

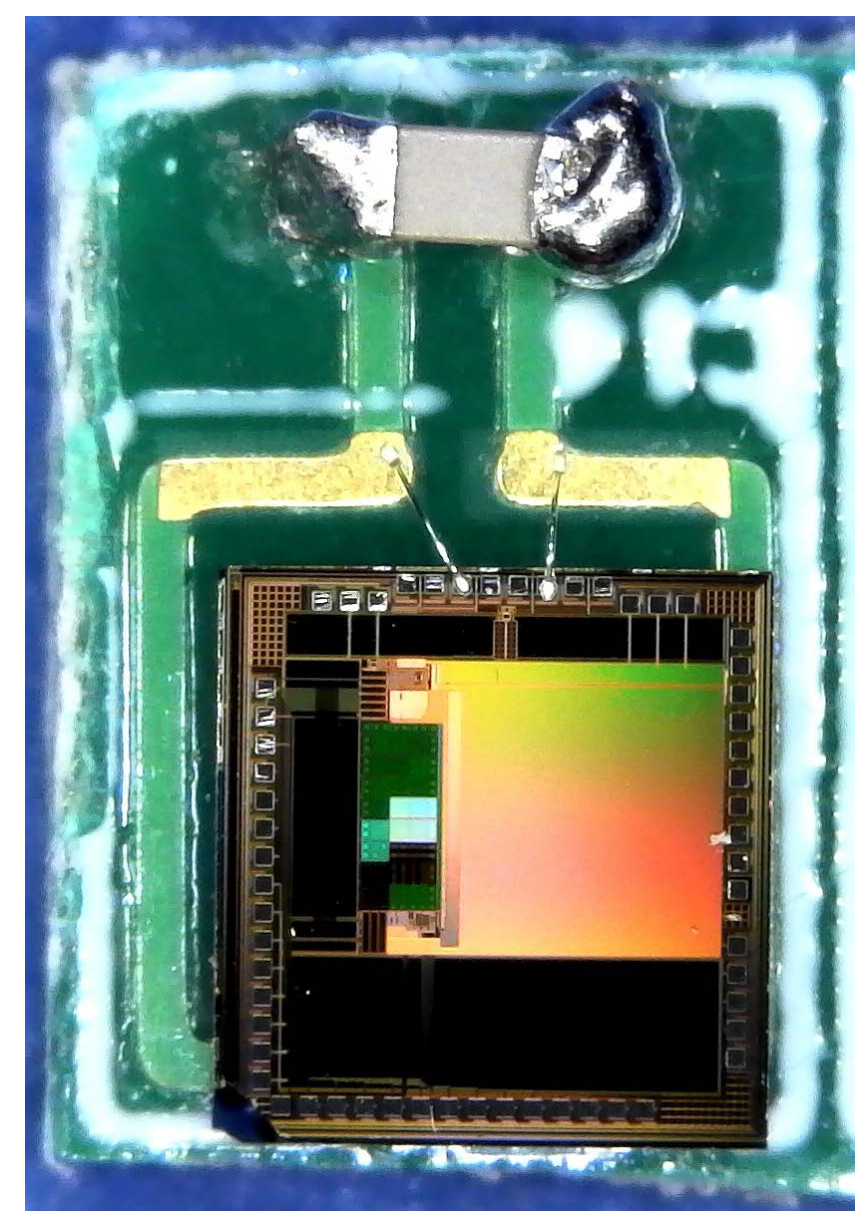
CPS: Medium: Leveraging Honey Bees as Bio-Cyber Physical Systems

Kirstin Petersen and Alyosha Molnar, Electrical and Computer Engineering, Cornell University
<http://cei.ece.cornell.edu/research/honey-bees/>

Can we improve upon the ability of social insects to sense and interact with the physical world, while providing data acquisition and control on par with explicitly engineered systems?

Approach: Attach miniature, ultra low-power flight recorders to the back of managed honey bees and leverage their collective foraging patterns to reason about noisy, low-resolution outputs related to bust and bloom in agricultural fields.

FLIGHT RECORDER



Intellectual Merit: Ultra-low power sensors

The flight recorder includes...

- Optical detection of solar angle of incidence
- Analog to digital conversion
- Clock, storage, and processing
- Photovoltaic power supply



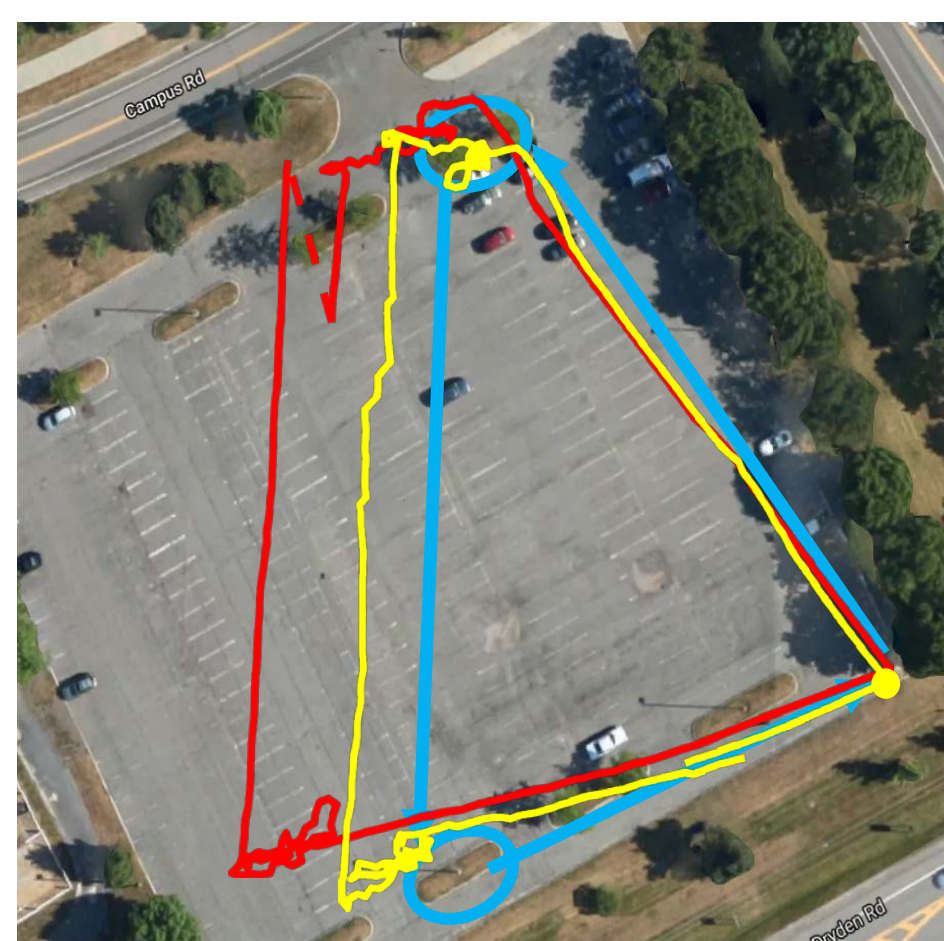
Entrance reader...

- Backscatter communication
- 15mm range

"An Autonomous, Optically-Powered, Direct-to-Digital Sun-Angle Recorder for Honey Bee Flight Tracking," in IEEE Transactions on Circuits and Systems II: Express Briefs.

FIELD TESTS

Intellectual Merit: Bio-Hybrid Technologies [paper in progress]



Person walking in parking lot



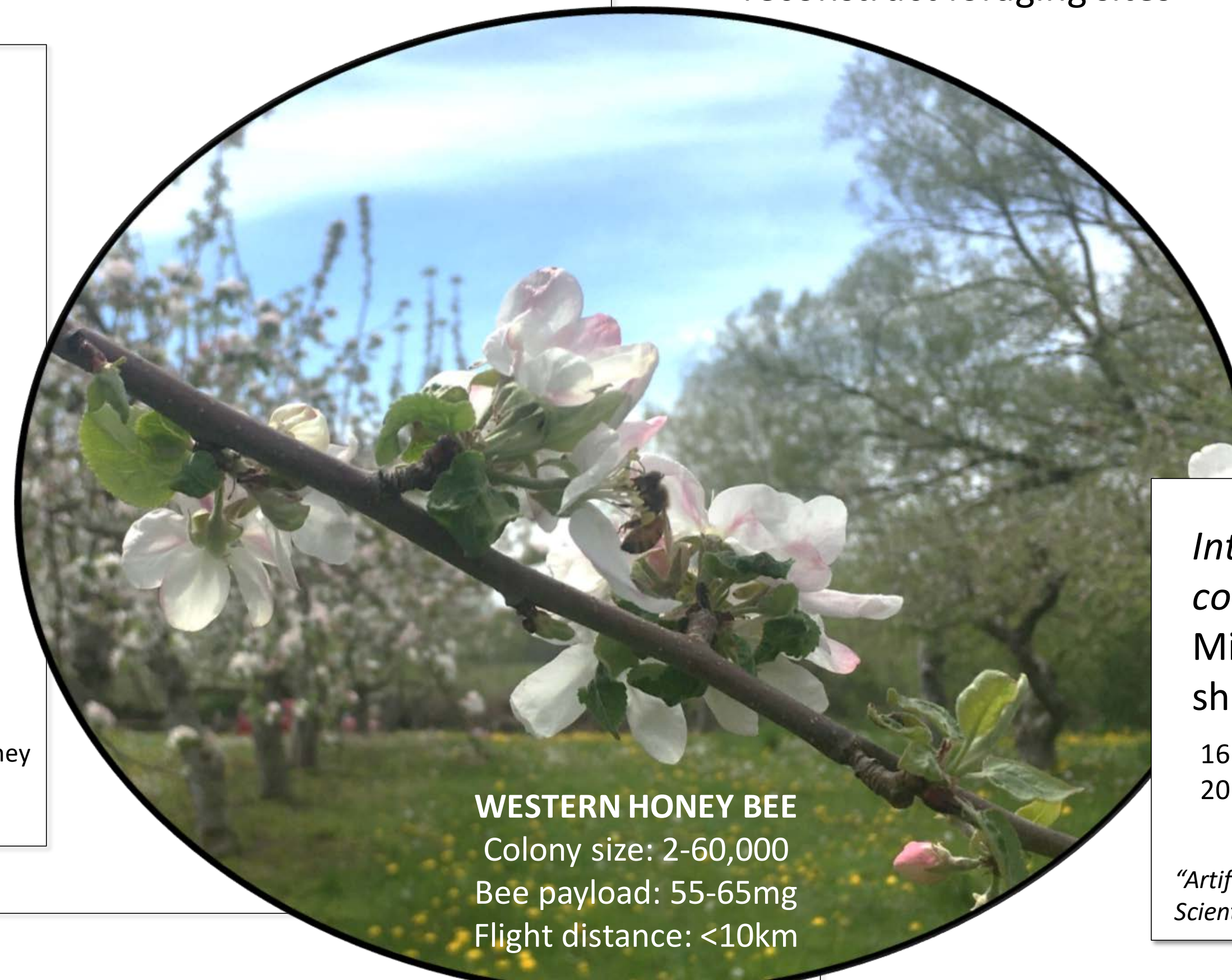
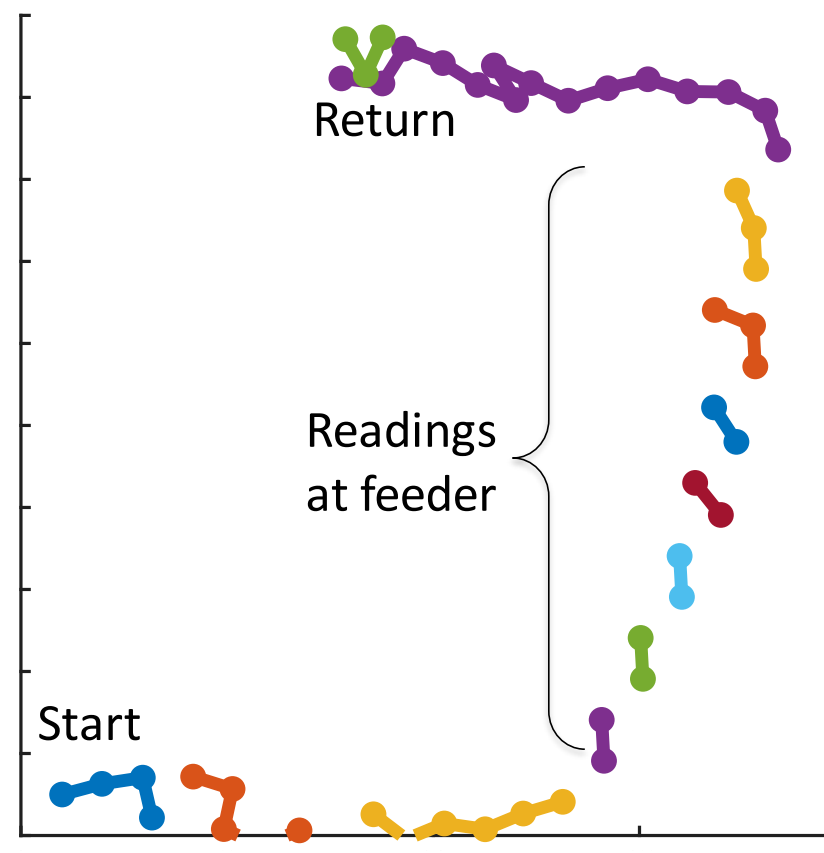
Drones



Bumble bees flying in tunnels (honey bee experiments planned over Summer)



Naive sample reconstruction



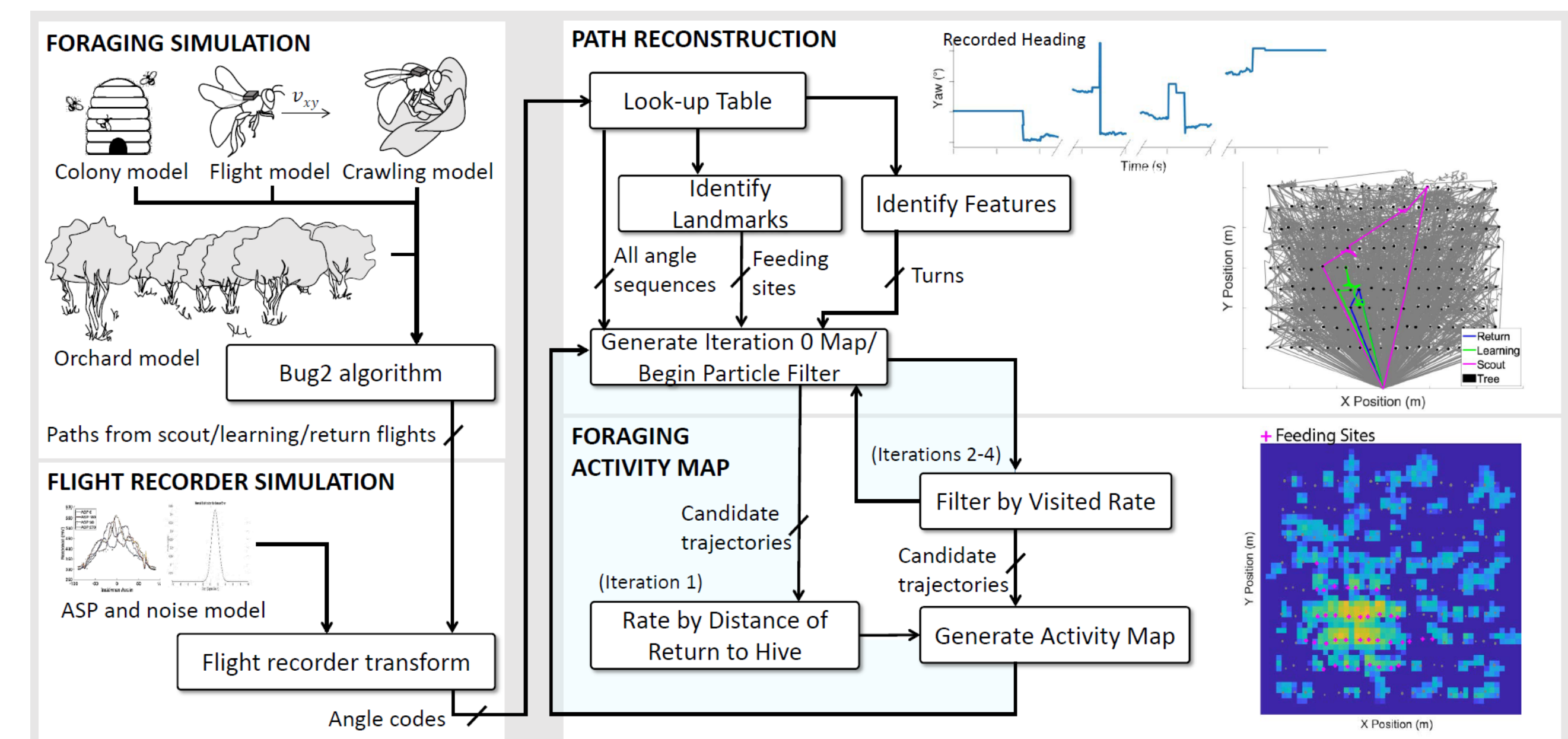
WESTERN HONEY BEE
 Colony size: 2-60,000
 Bee payload: 55-65mg
 Flight distance: <10km

INFERENCE FROM LARGE SENSOR NETWORKS

Intellectual Merit:

Probabilistic inference from large-scale noisy data sources

- Simulation capturing colony, flight, and feeding behavior
- Data-driven sensor model
- Particle filter methods to reconstruct foraging sites



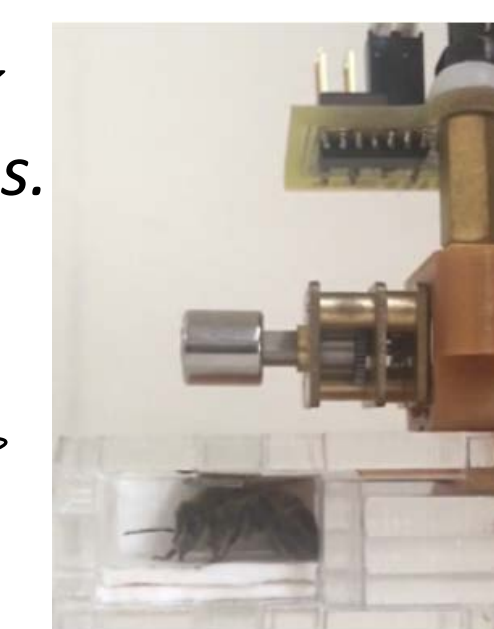
"System design for inferring colony-level pollination activity through miniature bee-mounted sensors", *Sci Rep* 11, 4239 (2021)

FEEDBACK CONTROL

Intellectual Merit: Feedback control of bio-hybrid systems. Mimicking the honey bee shaking signal

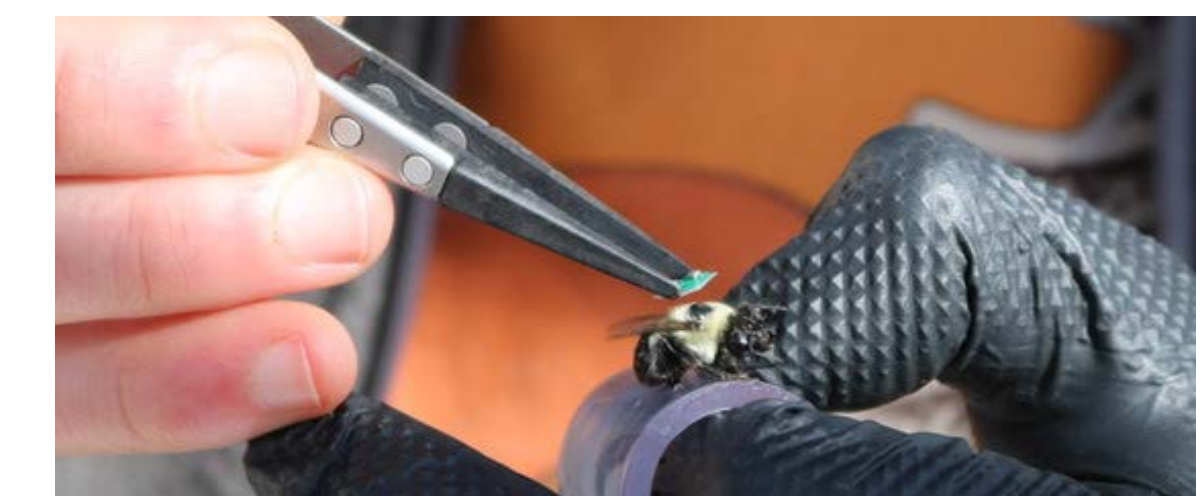
16Hz, 2 sec
 20 times/min

"Artificial shaking signals in honey bee colonies elicit natural responses", *Scientific Reports* 10, 3746 (2020).



INSTRUMENTED BEES

Best practices to instrument bees ... a guide for engineers [paper in progress]



BROADER IMPACTS

- A bio-hybrid system for tracking honey bee pollination activity in fields
- Improved understanding of methods for bio-hybrid systems
- Improved control of pollination and better design of multi-use landscapes
- Gains to apiculture and entomology
- K1-16 outreach events (in person and online)
- Festival exhibits
- Academic seminars and a seminar class

