International Assessment of Research & Development in Robotics

Control-Software-Architecture

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Major Subtopics

- **Algorithm (Control):**
  - Nonlinear: model based, neuro-fuzzy
  - Adaptive: model based, learning
  - Optimal: time optimality
  - Hybrid systems: discrete event system
  - Biomimetic based

- **Software:**
  - Simulation: order $N$, differential-algebraic system, flexibility (FEM), distributed communication
  - Programming: language, user interface, interpolation, demonstration
  - Real-time OS: QoS guarantees, plug & play

- **Architecture:**
  - Centralized, hierarchical, distributed, decentralized
  - Multi-rate, multi-resolution (quantization)

- **Application-specific:**
  - industrial manipulators
  - force control
  - parallel robots
  - multi-finger grasping
  - wheeled robots
  - biped locomotion
  - networked robotic system
  - vision feedback
  - haptic feedback
  - micro-robots, precision motion
  - multiple-robot collaboration
  - team robot
  - teleoperation
  - flexible (joint/link) robot
  - (hyper)redundant robot
  - nonholonomic systems
  - failure tolerance
Major Investigators

- US Universities (partial list!):
  - Caltech: J. Burdick, R. Murray (under-actuated systems, nonholonomic systems, hyper-redundant robots, team robot, distributed control).
  - Illinois: M. Spong, S. Hutchinson (flexible joint control, visual servo-control, teleoperation, networked control).
  - CMU: P. Khosla, M. Mason (vision feedback, real-time control architecture, manipulation).
  - Northwestern: M. Peshkin, E. Colgate, K. Lynch (cobot, teleoperation, manipulation).
US Universities (partial list!):
- U. Penn, V. Kumar, G. Pappas (team robot, hybrid system, UAV).
- Harvard, R. Brockett (nonlinear control, networked control with quantized communication).
- MIT, J-J. Slotine, H. Asada, S. Dubowsky, N. Hogan, R. Brooks (adaptive control, learning control, nonholonomic systems, impedance control, architecture).
Major Advances

- Inverse dynamics: application of feedback linearization to serial robots, now routinely used in industrial manipulators (e.g., ABB)
- Time optimal control: along a path subject to dynamics, velocity and accel constraints, also used in industrial manipulators
- Adaptive robot control: model based adaptive control with global stability guarantee, implemented on ASIC.
- Nonholonomic control: control using time varying feedback or cyclic input, application of differential flat system theory, mostly applied to mobile robots and underactuated robots.
Major Advances (Cont.)

- Flexible joint robot modeling and control: Application of feedback linearization to flexible joint robots, applied to some industrial arms.
- Teleoperation: wave variable based control for delay robustness. Guarantee stability, but user would feel delayed response.
- Order $N$ simulation: Application of order $N$ computation to forward and inverse dynamics. Essential for large number degrees of freedom, e.g., robot with flexible link, micro-robots.
- Hybrid force/position, impedance control: Simultaneous regulation of motion and force, applied to machining, assembly, haptic feedback, multi-finger control.
Major Papers

- **Sliding mode control:** Slotine, Sastry, “Tracking control of non-linear systems using sliding surfaces, with application to robot manipulators,” Int. J. Control, 38(2), 465-492, 1983. (314 cites)
Major Papers (Cont.)

Major Unsolved Problem

- Reliable assembly: robotic assembly (especially of microsystems) with imprecise geometric and dynamic models and environment
- Distributed operation: coordinated robot control with information and actuation distribution, communication bandwidth limitation, indirect communication through shared dynamics (stigmergy)
- Fault detection and mitigation: satisfactory controller performance in the face of drastic changes in the system dynamics.
- Modeling, control, and design of complex multi-body systems (e.g., protein folding, material design, surgical simulation)
Research Goals

- Motion and force control in microsystem assembly.
- Distributed robot transport, manipulation, assembly in the presence of delay, quantization, and noise.
- Simulation, analysis, and design of complex multi-body systems
- Real-time, fault-tolerant, plug & play software systems with QoS guarantees
- Control of emergent behavior
Major Accomplishments in Other Countries

- Micro-robot manipulation: Fukuda, Arai, Nagoya University (novel locomotion, optical tweezer cell manipulation)
- Micro-robot, precision engineering: Clavel, EPFL (high speed parallel robot design/control)
- Multi-robot collaboration: Uchiyama, Tohoku University (multi-robot load transport, manipulation)
International Collaboration

- Research into micro-robot modeling, design, and control.

- Networked based control: e.g., recent work by N. Xi with collaboration with Nagoya and HK Science & Tech Univ.

- OROCOS (Open Robot Control Software): European collaboration with H. Bruyninckx (Katholieke Universiteit Leuven), R. Chatila (Centre National de la Recherche Scientifique), H. Christensen, (Kungliga Tekniska Hogskolan)

- Industry-University collaboration like Lund-ABB