Editorial

Special Issue on the Ninth International Workshop on Algorithmic Foundations of Robotics (WAFR)

Robot algorithms are critical building blocks of any robotic system. They enable robots to interpret sensory data, plan courses of actions, control the execution of those actions, and learn new skills, in order to achieve greater autonomy. Today, the design and analysis of robot algorithms are more crucial than ever.

- Robotics is undergoing major transformations. Originally focused on industrial manufacturing, it is now rapidly expanding into new domains, such as medical surgery, care of the elderly, ocean and space exploration, transportation, entertainment, homes and offices, and search-and-rescue. In these new domains tasks are less repetitive, environments less structured, and events less predictable. It is impossible to consider explicitly all contingencies in the robot programs. Algorithms that adapt to uncertainties and changes are increasingly needed to achieve greater autonomy over long periods of time.
- Robot algorithms are finding applications beyond robotics, for example, in designing mechanical assemblies, modeling molecular motion, animating digital characters for video games and computer-generated movies, simulating architectural designs, and studying product ergonomy. These non-traditional applications of robot algorithms pose new challenges: dealing with hundreds or thousands of degrees of freedom, handling large populations of individually modeled characters, reasoning under complex physical constraints, and generating natural-looking motions. Solving these challenges will in turn benefit future robotics.

Robot algorithms are also rapidly evolving as a result of new technologies, for example, low-cost parallel computers, specialized processors (e.g. GPUs), cheaper and more diverse sensors, new interaction devices ranging from haptic to neuroprosthetic devices, new materials, and miniaturized devices (e.g. MEMS).

Unlike most traditional computer algorithms, robot algorithms interact directly with the physical world. They must operate safely, reliably, and efficiently under tight time constraints in imperfectly known environments. So, it is not surprising that the design and analysis of robot algorithms raises unique combinations of fundamental questions in computer science, electrical engineering, mechanical engineering, and mathematics. For example, minimalist robotics studies the minimal sensing and actuation capabilities required to complete a given task. It addresses not only computational complexity issues, but also “physical” complexity issues. Probabilistic methods are widely used as a modeling tool to handle uncertainties due to sensing and actuation noise, but they are also increasingly used as a computational tool to avoid prohibitively expensive computations by sampling partial information and handling the uncertainties that result from the lack of a “complete” computation.

The Workshop on Algorithmic Foundations of Robotics (WAFR) is a highly selective, multi-disciplinary, single-track meeting of leading researchers in the field of robot algorithms. Since its creation in 1994, WAFR has been held every two years and has published some of the field’s most influential contributions. Previous WAFRs have been held at Guanajuato, Mexico (2008), New York City, NY, USA (2006), Zeist, The Netherlands (2004), Nice, France (2002), Hanover, NH, USA (2000), Houston, TX, USA (1998), Toulouse, France (1996), and San Francisco, CA (1994).

This special issue contains expanded versions of eight papers that were presented at the 9th WAFR held at the National University of Singapore on December 13–15, 2010. This WAFR had a strong program of 24 contributed papers selected from 62 submissions. Each paper was rigorously reviewed by at least three reviewers with additional input from two program committee members. The workshop also featured six invited speakers: Leslie Kaelbling (Massachusetts Institute of Technology), Jean-Pierre Merlet (INRIA Sophia Antipolis), José del Millán (Ecole Polytechnique Fédérale de Lausanne), Yoshihiko Nakamura (University of Tokyo), Daniela Rus (Massachusetts Institute of Technology), and Moshe Shoham (Technion – Israel Institute of Technology). A vibrant poster and video session was a new addition to this WAFR program to encourage the open exchange of ideas.

The authors of some of the best contributed papers were invited to submit expanded versions of their papers for this special issue. These papers underwent the usual rigorous International Journal of Robotics Research (IJRR) review procedure. The eight papers contained in this issue of IJRR illustrate the breadth of topics addressed by the algorithmic robotics community.

Bekris, Grady, Moll and Kavraki develop a distributed planning method for several communicating robots operating in the same environment. Each robot follows second-order dynamics, has its own goal, and periodically replans its trajectory taking information received from the other robots into account. The proposed method considers the difficult case where the replanning cycles of the robots are not synchronized. It guarantees safe navigation of every robot by ensuring that no collision will occur before the next replanning operation and by not leading the robots to states where collisions cannot be avoided later.

When executing a planned trajectory, a robot may go off the planned path due to disturbances. Seiler, Singh, Sukkarieh and Durrant-Whyte address the problem of path correction, and present a technique that exploits Lie group symmetries. Their method yields smoother trajectories than myopic approaches which try to get back to the planned path as quickly as possible. They first study the problem for obstacle-free environments,
and then integrate the solution into an RRT for motion planning in cluttered environments. The technique is demonstrated in two applications: planning paths for a planar mobile robot and needle steering.

Knepper, Srinivasa and Mason consider the problem of testing a set of short paths of fixed length and bounded curvature for collision. Several planners explore the free space of a robot by repeating a single operation: generate multiple short paths starting at the same configuration and check them for collision. However, checking each path separately is expensive and leads to redundant computations, as the areas swept out (swaths) by the robot along several paths have many overlaps. The paper introduces a homotopy-like classification of paths that makes it possible to save many explicit collision checks and achieve major computational speedup.

Probabilistic sampling has dramatically changed the landscape of motion planning algorithms. The work of Pan and Manocha shows that parallelizing collision detection, which dominates the computational cost of many sampling-based motion planning algorithms, improves computational efficiency significantly. Their collision detection algorithm exploits parallelism at two levels: it checks multiple configurations simultaneously and performs parallel hierarchy traversal for each collision query. Experiments show that by exploiting both data parallelism and multi-threading on many-core GPUs, the algorithm can speed up the probabilistic roadmap (PRM) algorithm by up to 100 times.

Porta and Jaillet describe a new algorithm for motion planning on a highly-constrained manifold. In general, constraints negatively impact the performance of sampling-based motion planning algorithms, as a sample point from the higher-dimensional ambient space has zero probability of lying on the constrained manifold. The new algorithm builds on recently developed tools for higher-dimensional continuation, which provide numerical procedures to describe an implicitly defined manifold using a set of local charts. It has the advantage of directly operating on the constrained manifold rather than the higher-dimensional ambient space containing it.

Probabilistic inference algorithms are important for many applications in robotics, ranging from Simultaneous Localization and Mapping (SLAM) for building geometric models of the world to tracking people for human robot interaction. Kaess, Johansson, Roberts, Ila, Leonard and Dellaert introduce a Bayes tree that encodes a factored probability density and maps naturally to the square root information matrix of the SLAM problem. The Bayes tree offers several advantages. It provides a better understanding of batch matrix factorization in terms of probability densities. Its fairly abstract updates to a matrix factorization translate into a simple editing of the Bayes tree and its conditional densities. It can be used to obtain efficient sparse nonlinear incremental optimization that combines incremental updates with fluid re-linearization of a reduced set of variables.

Is there a systematic way to design the finger form for grasping? Rodriguez and Mason offer a principle based on the invariance of contact geometry over some continuum of varying shape and the pose of the grasped object in the plane. The principle leads to finger forms for scale-invariant and pose-invariant grasps of disks as well as the design of optimal shapes of common devices, such as jar wrenches and rock-climbing cams.

Miller, van den Berg, Fritz, Darrell, Goldberg and Abbeel consider how tedious household chores, such as folding clothes, can be performed by a robot. They define a cloth model that allows reasoning about the geometry instead of the physics of the cloth in significant parts of the state space. They also introduce the concept of g-folds, i.e. folds to be achieved while staying in the subset of the state space to which the geometric model applies. G-folds are easy to specify and sufficiently rich to capture the most common cloth folding procedures. Given polygonal geometry of the cloth, the number of grippers, and the desired fold sequence, they present an algorithm that computes a motion plan for the grippers that move the cloth through the C-space to reach the desired final arrangement specified as a sequence of g-folds. They consider folds involving single and stacked layers of material and describe their experiments folding towels, shirts, sweaters, and slacks using a Willow Garage PR2 robot.

We hope that you will enjoy this collection of papers and that you will find them as inspiring as we do!

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