CPS: Medium: Collaborative Research: Remote Imaging of Community Ecology via Animal-borne Wireless Networks

PIs: Naomi Leonard(Princeton U.), Greg Marshall(NGS), and Nuno C. Martins(U. of Maryland)
Key Collaborators: Kyler Abernathy(NGS), Konrad Aschenbach(NGS), and Barret Foster(NGS)

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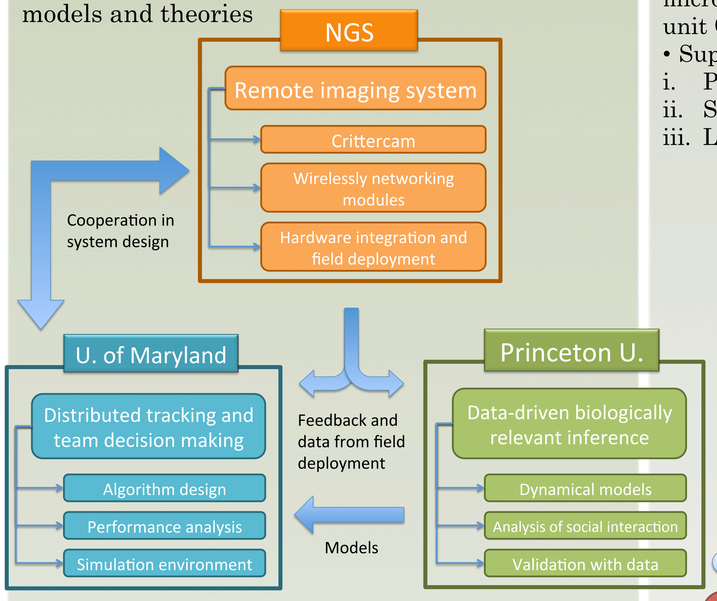
Award No. 1135726

Objectives

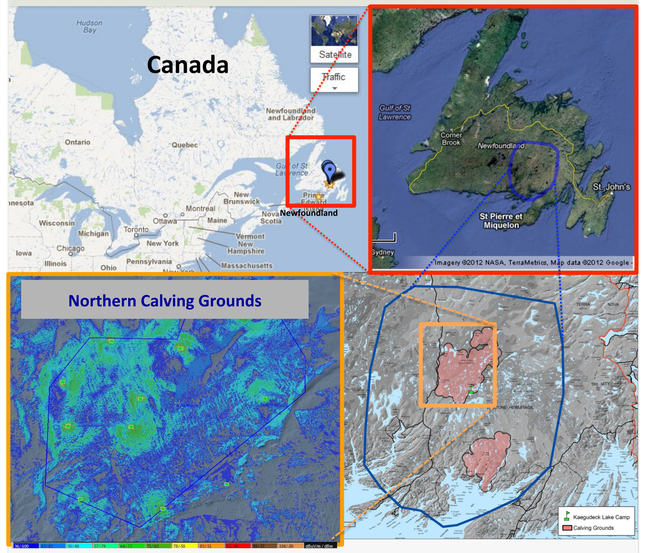
• Development of a wireless network of animal-borne embedded devices to record biologically relevant video, geo-location, and other sensor data
• Deployment of the developed system in Newfoundland (Canada)

Research Themes:

• Design of animal-borne wireless networks considering battery-life constraints
• Algorithmic approach to distributed team problems under communication and computation limitations
• Data-driven biologically relevant inference: models and theories



Collaboration Diagram



Newfoundland (Canada)

Bottom left picture shows a wireless coverage maps by 10 fixed relays (obtained by a RF terrain analysis tool).

Remote Imaging System

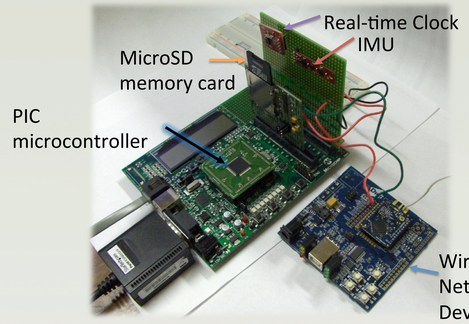
Development of a wireless network of animal-borne embedded devices
• Integration of Crittercam technology with wirelessly communicating sensing modules
• The system captures biologically relevant video, geo-location, and other sensor data

Selective Video Recording (with Crittercam):

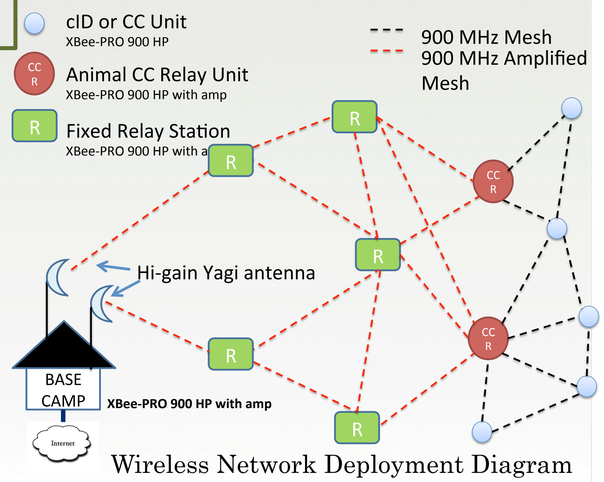
• Development of a strategy that selectively records video to save memory and battery-life.

Wireless Communication Sensing Module:

• Integration of a communication module with PIC microcontroller, GPS, camera, inertial measurement unit (IMU), real-time clock, and memory card.
• Supports mesh networking protocols:
i. Peer-to-peer architecture
ii. Self-healing capabilities
iii. Low power consumption



Module Integration



Wireless Network Deployment Diagram

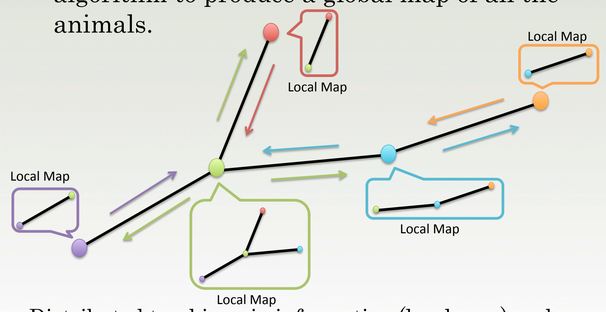
Education and Outreach

One of the primary goals of the project is to create undergraduate research opportunities and to interact with public of all ages
• Cooperating and mentoring 1 post-doctoral researcher and 4 graduate, 3 undergraduate, and 1 high school students
• Academic Collaborators: Ryan Kastner (UCSD) and Michael Young (GMU)

Distributed Algorithms

Distributed Tracking:

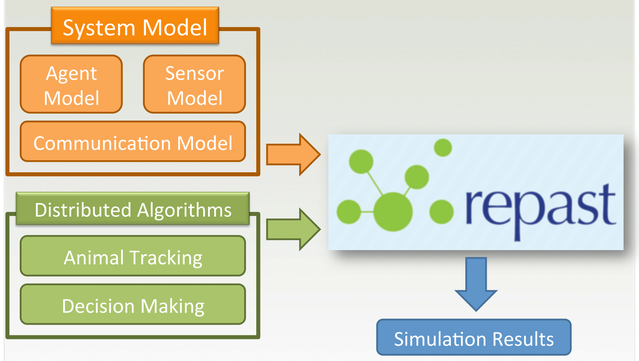
• Challenge: real-time tracking of all the animals under communication and computation constraints
• Approach: The algorithm seeks to merge sensor readings:
i. Each sensor, mounted on an animal, computes a local map of nearby animals.
ii. The local maps are exchanged and fused by the algorithm to produce a global map of all the animals.



Distributed tracking via information (local map) exchange

Multi-agent Simulator

Development of a simulator for testing and verifying distributed algorithms.
• Main feature: incorporates system models (both from experiments and theoretical studies) with distributed algorithms to produce simulation results
• The simulator is built on Repast (agent-based modeling and simulation system)

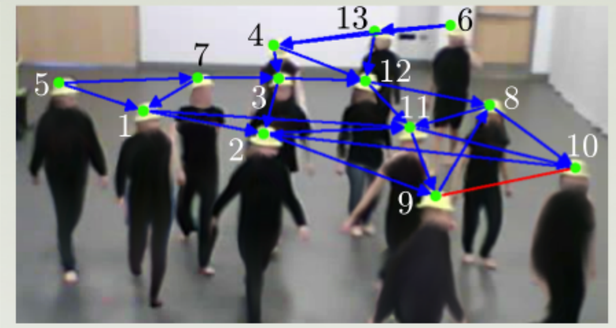


Multi-agent Simulator

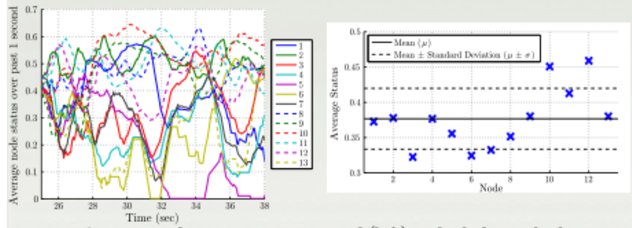
Models and Theories for Collective Motion

Quantifying Information Centrality (in a network of decision-making units):

• Derived a certainty index to capture information centrality
• Based on the index, we studied the effect of noisy environmental signal to group's steady-state variance (about the correct value of the signal)
• Preliminary experimental results has been conducted in a dance studio (Leonard et. al, ACC 2012)



A video frame and sensing graph



Average node status over 1 second (left) and whole tracked period (right): node status is used to infer emergent leaders.

A Framework for Motion Dynamics:

• Developed a dynamical model for a predator (bear) and preys (mother-calf pair)
• Studied the effect of evasion from the bear on separation of the mother and calf.
• Theoretical study is ongoing in formalizing the results and exploring connections with differential game theory.

Future Plans

• Continue developing and implementing the autonomous selective video recording strategy.
• Recon field site in Newfoundland (NL) to guide plans for pilot system deployment
• Design algorithms for distributed team decision making and analyze its performance
• Incorporate system models (both from the hardware experimentation and theoretical study on motion dynamics) into the multi-agent simulator
• Continue investigating the dynamical model for predator-preys

Publications

• N.E. Leonard, G. Young, K. Hochgraf, D. Swain, A. Trippe, W. Chen, and S. Marshall, "*In the dance studio: Analysis of human flocking,*" in the American Control Conference, June 2012.
• I. Poulakakis, L. Scardovi, and N. E. Leonard, "*Node Classification in Collective Evidence Accumulation toward a Decision,*" to be published in the IEEE Conference on Decision and Control, Dec. 2012
• Shinkyu Park and Nuno C. Martins, "*Necessary and Sufficient Conditions for Stabilizability of a Class of LTI Distributed Observers,*" to be published in the IEEE Conference on Decision and Control, Dec. 2012.