Name: Kostas E. Bekris
Affiliation: *(until 31 June 2008)* Physical and Biological Computing Group
Computer Science Department, Rice University
(after 1 July 2008) Assistant Professor
Computer Science and Engineering Dept., University of Nevada, Reno
Contact Info: (email) bekris@cs.rice.edu
(mail) 6100 Main Street, MS 132
Computer Science Dept., Rice University, Houston, TX, 77005
(phone) 832 687 4007 - (fax) 713 348 5930
(webpage) http://www.cs.rice.edu/~bekris

Robotics has been demonized in the past as a technology that eliminates manufacturing jobs. The reality, however, is different. While the investment in industrial robotics has been limited in the US compared to Asia and Europe, the transfer of factories to countries with cheaper labor has resulted in a significant slowdown of the US manufacturing sector. It is now understood that in order for the United States to be able to compete at a global level, it is necessary to invest in automation and regain a technological advancement in manufacturing. This realization has resulted in initiatives like the America Competes Act, which provide a golden opportunity to everyone working in robotics to identify the research goals that will enable the field to benefit the US economy.

As an academic interested in robotics, I am excited about this opportunity. With this proposal I am expressing my interest in participating in the CCC Roadmapping for Robotics Workshop related to problems in Manufacturing and Automation. I am also presenting three broad research areas, where I believe that progress in designing new scientific frameworks and algorithmic approaches will have a significant impact in the capabilities of industrial robots.

RESEARCH IDEAS

Modeling Factories with Physics Engines

Algorithmic advances, such as new multi-body dynamics algorithms, have allowed software packages to simulate Newtonian physics models, using variables such as mass, velocity, friction and wind resistance. These physics engines have been applied with success in physically-realistic computer games and scientific simulations. The business advantage of such software in manufacturing is that it enables machine designers to build virtual equipment, bypassing expensive and cumbersome physical prototypes. Such tools allow factory workers to train safely and quickly on 3D digital models. In this way, the simulation speeds up a company's machine development time and shortens the time-to-market phase of their products.

There have been small steps towards incorporating physics-based simulation in the manufacturing process (e.g., Siemens' GEM, PhysVis etc.) but further research can assist manufacturers to improve their efficiency, especially in relation to the following issues:

(i) Adaptability: Simulations often depend on many parameters to model various physical properties. It is important to automate parameter tuning in order to accurately model the real manufacturing environment. To achieve this objective, physics-based simulators must be integrated with sensor-based and estimation procedures. Given observations, learning can be employed to adjust parameters for physical properties, like friction and fluid resistance. In this way, the simulation can automatically adapt to changes in the factory or in materials and can also be used to detect potential undesired changes.

(ii) Computational Challenges: Many techniques employed in game engines to speed up the simulation are not acceptable for a factory simulation and more sophisticated methods are needed. It would be also highly desirable for the end user to have direct control over the trade-off between physical accuracy and computational efficiency. Additionally, the physical modeling of fluids and deformable objects, which can be important for manufacturing operations, corresponds to some of the most computationally demanding problems.

(iii) Abstraction and Usability: Abstract software packages are needed that can model a variety of factory setups by writing as little original code as possible, saving the industry both time and financial resources. The software packages should be easy-to-use and able to produce customized and interactive simulations.

Physics-Aware Planning for Mobile Manipulators
Many industrial robots have been designed for specific applications and apply a repetitive motion in a highly controlled environment. Although this approach results in high efficiency in the production line, it typically implies high costs and considerable time overhead when alterations have to be made to the industrial workspace, the materials used or the final product. More versatile platforms are desirable that can potentially be used in a variety of manufacturing tasks and can operate in more dynamic setups. The objective are platforms for which it is possible to autonomously recompute their operation and switch between different tasks depending on the changing necessities of the industrial process.

Mobile manipulators are one of the best candidates for this role as they combine the advantages of many other platforms. Nevertheless, there are still many research challenges in order to solve efficiently complex tasks with such systems that have many degrees of freedom and potentially high redundancy.

Search-oriented and graph-based planners are sufficiently good in computing collision-free paths. Although these algorithms can be extended to compute dynamically feasible trajectories, there are still many issues related to path quality and computational efficiency that limit their capabilities. One direction that will allow industrial mobile manipulators to better reason about their physical world is the incorporation of physics-based simulation in the motion planning process. In this way, the planned motions can anticipate the effects of inertia, gravity, friction and contacts. Additionally, planning in changing or dynamic environments is a significant challenge that requires real-time solutions. The combination of differential constraints and real-time requirements, however, leads to additional safety concerns that must be addressed. In real-time planning, it is no longer sufficient to compute a feasible collision-free trajectory but also a trajectory that will guarantee the existence of collision-free solutions into the future given the physical constraints. Addressing these challenges is important in order to have robotic systems that are both robust and versatile.

Instrumented Environments for Automated Manufacturing
Even if robots have on-board sensors, the advantage of an industrial environment is that it can be typically equipped with additional sensors that provide a high-level, global view of the factory's operation. Furthermore, when multiple robots are present and operate in the same floor, networking can be used to allow coordination between the robots as well as with an observation unit. Through this sensing and networking infrastructure, the robots can receive information about the status of the facility that is not directly accessible from their own sensors. Alternatively, robots can communicate even if they do not fall within communication range. This makes it easier for multiple robots to coordinate in order to execute a common manufacturing task.

Given the presence of multiple robots in a factory, scalability issues render a centralized infrastructure, where all the information is gathered at a single computation unit, which then distributes motion controls, nonviable. Instead, decisions must be taken in a distributed fashion and the information must be diffused appropriately into the network. Problems that have to solved in this context include distributed estimation, scheduling, task assignment problems, distributed collision-avoidance and motion coordination. As was the case in the previous section, all of these modules have to take into account the underlying physical properties of the systems and of the environment so as to achieve informed and feasible solutions.

An important requirement for this infrastructure is that it must come at a low cost, be minimally invasive in the factory's structure and should be equally adaptive to potential changes in the industrial process as required by the robotic units themselves.

SHORT BIO

Kostas Bekris is currently completing his Ph.D. degree at Rice University under the supervision of Prof. Lydia Kavraki. His doctoral work is in the area of motion planning under differential constraints and specifically through the incorporation of physics-based simulation in the planning process. His thesis has focused on the safety concerns that arise in real-time planning under dynamic constraints, especially for the case of multiple coordinating vehicles. He has also papers on bearing-only SLAM, bearing-only navigation, parallel motion planning and wireless localization. The work on motion coordination was awarded the best student paper distinction at the 2007 Robot Communication and Coordination conference. He has recently co-organized a workshop on "Algorithmic Motion Planning for Autonomous Robots in Challenging Environments", taking place in conjunction with IROS 2007. He will be joining the faculty of Computer Science and Engineering Department at the University of Nevada, Reno the academic year of '08-'09.