Cyborg Insect Networks for Exploration and Mapping (CINEMa)

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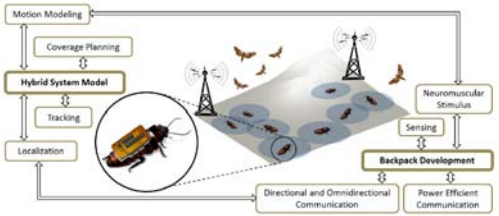
SUMMARY



The present day technology falls short in offering centimeter scale mobile robots that can function effectively under unknown and dynamic environmental conditions. The ultimate goal of this project is to enhance the technological infrastructure for Cyber-Physical Systems by establishing the fundamental physical and algorithmic building blocks of a biobotic swarm and producing a cyber-physical sensor network among the individuals of non-eusocial insects such as cockroaches and moths with an aim of searching and rescuing victims after natural disasters such as earthquakes.

The activities performed during the Year 2 of this project includes:

- development of acoustic and tissue-electrode impedance sensing capabilities and solar-charging for biobot backpacks,
- establishment of a long-term natural and biobotic control platforms inside an anechoic chamber
- investigation of fenceless boundaries and search for acoustic targets with cockroaches *Gromphadorhina portentosa*
- construction of localization & communication infrastructure,
- modeling and controlling collective motion by learning deterministic and stochastic motion models,
- topological motion modeling based on these models,
- experiments with the swarm robotic platform to test the proposed algorithms.

BIOBOTIC INSECT AGENTS

Common name	Hissing Cockroach	Carolina Sphinx Moth
Scientific name	*Gromphadorhina portentosa*	*Manduca sexta*
Size	50-75 mm	40-70 mm
Weight	5-10 g	1-2 g
Payload capacity	5-10 g	1 g
Max Speed	0.03 m/s	5 m/s
Life Span	2 years	4-7 weeks

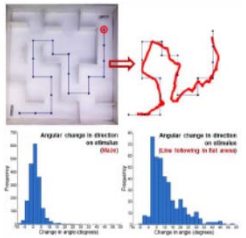
YEAR 2 PUBLICATIONS

1. Verderber A, McKnight M, Bozkurt A(2014). Early Metamorphic Insertion Technology for Insect Flight Behavior Monitoring. Journal of Visualized Experiments. 89 (e50901).
2. Whitmire E, Latif T, Bozkurt A. (2014). Acoustic Sensor Array for Biobotic Search and Rescue. IEEE Sensors Conference 2014. Valencia, Spain.
3. Bozkurt A, Lobaton E, Sichitiu M, Hedrick T, Latif T, Dirafzoon A, Whitmire A, Verderber A, Marin J, Xiong H. (2014). Biobotic Insect Swarm based Sensor Networks for Search and Rescue. SPIE Defense Security and Sensing,. Baltimore, MD.
4. Whitmire E, Latif T, Bozkurt A. (2014). Cyber-physical Network of Terrestrial Insect Biobots. The Government Microcircuit Applications & Critical Technology Conference (GomacTech 2014). Charleston, SC
5. Dirafzoon A, Betthauser J, Schornick J, Benavides D, and Lobaton E (2014). Mapping of Unknown Environments using Minimal Sensing from a Stochastic Swarm. IEEE/RSJ International Conference on Intelligent Robots and Systems. Chicago, IL.
6. Dirafzoon A, Betthauser J, Schornick J, Cole J, Bozkurt A, and Lobaton E (2014). Poster Abstract: Cyborg-Insect Networks for Mapping of Unknown Environments. International Conference on Cyber-Physical Systems. Berlin, Germany.
7. Latif T, Whitmire E, Novak T, Bozkurt A (2014). Towards Fenceless Boundaries for Solar Powered Insect Biobots. 36th International Conference of the IEEE Engineering in Medicine and Biology Society (EMBC'14). Chicago, IL.
8. Betthauser J, Benavides D, Schornick J, O'Hara N, Patel J, Cole J, and Lobaton E (2014). WolfBot: A Distributed Mobile Sensing Platform for Research and Education. Zone 1 Conf of the ASEE. Bridgeport, Connecticut.
9. Dirafzoon A and Lobaton E (2013). Topological Mapping of Unknown Environments using an Unlocalized Robotic Swarm. Intl. Conf. on Intelligent Robots and Systems (IROS). Japan.

BIOBOTIC CONTROL ACHIEVEMENTS

Maze Navigation

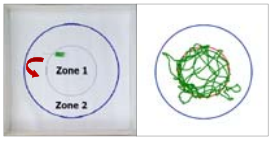
- Addition of walls to line following task
- Able to overcome natural inclination to stop at a wall or corner
- PWM pulse stimulus of 50ms evaluated every 300ms



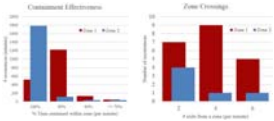
	Maze Navigation	Line Following
Mean angular change	1.5°	11.82°
Median Δangle	1.48°	8.29°
Skewness	0.52	1.99

Fenceless Boundaries (Invisible Fence)

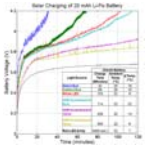
- Containment inside a designated area through directional control
- To establish a distributed network of biobot sensor nodes
- To maintain the position of biobots at certain regions to charge batteries

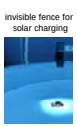


Zone 1: Fence threshold, Zone 2: Buffer zone



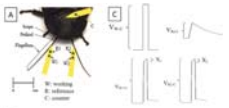
Solar Charging





invisible fence for solar charging

Neural Interface Tracker

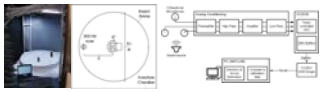


Multichannel PEDOT-PSS coated neural electrode array

Autonomous Sound Localization

- Useful for disaster site mapping
- Sound to identify location of survivors
- Array with three microphones 120° apart
- Amplitude and time-of-arrival localization
- High-throughput data transfer (1.25 kHz)

Biobot backpacks with (left) omnidirectional microphone for audio recording and streaming, (right) Unidirectional microphone array for source localization

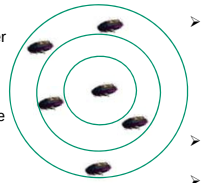


(left) Anechoic chamber used for microphone calibration, (middle) diagram of calibration setup, (right) architecture of sound processing and localization pipeline

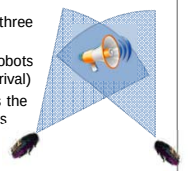
	Microphone Array	Single Microphone
Power consumption (streaming)	0.5 mW	26 mW
Size (mm)	32.5 (l) × 25.0 (w) × 20 (h)	36.0 (l) × 22.5 (w) × 16.5 (h)
Weight (no battery)	3.4 g	1.6 g
Weight (with 2S mAh LiPo battery)	4.1 g	2.3 g
Sampling rate	1.25 MHz	4.00 MHz

POWER EFFICIENT COMMUNICATIONS and LOCALIZATION

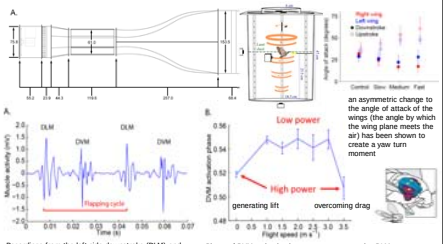
- Always on transceiver too power consuming
- Medium access control (MAC) layer for power efficient communications.
- Low duty cycle communications (<1%)
- Problem: preserving broadcast semantics at very low duty cycles in potentially very dense networks



- Two stage localization of sound sources:
  - Localization from a single biobot (time difference of arrival to the three microphones)
  - Localization from two or more biobots (distributed time-difference of arrival)
- Sound localization relies and informs the localization of the biobots themselves
- Distributed time-difference of arrival relies on precise synchronization
- Power efficiency is the main difficulty for all the tasks involving communications



BIOBOT FLIGHT CHARACTERIZATION



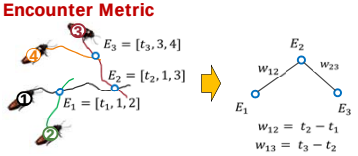
an asymmetric change to the angle of attack of the wings (the angle by which the wing plane meets the air) has been shown to create a yaw turn moment

Recordings from the left side downstroke (DLM) and upstroke (DVM) flight muscles in a hawkmoth biobot. Insects control muscle output via changes in activation timing and frequency, not motor unit recruitment.

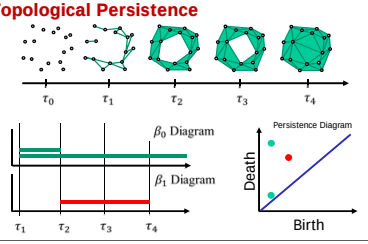
Phase of DVM activation between two consecutive DLM bursts. Changing phase changes the power output of the muscle pair and regulates the moth biobot's overall flight motor.

TOPOLOGICAL MAPPING and EXPLORATION

Encounter Metric



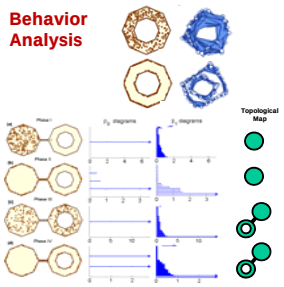
Topological Persistence



Topological Mapping

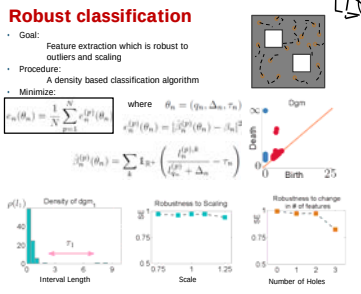
- Limited Sensing
- Agents can record: the IDs of agents near-by & the time of encounters.

Behavior Analysis

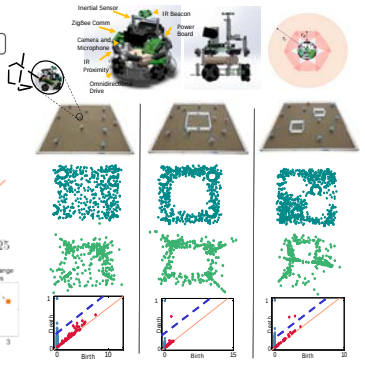


Robust classification

- Goal:
  Feature extraction which is robust to outliers and scaling
- Procedure:
  A density based classification algorithm
- Minimize:



Experiments



YEAR 2 OUTREACH

- Demo during the Society for Advancement of Chicanos and Native Americans in Science (SACNAS) Conference
- Poster presentation during the Science House Imhotep Academy annual presentation day (for 5th to 8th girls from underrepresented communities)
- Several lab tours for high schools and high school teachers
- Hosting 4 high school students as research intern
- Booth during the BugFest organized by the North Carolina Museum of Natural Sciences
- A public lecture on the Windows on the World stage during the BugFest
- A talk under the Science Cafe in the North Carolina Museum of Natural Sciences
- News articles in several prominent media outlets (including Nature News, BBC World News (live interview), NPR (live interview), CNN, Discovery Channel (interview), Newsweek (2 pages dedicated) etc.)
- Research highlighted as a 6 minute video under the Science Channel show Through the Wormhole hosted by Morgan Freeman where the research was explained by Morgan Freeman himself.