MARYLAND ROBOTICS CENTER
THE INSTITUTE FOR SYSTEMS RESEARCH

THE DEPARTMENT OF MECHANICAL ENGINEERING

DEPARTMENT OF ELECTRICAL & COMPUTER ENGINEERING

CPS: Medium: Ant-Like Microrobots - Fast, Small, and Under Control

Pamela Abshire, Sarah Bergbreiter, Nuno C. Martins, Elisabeth Smela

CISE
Award No. 0931878

Objectives

Development of the first wireless network of cooperative mobile autonomous robots at a very small scale

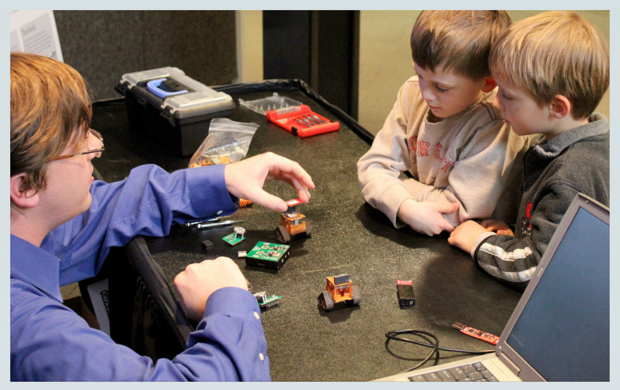
Research Themes:

- Sensing and odometry at very small scale
- Small robotic platforms
- Miniaturized low-power actuation
- Control algorithms subject to limited computational capability

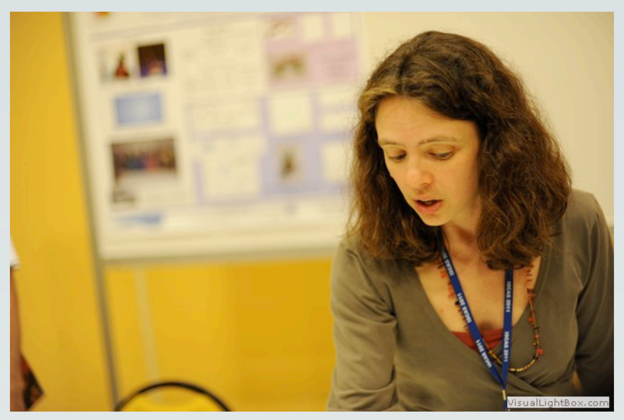
Education and Outreach

One of the main goals of the project is to expose undergraduate students to the research environment. Several undergraduate students have collaborated with graduate students in various aspects of the project.

- To date 13 graduate and 30 undergraduate students have worked on this project.



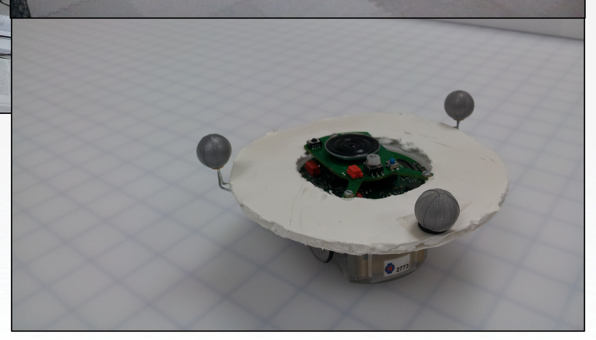
Koshland Science Museum (2011)



Demo at a conference in Brazil (2011)

CPS & Cooperative Autonomy Laboratory

- Development of a tested with an overhead camera for 2D tracking
- Laboratory equipped with 12- camera 3D tracking system, 4 small robots and 2 quadrotors
- Main goal: heterogeneous robotic network involving small robots

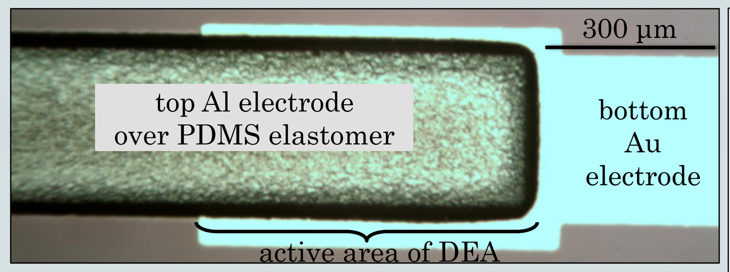


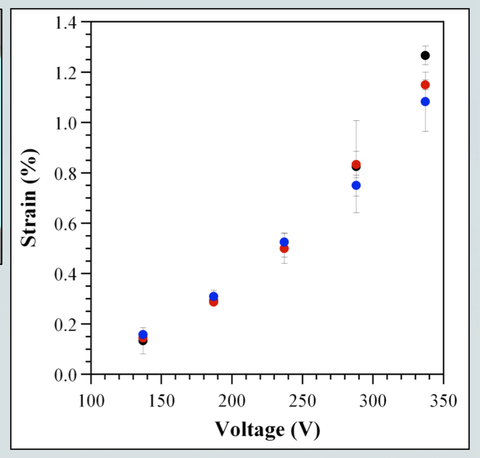
Top Left: in-house testbed with overhead camera. **Top Right**: 3D tracking system and quadrotor. **Right**: small robot with IR markers used for fast control and communication algorithms prototyping.

Actuation

Dielectric Elastomer Actuation (DEA)

- Successful microfabrication of a DEA using surface micromachining techniques
  - Allows for integration with on-chip circuitry
  - Contraction of over 100nm

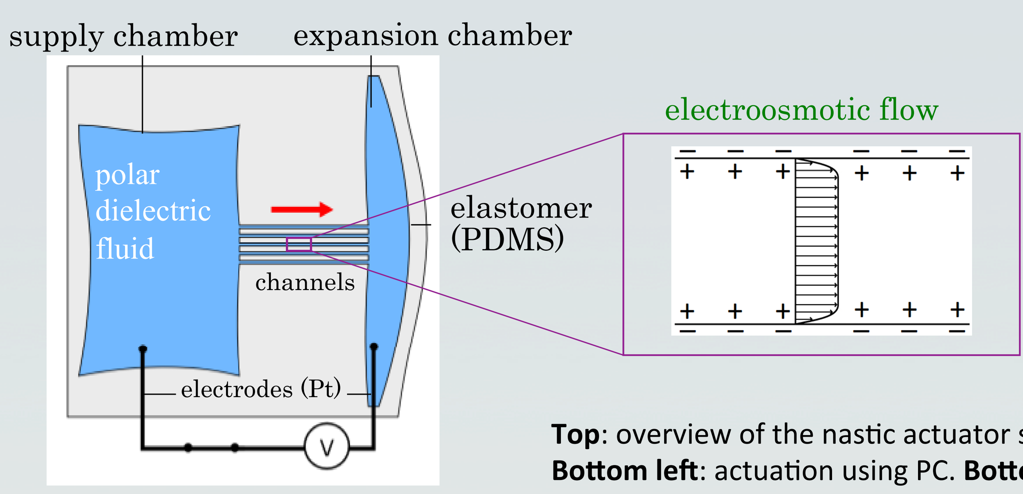




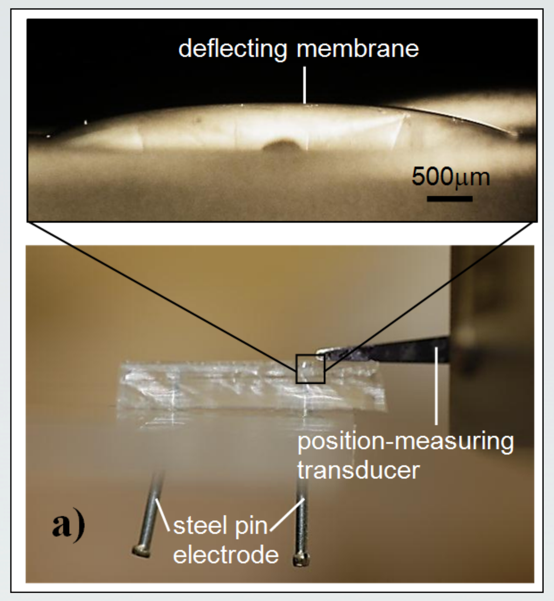
Top: overhead view optical micrograph of the microfabricated DEA. **Right**: out-of-plane strain as function of applied voltage for several of the surface DEAs.

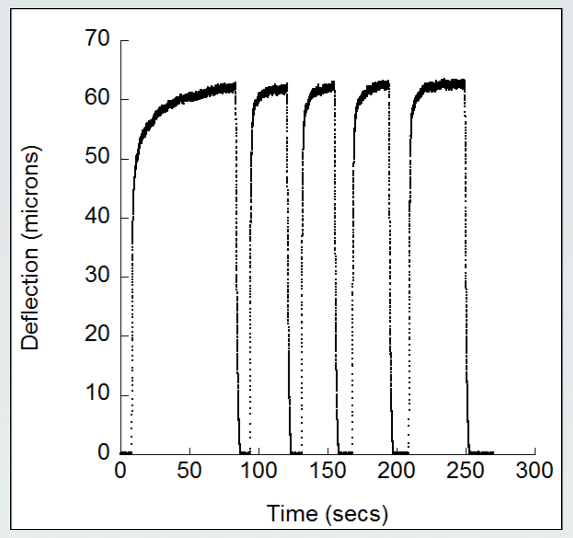
Nastic Actuator Mechanism

- Actuation based on electroosmotic pumping
  - Strokes of 100 mm are achieved within seconds
  - Stable performance: propylene carbonate (PC) results in bubble-free operation even up to kV



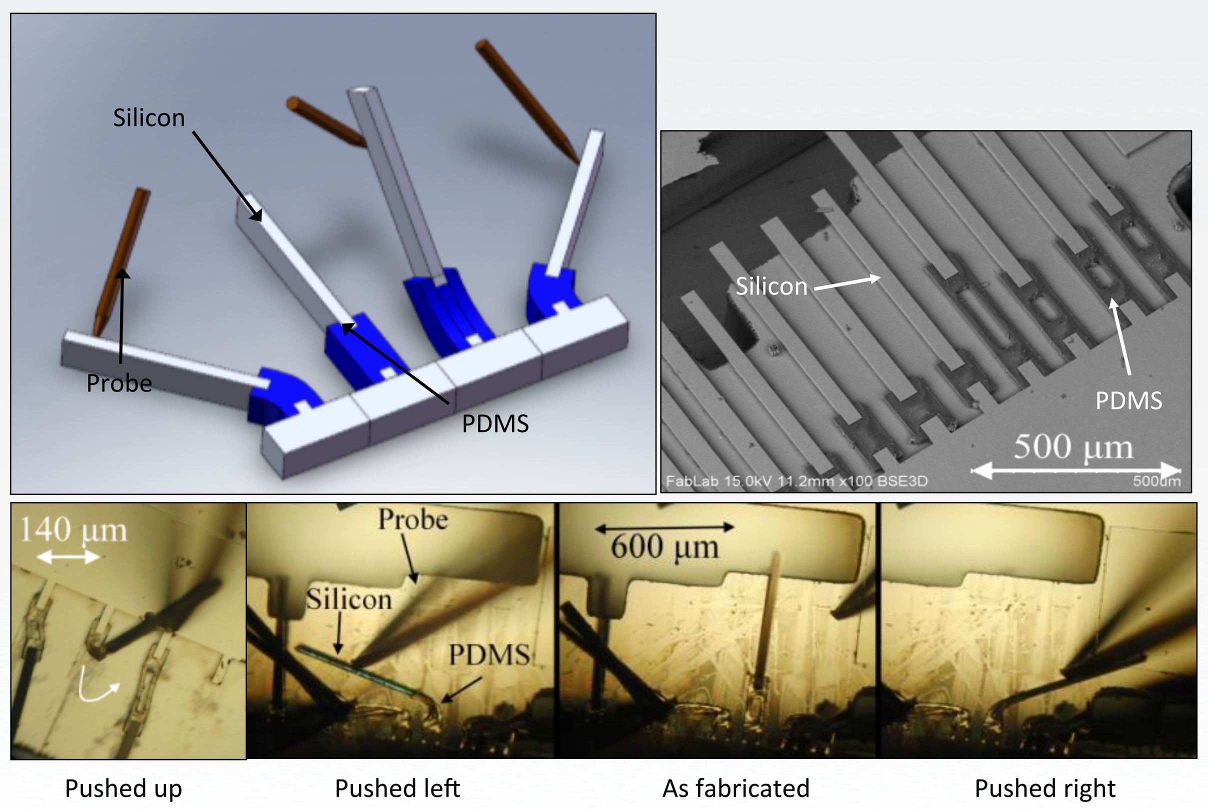
Top: overview of the nastic actuator system. **Bottom left**: actuation using PC. **Bottom right**: deflection as a function of time.





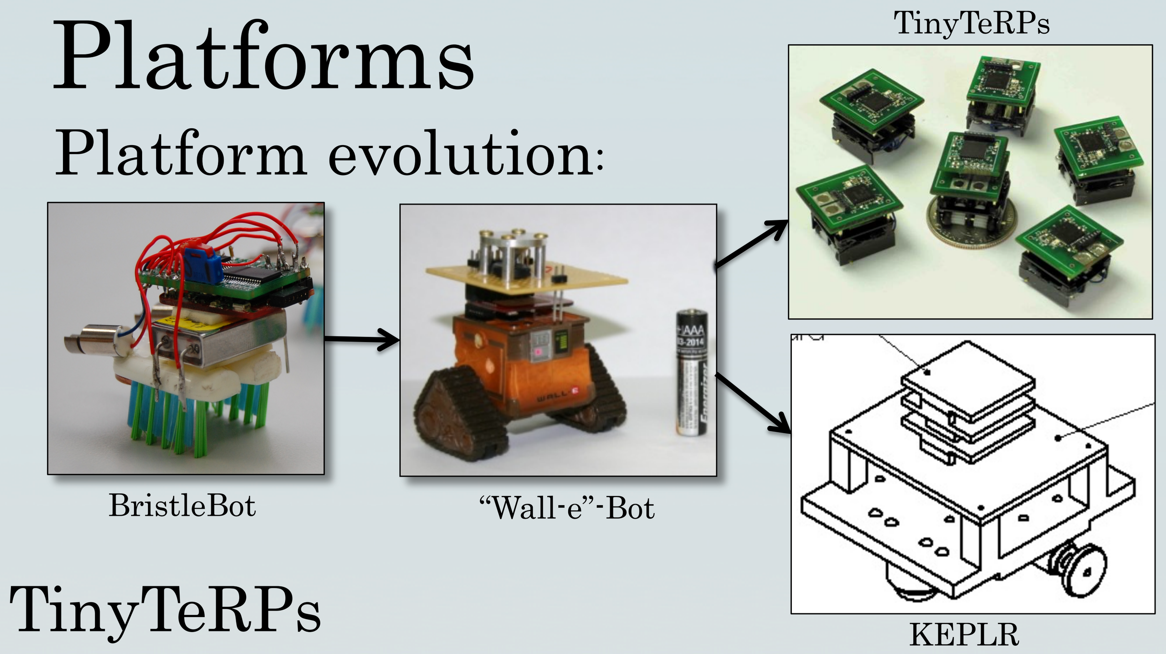
Little Legs

- Development of fabrication process that enables the addiction of elastomers to silicon MEMS



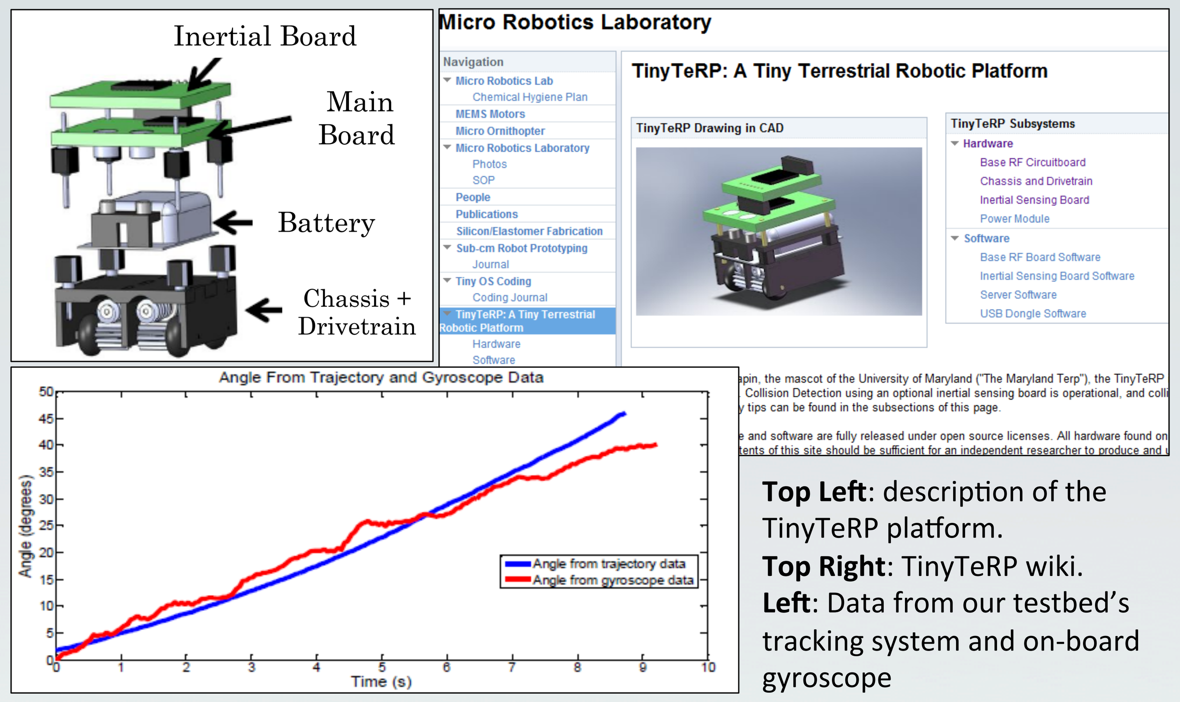
Platforms

Platform evolution:



TinyTeRPs

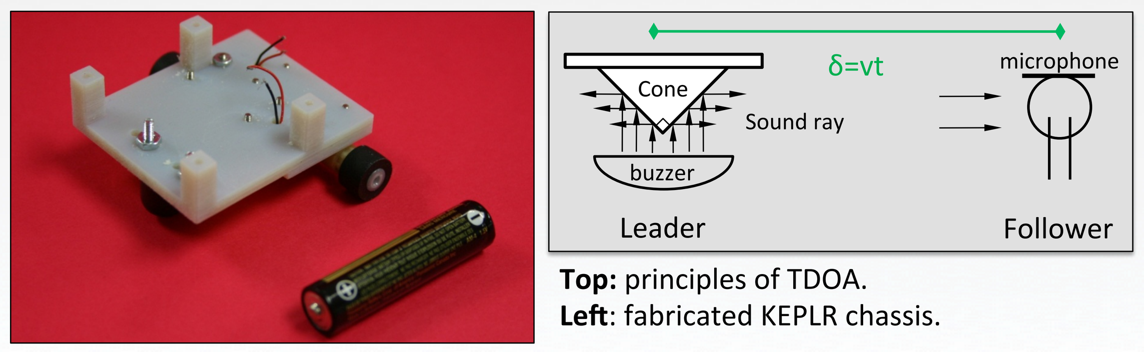
- Development of modular, low-cost small platform
- Open source hardware and software



Top Left: description of the TinyTeRP platform.
Top Right: TinyTeRP wiki.
Left: Data from our testbed's tracking system and on-board gyroscope

KEPLR

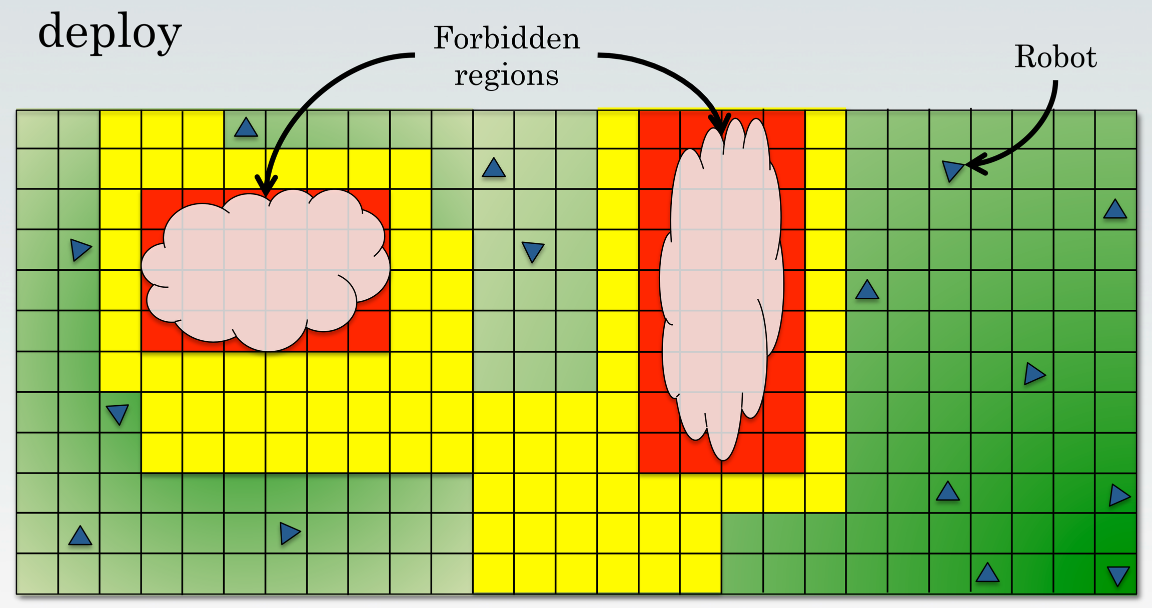
- Current development of a small platform with mixed-signal architecture
  - Sensing: Time Difference of Arrival (TDOA) and IR
  - Kalman filtering and receding horizon control



Top: principles of TDOA.
Left: fabricated KEPLR chassis.

Search and Surveillance

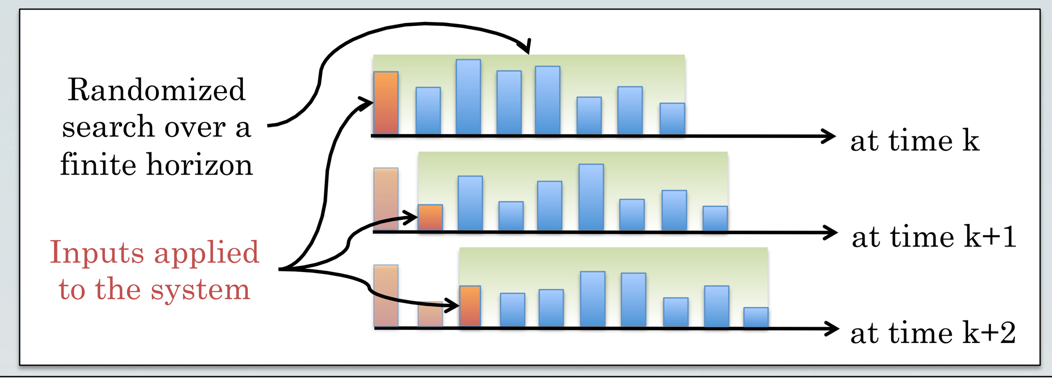
- Novel technique for control design and determination of safe states
  - Based on entropy maximization principles
  - Finitely parameterized convex program: highly scalable
  - Determination of where and how many robots to deploy

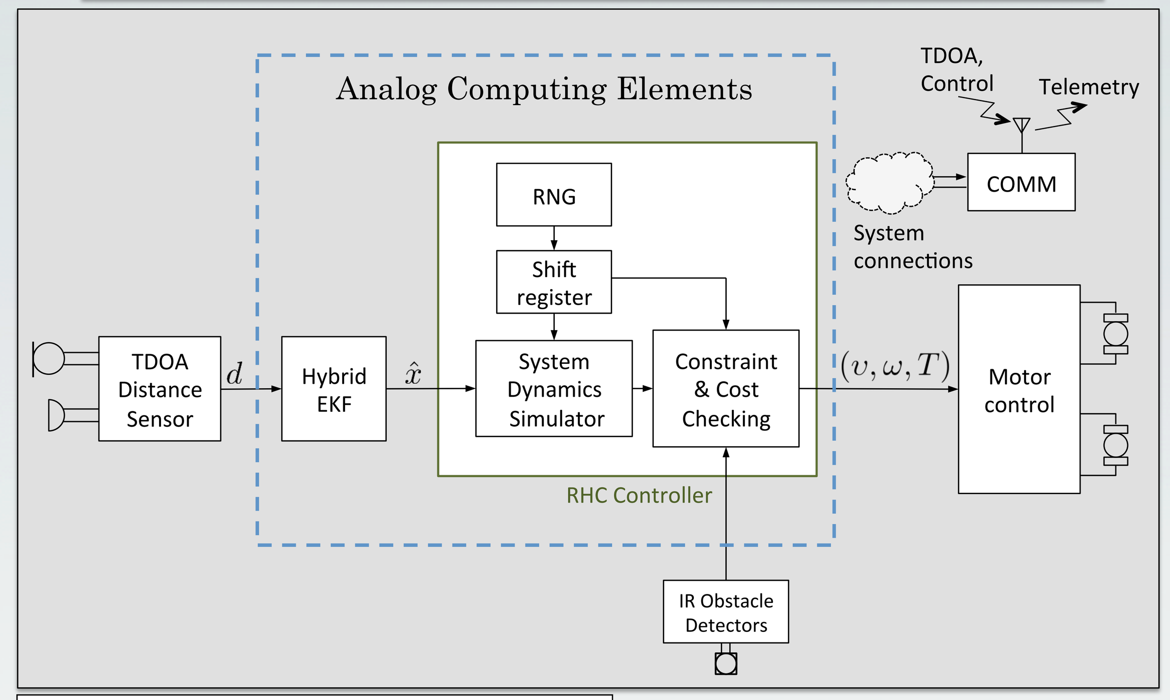


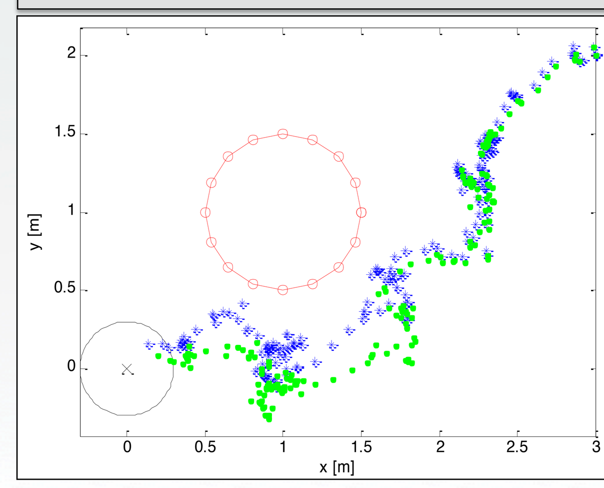
Search and surveillance scenario

Mixed-signal Randomized Receding Horizon

- Development of mixed-signal architecture for state estimation and RHC
  - Precursor of a fully analog low-power architecture.
- Randomized strategy drastically reduces computational complexity of RHC.







Top: Receding horizon control principles with random search. **Immediately above**: RHC mixed-signal architecture with sensing and Kalman filter (to be implemented in the KEPLR platform)
Left: Randomized receding horizon control MATLAB simulation. Blue starts represent trajectory, while green dots represent Kalman filter estimates.

Publications

C. Perkins, L. Lei, M. Kuhlman, T. Lee, G. Gateau, S. Bergbreiter, and P. Abshire, *"Distance Sensing for Mini-Robots: RSSI vs. TDOA,"* in 2011 IEEE International Symposium on Circuits and Systems (ISCAS). IEEE, 2011, pp. 1984-1987.

G. Sineriz, M. Kuhlman, and P. Abshire, *"High Resolution Distance Sensing for Mini-Robots using Time Difference of Arrival,"* in IEEE International Symposium on Circuits and Systems, May 2012.

M. Kuhlman, E. Arvelo, S. Lin, P. Abshire, and N. C. Martins, *"Mixed-Signal Architecture of Randomized Receding Horizon Control for Miniature Robotics,"* to be published in IEEE International Symposium on Circuits and Systems, August 2012

A. P. Sabelhaus, D. Mirsky, M. Hill, G. M. Gateau III, N. C. Martins, and S. Bergbreiter, *"TinyTeRP: A tiny terrestrial robotic platform with modular sensing capabilities,"* submitting to IEEE ICRA 2013.

A. P. Gerratt and S. Bergbreiter, *"Incorporating compliant elastomers for jumping locomotion in microrobots,"* submitted to Smart Materials and Structures.

A. P. Gerratt and S. Bergbreiter, *"Microfabrication of compliant all-polymer MEMS thermal actuators,"* Sensors and Actuators A: Physical, vol. 177, no. 4, pp. 16-22, April 2012.

A. P. Gerratt, B. Balakrisnan, and S. Bergbreiter, *"Batch microfabricated bidirectional dielectric elastomer actuators,"* in Transducers, Beijing, June 5-9, 2011.

D. Sritharan, A. Chen, J. Tumbic, B. Naved, E. Smela, *"Bubble-Free Electroosmosis at High Voltage Using Propylene Carbonate",* in preparation for submission to Sensors and Actuators B.

B. Balakrisnan, D. Sritharan, and E. Smela, *"Surface Micromachined Dielectric Elastomer Actuators",* in preparation for submission to Journal of Microelectromechanical Systems.

B. Balakrisnan and E. Smela, *"Challenges in Microfabrication of DEAs, Electroactive Polymer Actuators and Devices"* ,(EAPAD) XI, SPIE Smart Structures, 2010.

C. Perkins, L. Lei, M. Kuhlman, T. H. Lee, G. Gateau, S. Bergbreiter and P. Abshire, "*Distance Sensing for Mini-Robots: RSSI vs TDOA",* IEEE International Symposium on Circuits and Systems (ISCAS), Rio de Janeiro, Brazil, 2011.

T. Datta, P. Abshire, A. Turner, *"Towards a Legged Chip",* IEEE International Symposium on Circuits and Systems (ISCAS), Rio de Janeiro, Brazil, 2011.

W-J. Ma, E. Arvelo and N.C. Martins, *"Designing Networked Control Architectures for Incremental Robustness",* IFAC 18th World Congress, Milano, Italy, 2011.

E. Arvelo and N.C. Martins. *"Control Design for Markov Chains under Safety Constraints: A Convex Approach",* Submitted to Automatica, 2012.

S. Sabau and N.C. Martins, "Stabilizability and Norm-Optimal Control Design subject to Sparsity Constraints,"submitted to the IEEE Transactions on Automatic Control." …

Invention disclosure filed with the Office of Technology Commercialization at the University of Maryland on 7/30/12: *"Bubble-Free Electroosmosis Using Propylene Carbon*