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

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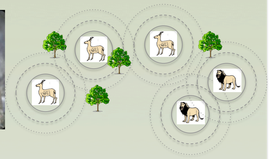
ENG

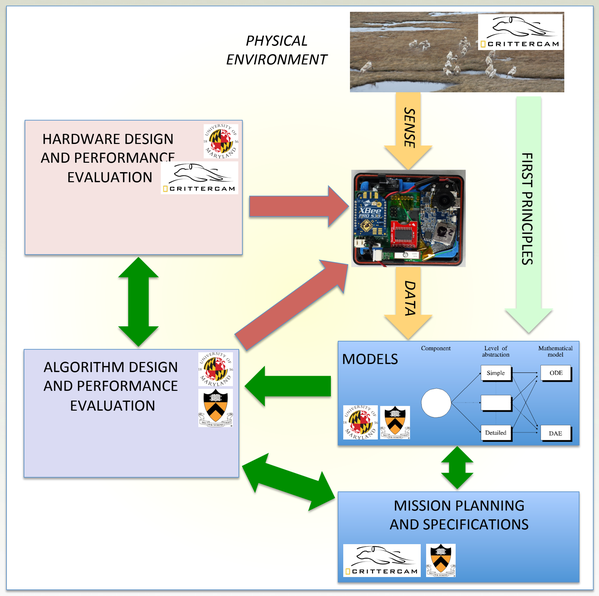
Award No. 1135726

Research Goals

- Cooperative data collection and data-driven statistical modeling to extract animal group behaviors of sociobiological significance
- Team-decision strategy design to optimize system performance
- Development of a test-bed to validate and foster the development of new model-based principles for the design of power-constrained networked CPS

High definition video recording
Onboard processing capabilities



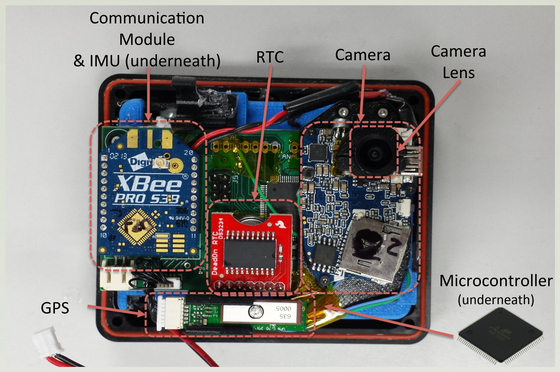


Project Anatomy

Remote Imaging System

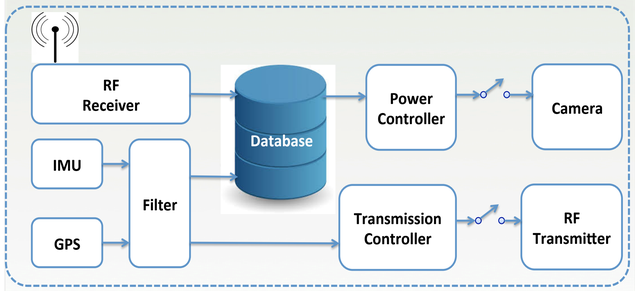
New System Design and Integration

- New circuit board design enables reduction in the size and weight of animal-borne tracking devices
- New system will allow the study of smaller but important animals such as coyotes, lynx, and foxes



New Firmware Design

1. Online parameter estimation of animal motion models
2. Adaptive control of sensing and communication rates based on activity and battery levels
3. Event and time-based camera power control



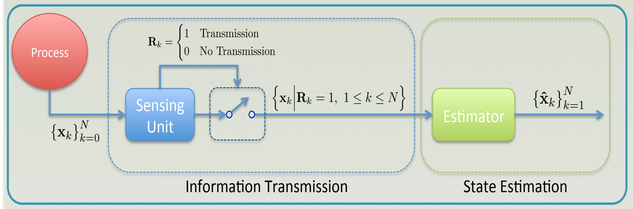
Firmware Architecture

Distributed Algorithms

Optimal Remote State Estimation for Self-Propelled Particle Models

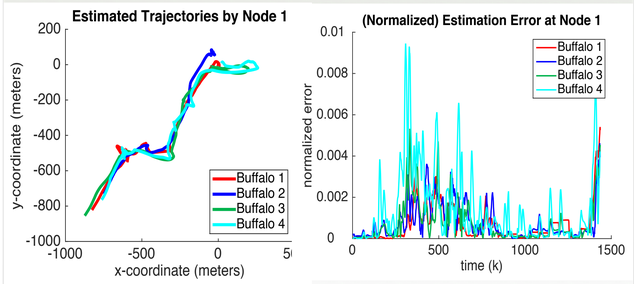
- Key features:

1. Specifies when to share sensor measurements so as to balance the cost of communication and the variance of the estimation error.
2. Applicable to a wider class of animal motion models compared to existing methods



Distributed Estimation for State Omniscience

- Improvement in complexity of the algorithm: the average size of its update rule does not depend on the size of the underlying communication network
- Verification of the algorithm with the dataset obtained from the Mozambique deployment

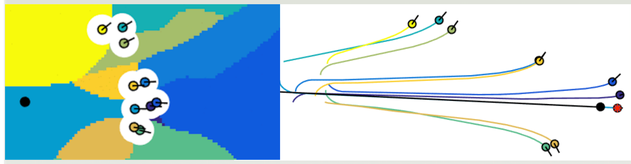


Estimated trajectories and estimation error

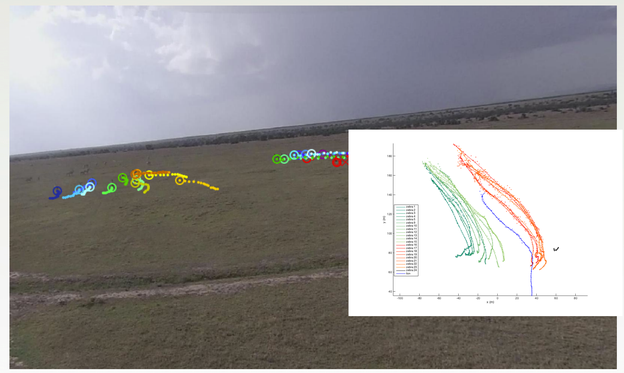
Models and Theories for Collective Motion

Pursuit and Evasion Strategies

- Model evasion strategies and dynamics of heterogeneous herds to account for key constraints on speed, turning rate, and lateral acceleration
- Derive optimal strategies for predator and evaders with constraints using differential game theory with time-to-capture as payoff
- Domains of danger depend on relative positions and relative headings: an evader that keeps the pursuer from entering its domain of danger will not become a target and can avoid capture
- Analysis of 17 video data sets of zebra herds in Kenya evading a remotely controlled robo-lion provide data for model development



Domains of danger and trajectories from new model

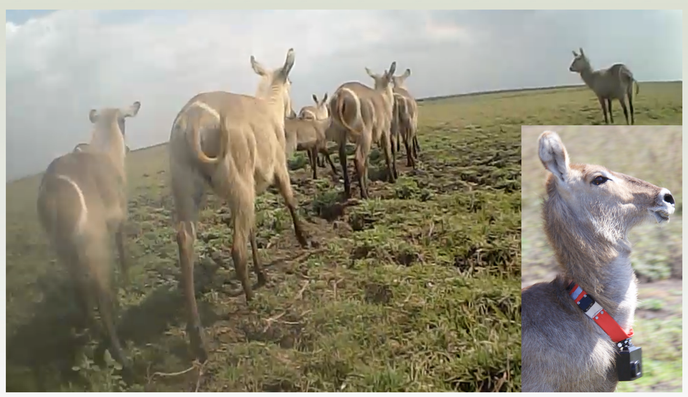


Analysis of video data from zebra experiments

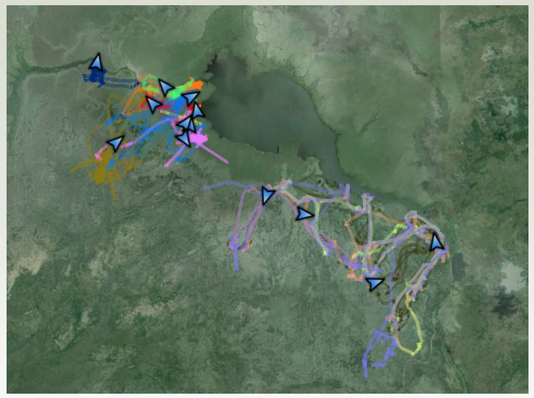
System Deployment and Data Collection:

2nd deployment in the Gorongosa National Park (Mozambique) in August 2016 (3rd deployment overall)

1. 29 devices were deployed on waterbucks and water buffaloes
2. Successfully tested improved hardware, algorithms and software.



Animal Point-of-View Screenshot



GPS Data Visualization

Future Plans

- Improvement of the software to calibrate the devices for deployment.
- Plan for a new final (fourth) deployment.
- Analysis of the dataset obtained from the deployment and development of collective mobility models.
- Use data from the latest deployment to analyze the performance of the overall network in terms of longevity, power consumption and reliability.

Education and Outreach

- Dr. Shinkyu Park defended his Ph.D. dissertation and is now a postdoctoral researcher at MIT
- Dr. Konrad Aschenbach completed is now working for Proteus Digital Health, Inc.
- We have hired a new M.S. student to work on improvements in the hardware/software and also assist in the deployments and performance analysis.

Publications

- S. Park and N. C. Martins, "Optimal Remote State Estimation for Self-Propelled Particle Models," IEEE CDC, to appear
- W. L. Scott and N. E. Leonard, "Time-Optimal Trajectories for Steered Agent with Constraints on Speed and Turning Rate," 2016 ASME Dynamic Systems and Control Conference, to appear
- K. E. Fitch and N.E. Leonard, "Joint Centrality Distinguishes Optimal Leaders in Noisy Networks," IEEE Transactions on Control of Network Systems, to appear
- K.E. Fitch and N.E. Leonard, "Optimal Leader Selection for Controllability and Robustness in Multi-Agent Networks," European Control Conference, 2016
- K. E. Fitch, Optimal Leader Selection in Multi-Agent Networks: Joint Centrality, Robustness and Controllability, PhD Thesis, Princeton, 2016
- I. Poulakakis, G. F. Young, L. Scardovi, and N. E. Leonard, "Information Centrality and Ordering of Nodes for Accuracy in Noisy Decision-making Networks," IEEE Transactions on Automatic Control, vol 61, no 4, p. 1040-1045, 2016
- M. M. Vasconcelos and N. C. Martins, "A Survey on Remote Estimation Problems," Principles of Cyber-Physical Systems: An Interdisciplinary Approach edited by S. Roy and S. Das, Cambridge University Press, to appear
- S. Park and N. C. Martins, "Individually Optimal Solutions to a Remote State Estimation Problem with Communication Costs," IEEE Conference on Decision and Control, 2014
- S. Park and N. C. Martins, "Design of Distributed LTI Observers for State Omniscience," to appear in the IEEE Trans. on Autom. Control
- S. Park, "Distributed Estimation and Stability of Evolutionary Game Dynamics with Applications to Study of Animal Motions," PhD Dissertation, U. of Maryland, 2015