Physical Modeling and Software Synthesis for Self-Reconfigurable Sensors in River Environments

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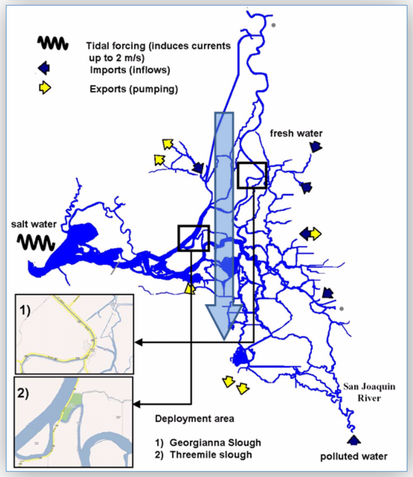
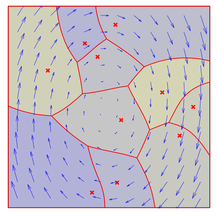
Abstract

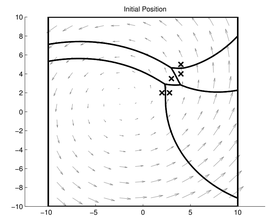
Our work in this collaborative research project examines the role of software synthesis for monitoring and planning of autonomous sensors evolving on tidally forced rivers. The goal of the sensors is the coordinated sampling of currents and salinity to reconstruct the distributed state of the river. This project integrates the development of theory for the coordination of autonomous agents in motion-constrained environments, and of algorithms to perform motion planning tasks, with software tools for design, analysis, and code synthesis for implementation.

San Joaquin River Delta



Control for Coverage



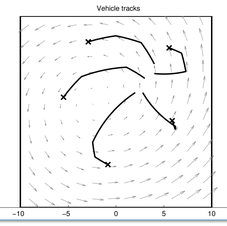


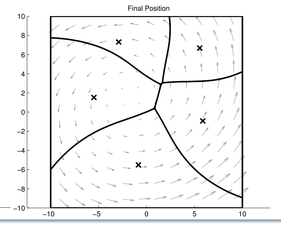
$$J_{mix}(p^1,p^2) = \beta J(p^1,p^2) + (1-\beta)t_f, 0 \le \beta \le 1$$

$$\mathcal{H}(P) = \int_D \left(\min_{p^i \in P} J_{mix}(p^i,q)\right) \phi(q) dq$$

$$\frac{dp^i}{dt} = -\frac{\partial \mathcal{H}}{\partial p^i}\Big|^{approx}$$

$$\frac{\partial \mathcal{H}}{\partial p^i}\Big|^{approx} = \int_{V_{lower}^{refined}(p^i)} \frac{\partial J_{mix}(p^i,q)}{\partial p^i} \phi(q) dq$$





Energy Metric

- Let the energy metric be defined as

$$J(p^1,p^2) = \min \int_0^{t_f} U^T U dt$$

$$\dot{p} = U + \begin{bmatrix} B \\ 0 \end{bmatrix}$$

$$p(0) = p^1, p(t_f) = p^2$$

- Calculation is thus

$$J(p^1,p^2) = 2B(d_{p^1p^2} + x_{p^1} - x_{p^2})$$

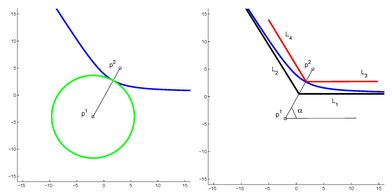
Closing the loop

Solutions to problems such as this require an approach that considers reliable sensing, fast computation and safety verification. Our approach utilizes Kalman filter based localization algorithms to facilitate calculating Voronoi partitions and autonomously deploying drifters (to detect salinity intrusion). Safety verification blocks can be inserted to controller models to ensure parameters for the controller are within the safety range. In addition, low-level event based control has been studied to ensure the safety of drifters.

Energy-Based Voronoi Partitioning

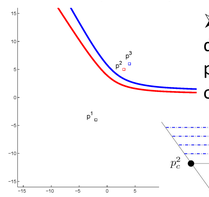
Voronoi Cells and Approximations

- Lower bounds are obtained with a disc , and are coupled with asymptote-based upper-bounds for neighbors

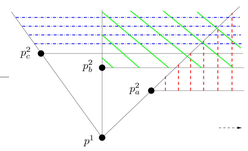


Dominance

- Given p^1, p^2, and p^3, it is not necessary to compute V(p^1)

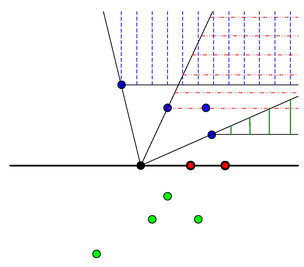


- Given p^1 and different locations of p^2, dominance regions of p^2 are highlighted



Upper Bound on Neighbors

- Upper bound on Voronoi neighbors of p^1: the set of points that are not dominated by any other point



Putting Water Online

A demonstration of 100 floating self-contained sensors for river environments was conducted in the Sacramento River near Walnut Grove, CA on May 9, 2012.

The mixed fleet of active (self-propelled) and passive (purely floating) sensors was deployed from a dock and retrieved by boat after four hours. The active sensors used their propulsion to avoid obstacles and navigate the junction between the Sacramento River and the Georgiana Slough.

The propulsion feature allows the floating sensors to stay safe without human supervision as well as to distribute themselves across the network of channels in order to fulfill sensing objectives.

100 sensors, ready to deploy.

Deploying a sensor

Retrieving sensors downstream.

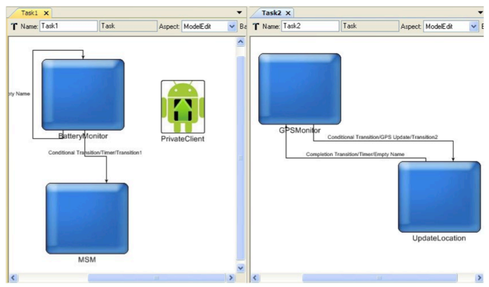
Visit http://float.berkeley.edu/news for news coverage and listings.

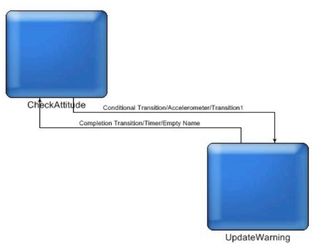
Photos credit: Berkeley Lab - Roy Kaltschmidt

Model-Based Software Synthesis

- Approach utilizes elements of a drifter's modal controller to provide a modeling environment to synthesize Android code that monitors the health and behavior of a drifter
- As many parallel states as desired can be modeled, and easily integrated into the standard controller, also implemented in Android.

- Example (right): design a parallel state model that will send warning messages via SMS to an observer, if the battery state of the device drops below 10%. The SMS should be made up of the last estimated GPS location, and battery state percent.





- Model to send a warning SMS if the device flips over.

Outreach and Broad Impact

- Sponsored a capstone engineering project at Univ. of Arizona. The project developed control algorithms and hardware for a Micro Air Vehicle, and the vehicle placed 1st, "Indoor Autonomy - Fixed Wing" at IMAV 2012.
- UA results in reachability were adapted to demonstrate how a new kind of thermostat that used cost (instead of temperature) as a set point could be built. This idea was recently funded as an NSF I-Corps Project (IIP-1249175), and has spawned Acomni, LLC.

More Reading

1. Y. Ru and S. Martinez, "Energy-based Voronoi partition in constant flow environments", submitted to IEEE Transactions on Automation Science and Engineering, 2011. http://arxiv.org/abs/1111.0071
2. Y. Ru and S. Martinez, "Coverage control in constant flow environments based on a mixed energy-time metric", to appear in IEEE Conf. on Decision and Control, 2012.
3. A. Tinka, M. Rafiee and A.M. Bayen. "Floating sensor networks for river studies" *IEEE Systems Journal*. To appear, available at http://dx.doi.org/10.1109/JSYST.2012.2204914
4. J. Sprinkle. "Teaching students to learn to learn mobile phone programming." In Proceedings of the compilation of the co-located workshops on DSM'11, TMC'11, AGERE!'11, AOOPES'11, NEAT'11, & VMIL'11, pages 261-266, 2011.

Access poster and papers here:

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