Auton Robot (2010) 28: 1–3
DOI 10.1007/s10514-009-9147-6

Guest editorial: special issue on autonomous mobile manipulation

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Received: 15 August 2009 / Accepted: 18 August 2009 / Published online: 23 September 2009
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Research in autonomous mobile manipulation seeks to develop mobile robotic systems that autonomously perform manipulation tasks in unstructured environments. Such robotic systems could have a profound impact on many application areas of societal, economic, and scientific importance, including domestic assistance, healthcare, flexible manufacturing, automated supply chain management, planetary exploration, and emergency services. The development of robotic systems for autonomous mobile manipulation is inherently interdisciplinary. Successful systems are likely to require new approaches and innovations involving multiple areas of robotics, such as perception, control, mechanisms, motion planning, manipulation, navigation, human–robot interaction, artificial intelligence, and machine learning.

In this Autonomous Robots special issue on autonomous mobile manipulation, we have sought to capture the state of the art in this challenging domain. The issue consists of eight carefully selected papers, each of which includes empirical results from experiments with a real robot performing manipulation tasks of importance to this area of research. We consider this real-world validation to be important, since it directly addresses both the challenges and opportunities for autonomous mobile manipulation. The robots described within these papers perform a variety of challenging tasks with relevance to real-world applications of value, including pick-and-place operations, opening various doors, grasping objects, moving large objects, inserting objects, and achieving coordinated motion in dynamic and unstructured environments. Each paper emphasizes a different approach to handling the challenges of autonomous mobile manipulation in unstructured environments, ranging from motion planning to mechanical design. Arguably, however, the most significant contributions relate to the creation of integrated systems that achieve new capabilities by combining perception, mechanics, computation, and control.

We now briefly introduce the papers within this special issue.

The first three papers emphasize pick-and-place operations within home-like environments. The first paper, entitled "HERB: A Home Exploring Robotic Butler," explores the potential for model-based planning to enable a robot to operate within a kitchen environment with fiducial markers. Siddartha et al. from Intel Research and Carnegie Mellon University describe HERB, a robot that integrates a number of novel methods, including caging grasps for constrained manipulation, object recognition and registration in clutter, and navigation in dynamic environments. HERB successfully performs many impressive tasks, including operating cabinet drawers, grasping a variety of modeled objects in clutter, and operating a refrigerator door. In addition to describing these methods and long-running demonstrations of the robot, the paper discusses the lessons the authors have learned during the robot's development.

The second paper, "Generality and Legibility in Mobile Manipulation: Learning Skills for Routine Tasks," looks at how robots might exploit diverse sources of knowledge to perform novel tasks and improve at frequently occurring, stereotypical tasks. Beetz et al. present methods designed to enable a robot to learn from simulation and experience, find and manipulate objects using Google3D Warehouse,

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and learn by observing human reaching trajectories. Simulation and experience enable the robot to learn at which locations it can more effectively grasp an object on a table. The use of robot trajectories based on human trajectories has the potential to improve the ease with which a human can interpret the robot's motion. Finally, the use of Google3D Warehouse could enable the robot to manipulate novel objects that it has not previously encountered. In addition to these exciting ideas, Beetz et al. describe experiments in which their mobile manipulator was required to pick-and-place a coffee mug in a kitchen. In their tests, the robot achieved impressively high rates of success, especially when using task-level feedback.

The third pick-and-place paper is motivated by the potential for robots to fetch and put away objects for people who need daily assistance, such as people with disabilities. In contrast to the first two papers, the robot in "EL-E: An Assistive Mobile Manipulator that Autonomously Fetches Objects from Flat Surfaces" does not make use of pre-existing 3D models of objects or the environment. Instead, it uses specialized behaviors that rely on low-dimensional, task-relevant features. The user provides a 3D location, which the robot either interprets as a location at which to pick up an object or place an object. The robot approaches this location and then looks for an object by first attempting to segment a flat plane, and then attempting to segment any structures protruding from this plane. The authors, Jain and Kemp, show that the robot can approach and pick up a variety of everyday objects (e.g., glasses, cups, keys, etc.) from a variety of everyday surfaces (e.g., counter tops, tables, the floor, etc.). This work suggests that specialized behaviors can sometimes generalize over significant, real-world task variation. This also supports Beetz et al.'s perspective on the value of specialized skills for routine tasks.

Whereas the first three papers describe integrated systems that grasp objects in the environment using sophisticated 3D perception and precise movements, the paper "Contact Sensing and Grasping Performance of Compliant Hands" by Dollar et al. describes how simple sensing and control coupled with a compliant physical mechanism can grasp objects in the presence of significant uncertainty. Dollar and his colleagues have previously shown that their shape deposition manufactured (SDM) hand can robustly grasp objects with low interaction forces. In this paper, they show that integrating contact sensing and reactive control can dramatically enhance the SDM hand's grasping performance relative to variations in the object's pose and shape. This work raises fascinating questions about the relationship between mechanical design, sensing, and computation. It also indicates that careful mechanical design and compliance can help a robot generalize its capabilities over significant, real-world task variation.

The first four papers were concerned with the mobile manipulation of objects that can be grasped with a single hand. Many objects of interest are too bulky or heavy for these methods to apply. The next paper, "Pivoting Based Manipulation by a Humanoid Robot" by Yoshida et al., considers manipulation at a larger scale. The paper looks at a very interesting form of manipulation that can enable a robot to manipulate very large objects by exploiting the physics of the environment. Specifically, the robot moves a large, heavy object by pivoting it on the ground. The authors present a planning algorithm for whole-body manipulation that enables a humanoid robot to move a large, heavy object over long distances by repeatedly tilting the object and rotating it around points of contact between the object and the ground. The authors show impressive experimental results, in which the humanoid robot HRP-2 moves a large box in this manner.

There has been a long history of research into how robots should use articulated end effectors to make contact with the environment, and how robots should move their end effectors in order to perform tasks. Yet, relatively little research has considered the intersection of these two important domains. Often researchers assume that appropriate contact has already been made with the environment, such as in the previous paper, or focus on achieving contact in isolation from a complex task, such as in Dollar et al.'s paper. Prats et al. present their vision for a framework that pulls these two areas together. Their framework, described in the paper "A Framework for Compliant Physical Interaction: the grasp meets the task," combines the task-frame formalism (task-oriented research) with knowledge-based grasping (grasping research). They demonstrate the value of their framework with experiments using a variety of mobile manipulators performing diverse and challenging tasks.

Once the parameters of the physical interaction between the end effector and the environment have been specified, a mobile manipulator has to move in such a way that all the required forces, moments, and displacements are realized. This task is complicated by the fact that it has to happen robustly and reliably in spite of a changing environment and sensing uncertainties. The paper "Elastic Roadmaps—Motion Generation for Autonomous Mobile Manipulation" by Yang and Brock addresses this problem. It presents a motion generation method for mobile manipulation that is part motion planner, part hybrid control system. Together these two parts can realize all aspects of tasks, ranging from globally planned motion to obstacle avoidance and low-level force control. Impressive experimental results on a mobile manipulation platform show the effectiveness of the elastic roadmap approach in real-world scenarios.

As represented by the first three papers, research on autonomous mobile manipulation for dynamic, unstructured environments often considers home-like environments. For example, robots operating within kitchens often present a nice contrast to traditional industrial robots in well-controlled factory settings. The final paper in this special issue, entitled "An Autonomous Mobile Manipulator for Assembly Tasks," brings things full circle. It looks at how autonomous mobile manipulation might lead to new methods of flexible manufacturing. Hamner et al. present results from extensive experiments with a mobile manipulator that inserts a wiring harness into a car door. These results convincingly demonstrate their robot's robustness. They show that careful integration of visual and haptic sensing through structured behaviors can significantly reduce uncertainty and improve performance. This research points the way towards new flexible manufacturing methods for which the robot is no longer fixed in place, but instead moves through the environment using rich sensory feedback.

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