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

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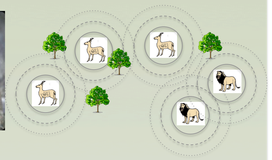
ENG

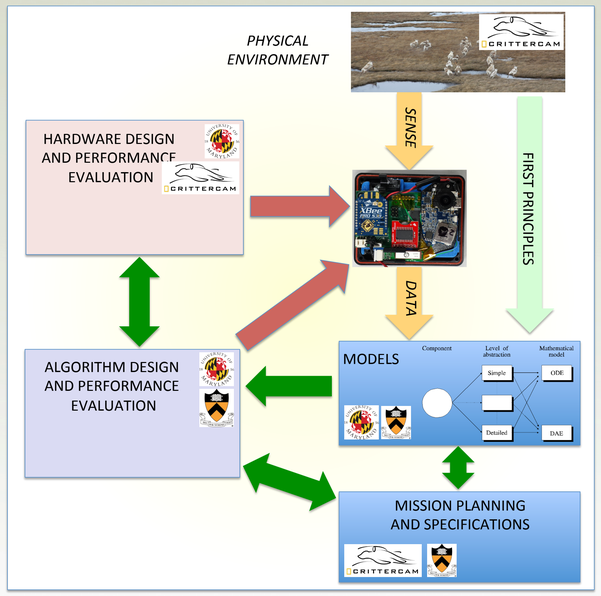
Award No. 1135726

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



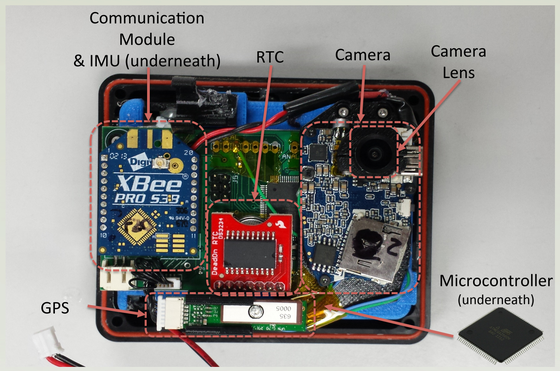


Project Anatomy

Remote Imaging System

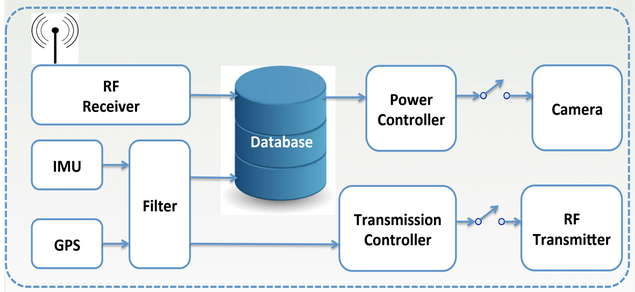
New System Design and Integration

- 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



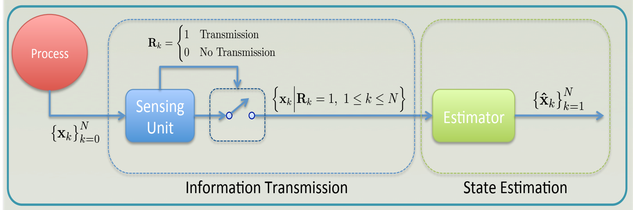
Firmware Architecture

Distributed Algorithms

Optimal Remote Estimation

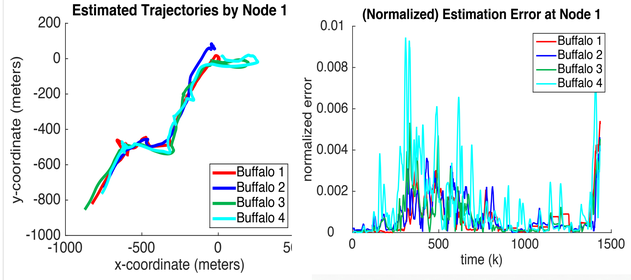
- Design of an optimal remote tracking algorithm for Markov processes
- Key features:

1. Specifies when to share sensor measurements and how to determine the best location estimates
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

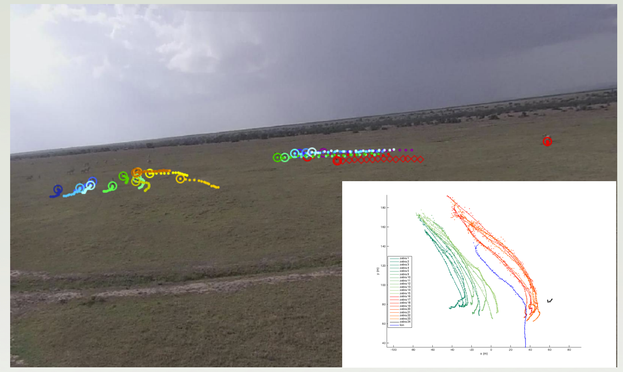


Estimated trajectories and estimation error

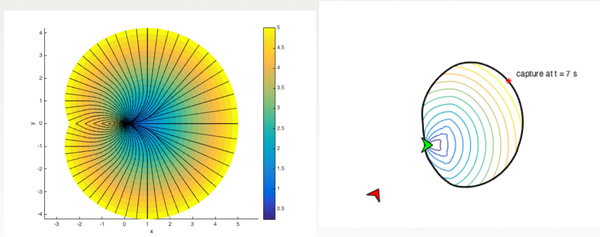
Models and Theories for Collective Motion

Data-driven Modeling of Pursuit and Evasion

- Field experiments to capture interactions between a zebra herd and a robo-lion
- Analysis of video data from the experiments to develop a new model for pursuit and evasion: the model takes physical constraints on speed, turning rate, and lateral acceleration of animals into consideration
- Examination of efficacy of the new model in a game theoretic setting



Analysis of video data from the experiments

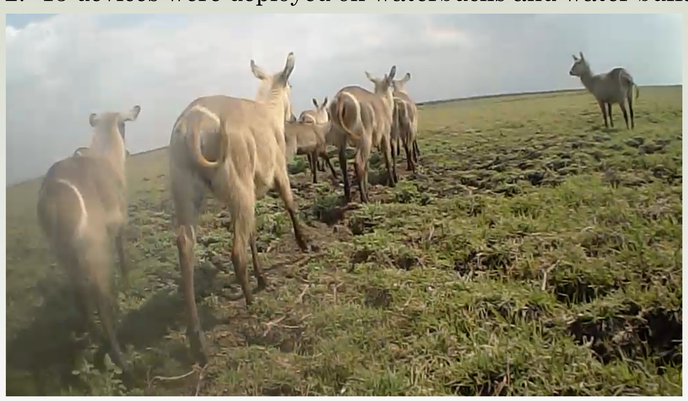


A new model for study of pursuit and evasion

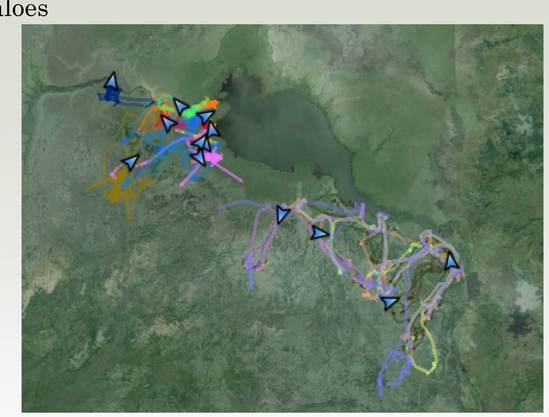
System Deployment and Data Collection:

- Deployment in the Gorongosa National Park (Mozambique) in August 2015

1. Collaboration with Pringle's research group
2. 15 devices were deployed on waterbucks and water buffaloes



Animal Point-of-View Screenshot



GPS Data Visualization

Future Plans

- Improvement of the current firmware architecture
- Analysis of the dataset obtained from the deployment and development of collective models for water buffaloes
- Design of optimal cooperative strategies for event detection based on established models

Education and Outreach

- Cooperating and mentoring 1 post-doctoral researcher, and 2 graduate and 2 undergraduate students
- ARDUINO-based architecture enables the effective integration in undergraduate projects
- Deployment in the Gorongosa National Park to monitor waterbucks and water buffaloes.

Publications

- W. L. Scott and N. E. Leonard, "Dynamics of Pursuit and Evasion in a Heterogeneous Herd," IEEE Conference on Decision and Control, 2014
- N. E. Leonard, "Multi-agent System Dynamics: Bifurcation and Behavior of Animal Groups," IFAC Annual Reviews in Control, 2014
- K. E. Fitch and N.E. Leonard, "Joint Centrality Distinguishes Optimal Leaders in Noisy Networks," IEEE Transactions on Control of Network Systems, to appear 2015
- V. Srivastava and N. E. Leonard, "On First Passage Time Problems in Collective Decision-making with Heterogeneous Agents," American Control Conference, 2015
- 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, to appear March 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," submitted for journal publication
- S. Park, "Distributed Estimation and Stability of Evolutionary Game Dynamics with Applications to Study of Animal Motions," PhD Dissertation, U. of Maryland, 2015