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Editorial

Research in control of nonlinear systems has prospered during the last few decades. Globally stable controllers for a class of robotic-type mechanical systems have been obtained, but under some restrictive assumptions on the systems. Some of these assumptions, e.g. related to the availability of measurements of both position and velocity, have been removed. Although slight variations in the control of rigid robots are still being studied, this field seems quite mature.

Other assumptions, such as requiring the number of actuators to be equal to the number of degrees of freedom, are more difficult to remove. The class of underactuated systems, i.e. systems with less actuators than degrees of freedom, is quite large, and includes examples such as mobile robots, a truck with trailer(s), the rolling Euro, the knife edge, etc.

It is known that using discontinuous control for underactuated systems, such as that used in parking a car, allows for more freedom than is available by continuous (time-invariant) controllers alone. This makes the problem harder, because this type of control, and hybrid control in general, is more difficult to analyze and synthesize.

The purpose of this special issue of the *International Journal of Robust and Nonlinear Control* is to bring together tutorial, fundamental, and application papers addressing the general theme of 'Control of Underactuated Nonlinear Systems'. Subject areas treated include:

- theoretical developments in underactuated systems:
  - flatness of underactuated systems
  - modelling
  - stabilization and tracking
- control techniques based on:
  - compensation of nonlinearities
  - geometric nonlinear control
  - hybrid and switching control
  - passivity and saturation
- applications in:
  - animal and robotic locomotion
  - serial robots
  - steering and path planning
  - wheeled vehicles

A sketch of the content of the papers, in order of appearance, i.e. alphabetical on first author, will illustrate the diversity and the commonality of the contributions in this issue.

The first paper, by De Luca *et al.* discusses the stabilization of a (non-smooth stabilizable) mechanical system with two rotary joints with only the base one actuated. Use is made of an error contracting open-loop finite time control law, in combination with partial feedback linearization and nilpotent approximation. By repeated application using the last error states, making it closed loop, the error will decrease exponentially to zero.

Dixon *et al.* in the second paper, treat the tracking and regulation problem for mobile robots. A kinematic control law is derived that achieves global exponential convergence of the tracking error, in both position and orientation, to an arbitrary small neighbourhood around the desired state. Ther controller can be tuned to improve robustness.

The paper by Kelly and Murray targets the control of "swimming" robots. As a first step a model is derived, based on an analogy with marine animals, that predicts the effects of a certain actuator. The model is in a control-affine nonlinear form with drift terms, making it accessible to standard analysis and design tools for nonlinear control systems.

Lefeber and coauthors address systems that fall in a class of non-holonomic chained form models, using wheeled mobile robots as an example. Solving the static state and dynamic output feedback tracking problems with linear controllers, they obtain K-exponential stability of the tracking errors. Also considered is the case with input saturation, giving the paper an application oriented twist.

The paper by Reyhanoglu *et al.* is reminiscent of the first paper. Both discuss underactuated robot manipulators and apply the theory on a planar robot. Also, in this paper a discontinuous feedback law is derived that achieves global attractivity of the equilibrium. However, the techniques used are quite different.

A two-step approach to achieve stabilization in the regulation problem is taken by Shiriaev and coauthors. The first step stabilizes the system to a set around the equilibrium, and then a local stabilizing control is used to obtain stabilization of the target position. The ubiquitous inverted pendulum problem is used as carrier to demonstrate the theory, but potential applications are more general.

The final paper by Sira-Ramirez *et al.* targets helicopter control as application area and provides controllers for trajectory tracking. The control laws are based on approximate state linearization around the off-line computed desired trajectory. Techniques employed are based on (partial) differential flatness and special properties of the kinematic helicopter model.

We are pleased with the input of all the contributing authors and the help of all reviewers that make this issue burst with new ideas and applications that hopefully will enhance, stimulate and refresh the readers research work.

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