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RoboCup

White Paper

RoboCupSoccer – Nanogram Competition

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Factories of the future will not be contained within city blocks…

they will be contained within blocks of silicon!

Introduction

RoboCup is an international research and education initiative with the goal of fostering artificial intelligence and robotics research by providing a standard problem [1]. The initiative challenges students and researchers to build robots capable of playing soccer against one another in live competition. Different leagues within RoboCup provide for competition between different classes of robots, ranging from meter-scale robots of the RoboCup Humanoid League, down to the 15 cm table-top robots that play in the RoboCup Small-Size League.

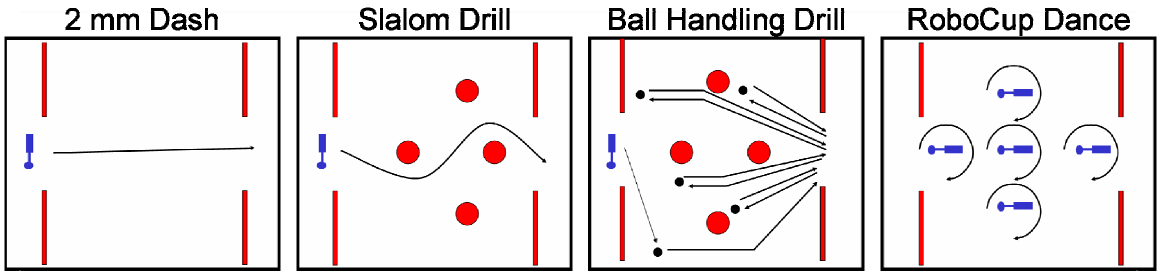
Consider the possibility of a RoboCup competition where the players are a *billion* times smaller in volume and mass than the robots that compete in the RoboCupSoccer Small Size League. The action would take place under a microscope, and each player would fit into an area no bigger than the cross-section of a strand of hair. The playing field would be no bigger than a grain of rice, and the ball would be the size of a human red blood cell.

The technological returns would be anything but small.

A Long-Term Vision for Micro-Robotics

What could be accomplished with an autonomous mobile robot whose characteristic dimensions are best measured in microns? Such a device would be able to penetrate small pores and cavities, and it could explore tiny environments, such as the vascular system of the human body. As with today's transistors, the material costs for such small robots would be insignificant, so that building a million of them need not be much more expensive than building a dozen. This opens up the possibility of massively-parallel robotic systems which can merge sensing, computation, communication, and locomotion to realize enhanced levels of perception and control to perform searches of disaster sites, exploration of planetary surfaces, and other as yet unimagined tasks.

The field of micro-electromechanical systems (MEMS) has already pushed forward the capabilities of microscopic sensors and actuators to the point of commercial viability. Like the electronic components of integrated circuits, these sensors and actuators are manufactured with high precision and low marginal cost through the use of photolithographic techniques. However, the task of



Microrobots race in a straight line across the playing field in a test of raw speed. *Microrobots dart around obstacles to test their agility and controllability.* *Microrobots must retrieve a set of balls and dribble them across the goal line.* *Synchronized motion of the microrobots is judged for artistic expression.*

integrating these sensors and actuators into mobile, microscopic, autonomous systems poses significant challenges for a new breed of roboticist [2].

Near-Term Applications

Near-term applications include those that allow a controlled environment for micro-robot operation, in which cleanliness and surface smoothness can be carefully maintained, in which an ambient power source can be conveniently applied, and in which global sensing systems can be effectively employed. Such applications include micro-factories for the manipulation and assembly of hybrid microsystems [2-7], sample preparation for electron microscopy [6], and parallel alignment of sub-micron spheres for quantum optical measurements [8]. While these applications could allow for simplified locomotion, power delivery, and task planning, they still require considerable speed and agility, as well as highly-parallel operation.

The Contest

RoboCup could become a catalyst for progress in micro-robotics by stimulating research interest, supplying a forum for collaboration and competition, and providing standard problems. In initial years, the required tasks will be modest compared to those performed within the other leagues, due to the relative immaturity of the field and the difficulty of fabricating robots so small. These tasks will consist of simple agility drills that demonstrate the basic skills and capabilities required for a microrobotic soccer game. The contest will take place within a highly-structured environment that simplifies the problems of power delivery, locomotion, communication, sensing, and control.

For the demonstration competition to be held at the Georgia Institute of Technology in July 2007, the contest will consist of four compulsory exercises:

1. The 2 Millimeter Dash
2. The Slalom Drill
3. The Ball-Handling Drill
4. RoboCup Dance

In the 2 Millimeter Dash, each microrobot must sprint across the playing field from one goal to the other. Each team will be allowed three trials. The winner is determined by the team with the fastest time for the best of its three trials.

In the Slalom Drill, the path between goals is blocked by inanimate “defenders” that the micro-robot must avoid as it races between the goals. These defenders are made from a thick film of photoresist that is patterned at specified locations on the field of play. Each team will be allowed three trials, and the winning team will be the one with the fastest time for the best of the three trials.

The Ball Handling Drill requires the microrobot to dribble as many balls as possible into the goal within a fixed period of time, while avoiding “defenders” in the field. The balls will consist of thin-film discs of silicon nitride, with dimples on their base to promote sliding along the surface of the field of play. Each team will run three trials of the ball handling drill, with the defenders placed in different locations for each trial. The winning team will be the one with the most goals for the three trials combined. In the event of a tie, additional trials will be conducted.

The RoboCup Dance contest challenges teams to demonstrate synchronized motion of their micro-robots in visually appealing sequences. This latter contest will be judged by the contest participants themselves. After viewing the dance competitions of all the teams, each team will cast two votes, which must be for two different teams. The winner is the team with the most votes.

In future years of competition, the contests should become more complex and the environment less structured, to encourage progress in the following target areas:

1. Cooperative motion and highly-parallel teams.
2. Three-dimensional manipulation.

3. On-board power supplies.
4. Integrated logic and sensing.
5. Locomotion over rough terrain.
6. Robust operation in dirty, wet, and volatile environments.

As the technology advances in these directions, there will be opportunities for Nanogram competitions within other classes of robot competition such as RoboCupJunior and RoboCupRescue.

The Playing Field

In the initial year of competition, the contestants will be able to rely on an overhead video microscopy system, a communication system for commanding the microrobot players, and a venue-supplied power delivery mechanism. The playing field would close the control loop between these external systems.

The playing field consists of a set of insulated interdigitated electrodes, across which an AC waveform can be applied, as described in [9] and [10]. This waveform provides both the electrical power and the control instructions for the micro-robotic players through a capacitive coupling. Above the field, a digital camera captures the action through an optical microscope and streams the video to the spectators as well as to the players' off-board control systems. The control systems process the video and define the waveform to be delivered to the playing field.

The National Institute of Standards and Technology will provide the playing fields to be used at the competition and will provide contestants with practice fields of play so that they can experiment with their microrobots in the months preceding the competition.

The Microrobotic Players

Each player must fit within a bounding box measuring 300 micrometers on a side and must be capable of operation on the playing field without the presence of any physically connected wires or tethers. The power waveforms used by the players can require no more than 250 V and must be within the specification of the electrical amplifier to be provided at the competition.

A method for fabricating microrobots has been previously detailed in the literature [10]. This method utilizes the PolyMUMPs multi-project wafer service [11] provided by MEMScAP, Inc. For contestants in the RoboCup Nanogram Demonstration Competition, MEMScAP has agreed to offer this service at a discount off of their standard academic rate. Alternative fabrication processes are feasible and are encouraged for the competition.

The Operating Environment

The operating environment in which the RoboCupSoccer Nanogram competition is conducted will be similar to what is used in the RoboCup Small Size League. An overhead global vision system provides sensing data, which is processed on a computer off-board the robots. Based on the sensing data, the robot teams' command software provides signals to be broadcast to the field of play. Robots on the field of play receive these command signals and react accordingly.

The global vision system will consist of a digital camera mounted on an optical microscope and attached to a personal computer. The microscope and camera will be provided by the venue, while each team will provide its own computer and vision processing algorithms.

A common mode of failure for many micro-electromechanical systems is adhesion due to the presence of a meniscus on contacting surfaces. This can be significantly reduced by operating in a dry nitrogen atmosphere. For this reason, the playing field and optics will be located within a sealed glove box, and the humidity within the glove box will be reduced to less than 5 % RH. The glove box and environmental controls will be provided by the venue.

Before play begins, the microrobotic players and balls must be deployed onto the playing field. This requires the use of a microprobe system capable of picking up and placing very small parts. This can be done with a vacuum microprobe as described in [10], and many other such systems are commercially available.

Participating in the Contest

A demonstration competition for the RoboCup Nanogram contest will be held at the RoboCup International Championships at the Georgia Institute of Technology in July 2007. Persons interested in participating in the demonstration competition should notify the authors as soon as possible and will be required to submit a Team Description Paper (TDP) by October 1, 2006. The TDP must name the individuals contributing to the team, the facilities available for fabrication, operation, and characterization of microrobots, an overview of the microrobot design, and an overview of the fabrication process to be used.

With the exception of the team membership, this information will be kept private until the competition. Teams will be notified of their acceptance into the competition by November 1, 2006, and will then be delivered contest materials, including a set of practice playing fields. Teams must be able to travel to Atlanta for the RoboCup Championships in July 2007 to be considered for the competition.

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