE NTC Technical Committee on Nano Energy, Environment, and Safety.