# RESEARCH STATEMENT

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My research interests span the areas of Robotics, Artificial Intelligence and Cyber-Physical Systems. In particular, my research is focused on devising minimalist solutions to problems that involve sensing, actuation, communication and computation. Examples of such problems are navigation, patrolling, and coverage, and localization for mobile robots and tracking moving agents. My research involves a substantial experimental component where ideas and algorithms are validated through physical deployments.

## Background and Current Work

Robotics and Cyber-Physical Systems (CPS) hold the promise to make a major impact in diverse segments of society such as health care, automotive and aeronautical industry, agriculture, energy systems and security. It has been identified by the President's Council of Advisors on Science and Technology (PCAST) as a top priority for research investment [6]. At the core of many CPS applications is the ability to challenged environments.

Advances in technology have allowed systems to be equipped with powerful sensors, complex actuators, computers with high processing capabilities, and high-bandwidth communication links. This trend has enabled the development of sophisticated systems and algorithms to solve tasks such as navigation, patrolling, coverage, localization, and tracking. However, these systems have to deal with issues such as dynamical system identification, significant sensor calibration and computation of powerful filters for state-feedback plans.

My research proposes novel techniques for tackling the above mentioned tasks that depart from traditional approaches given that they do not require system identification, geometric map building or state estimation.

### Solving Robotic Tasks in Resource Constrained Environments

We are interested in scenarios where traditional sensors such as vision, magnetometers, and GPS are denied. In these cases, we have to rely on robots with limited sensing and actuation, minimal onboard processing, moderate communication, and insufficient memory capabilities.

We start by investigating a robot with limited linear and angular sensing capabilities as a basis for investigating the intrinsic limits of the localization problem. We focus on a setup that considers a known polygonal environment with obstacles and a robot equipped only with a clock and contact (or bump) sensor. Can this bouncing robot be globally localized without even knowing its initial configuration? Using our setup, we have presented a global localization method for this bouncing robot [2]. We synthesize finite automata-based combinatorial filters from discrete limit cycles for the robot localization that take less computation time and space compared to Bayesian filter-based localization approaches.

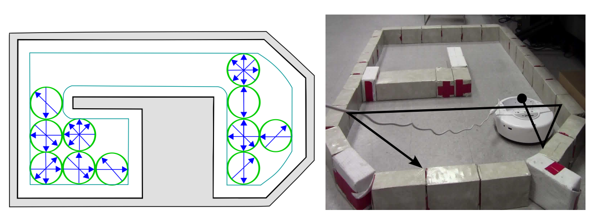


Figure 1: Localization from limit cycles

Once the localization is solved, we were interested in solving common robotic tasks such as navigation and coverage with this simple robot. The proposed solution for the bouncing robot [**?**] finds a navigation plan with limited sensing and also combines probabilistic paths from several bouncing policies of the robot optimally so that the actual coverage distribution can become as close as possible to a desired coverage distribution.

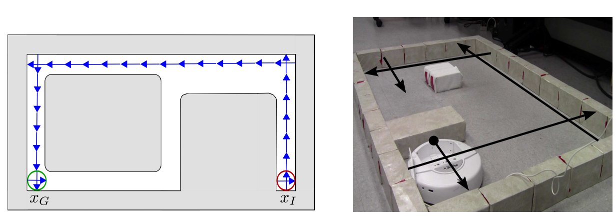



Figure 2: Bouncing-based navigation

We tried to extend this in multi-robot settings to solve coverage and persistent monitoring tasks. Multiple robots have the advantage that they can cover an environment more quickly and can also increase the robustness through redundancy. However, the hardness comes through dealing with robot-robot collisions and a high dimensional state space. We also consider that some regions of the environment may be more important than others. We have proposed an approach that finds a joint trajectory for multiple robots to visit all the locations of an environment and also generates cycles for the robots to persistently monitor the target regions in the environment [1].

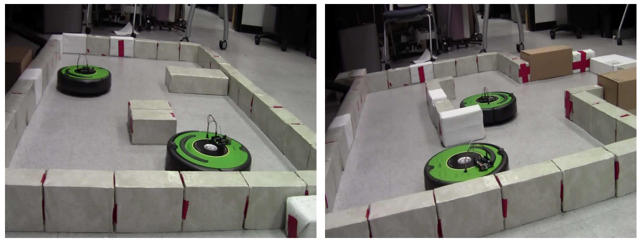


Figure 3: Coverage and persistent monitoring experiments

**Planning in Communication Constrained Environments**

In one of my group's research thrusts, we focus on efficient mission planning for autonomous vehicles in *communication constrained* environments. This problem arises when a number of autonomous vehicles are scattered in an environment cluttered with obstacles and try to achieve a set of goals through collaboration among themselves. The initial location of the robots and their paths have central importance for optimal communication that helps to accomplish their task. The motivating scenarios of this work is real world problems such as surveillance, construction, military missions.

One potential weakness of multi-robot vehicle systems is that the communication between vehicles and humans can be interrupted and degraded due to several factors, including involuntary movements, out of range locations, physical obstructions, atmospheric conditions, electromagnetic interference, and adversarial attacks (e.g jamming and sniffing). In order to overcome these issues, our research focuses two directions: 1) Communication connectivity Preserving and Replanning using Line-of-Sight Communication and 2) Communication Aware Mapping.

In the first part, we have used Line-of-Sight (LoS) to establish communication between Autonomous Vehicles. This form of communication is harder to jam or intercept because a potential attacker would need to physically interrupt the communication line between sender and receiver. In this research thrust, we have: 1) study centralized and distributed algorithms to verify whether the LoS based robot network is connected; 2) proposed techniques that can repair connectivity by relocating one or more vehicles; and 3) study the computational complexity of this class of problems and propose approximated procedures to calculate suitable paths for the robots. In the second part, we have investigated how to build communication aware world maps and how to integrate them effectively into traditional world models. This is motivated by scenarios mobile unit needs to perform surveillance in a partially known environment controlled by a remote operator and a relay robot vehicle moves from place to place as needed for the purposes of establishing and keeping the connection between the operator and the autonomous robot. In such scenarios, the optimal placement for the relay robot depending on the operator and the unit locations needs to be computed.

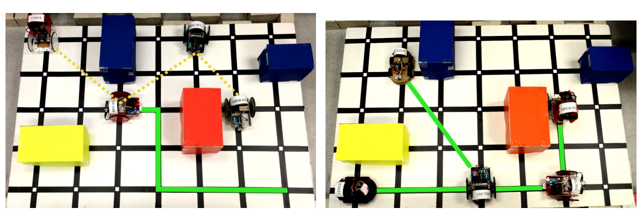
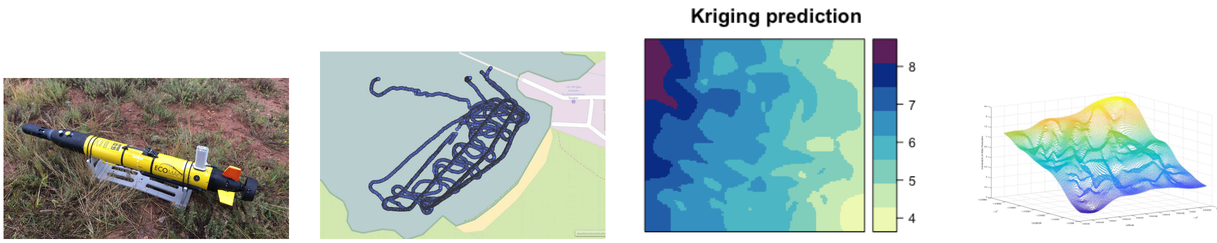


Figure 4: Communication relays in chain and tree arrangements

Videos and more detail on this work can be found in and the websites `http://users.cis.fiu.edu/~jabobadi/relaynetwork/` and `http://users.cis.fiu.edu/~jabobadi/visibilitynetwork/`.

**Underwater Localization in GPS denied environments**

My research group and our collaborator Ryan Smith from Fort Lewis college have tackled the problem of localization in aquatic environments.




(a) (b) (c) (d)

Figure 5: The YSI Ecomapper AUV used to collect data and to be used in the localization experiments is shown in (a); (b) shows a trajectory executed in one of the deployments at Big Fisherman's Cove in Santa Catalina Island, USA; in (c) a prediction of the terrain map using interpolation method is shown; and (d) shows a scalar field consisting of a combination of depth and chemical properties of the water that will be used as a map.

The dynamics of the ocean coupled with reduced communication capabilities complicates the localization and navigation of underwater vehicles. Another challenge comes from the time scale of the task since the study of some ocean processes requires monitoring over long periods of time (weeks to months). Ideally, persistent monitoring can be executed with minimal surfacing (for location updates) and no deviation from their trajectory. To accomplish this, underwater vehicles should remain submerged without expending energy in communication and surfacing.

We proposed augmenting terrain-based representations (bathymetry maps) that combines scientific and bathymetric (depth data) with a linear weighting schema that maximizes the contrast of the resulting map. The methodology proposes also interpolation and extrapolation for constructing maps in the entire survey area.

Once these maps are created, we attempt to solve the mobile robot localization problem (determining the robots configuration (position and orientation) in its environment. This is a fundamental problem and a prerequisite other robotic problems. Given a map and a list of observations collected by the robot, we want to narrow down the set of possible locations efficiently without GPS information. We have proposed global localization algorithms that converge to a localized trajectory with low errors.

Videos and more detail on this work can be found in [8, 7]

## Research Philosophy

I strongly believe that in Robotics and Cyber-Physical Systems, application and theory should advance hand-in-hand. In my experience, physical deployments not only validate our algorithms and theoretical ideas, but can also point out directions where theoretical understanding is lacking and needs to be deepen. Robotics research draws from different disciplines beyond the traditional boundaries of Computer Science and I have enjoyed building strong collaborations with other departments as a part of my research agenda. undergraduate and graduate students have also contributed to our research ideas and I enjoyed the research mentoring process.

# References

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