A3EM: Animal-Borne Adaptive Acoustic Environmental Monitoring

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Key Problem

- Acoustic monitoring is increasingly being applied to ecological research and wildlife conservation; however, there is a lack of convergence between two concurrent research veins:
  - Increasing the accuracy of Environmental Sound Classification (ESC) using Artificial Intelligence, and
  - Combining AI with ultra low-power microprocessing capabilities
- Additionally:
  - Traditional static sensor units can only monitor a single location at a time limiting their utility, and
  - Animal-borne sensors must be ultra-low power to be used for long-term deployments.

Scientific Impact

- Adaptive resource optimization and embedded machine learning research results are highly applicable to other CPS domains:
  - CPS application areas in which there is insufficient data for training
  - Systems which need to adapt to an unknown environment
  - Severely resource-constrained embedded applications
  - Deployments with dual research-/conservation-based goals
- Newly created methodologies are also applicable to other domains of research, including computer vision and big data management, increasing the likelihood of their general adoption and their intrinsic value to related fields.

Technical Approach

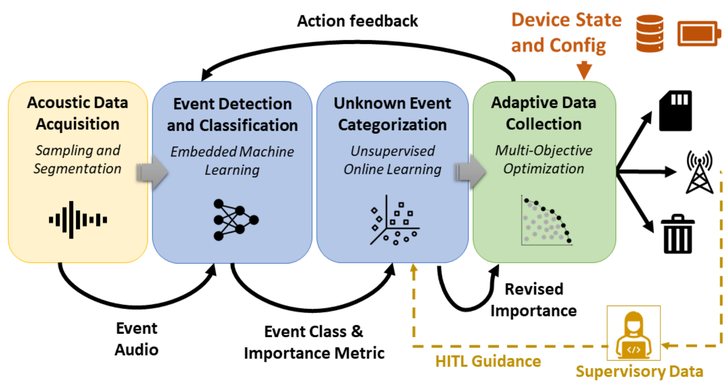
Acoustic Data Acquisition

- Uses a custom, ultra-low-power acoustic sensor board with an Ambiq Apollo4 MCU to allow continuous monitoring for over a year
  - Coupled with a small, on-device solar panel
  - Attached to a specialised animal collar that falls off after deployment completion
- Configurable microphone sensitivity for better hardware generalizability to diverse use-cases

Event Detection and Classification

- Utilizes supervised and semi-supervised ML
- Only small or weakly labeled data sets are typically available for environmental monitoring
  - Will employ transfer learning to increase the quantity of data available for initial training
- Most important output is the detection of **unknown** but **important** events of interest

Data collection decision-making pipeline



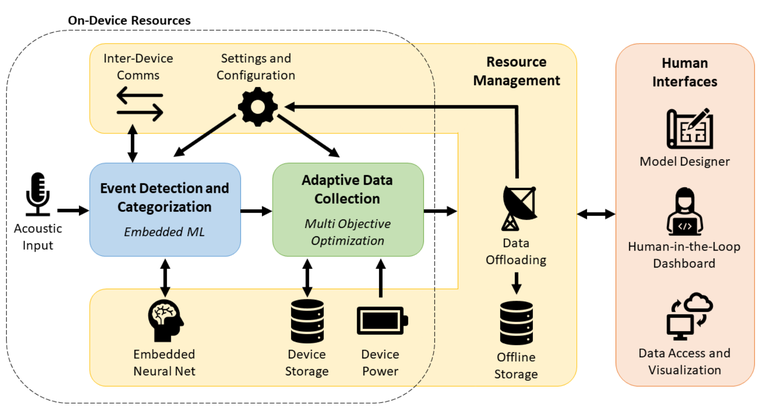
- Dual-storage mechanism:
  - Cell/LoRaWAN/Satellite comms for high priority alerts
  - SD card storage for routine data collection
- Human-in-the-loop guidance for real-time deployment updates and reconfigurations
- Data storage based on multi-objective optimizations including explicit mission directives and implicit resource constraints

Unknown Event Categorization

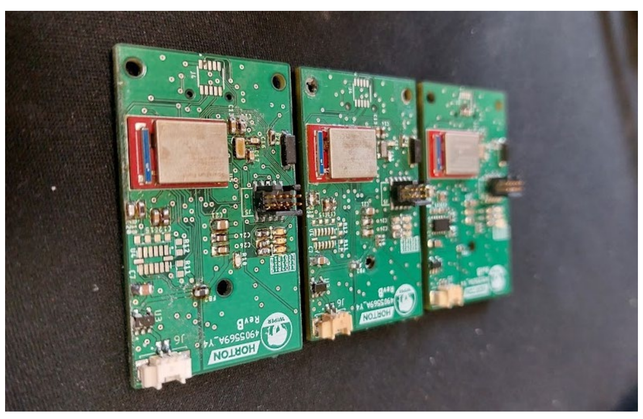
- Promising results using an unsupervised clustering algorithm that groups similar sounds into a predefined number of dynamically growing, shrinking, and changing buckets
- An "importance metric" can be assigned to each event based on its unique characteristics and its relative frequency of occurrence

Adaptive Data Collection

- Adaptive methodology used to determine:
  - Which data should be stored and in what format
  - Which data should be transmitted to a human
  - Which data should be dropped or ignored
- Decisions are based on a multi-objective optimization routine combining ML outputs, remaining power and storage metrics, network availability, and mission configuration settings



A3EM adaptive data collection architecture



Low-power, animal-borne acoustic sensor hardware

Acoustic collar field testing on deer in Colorado

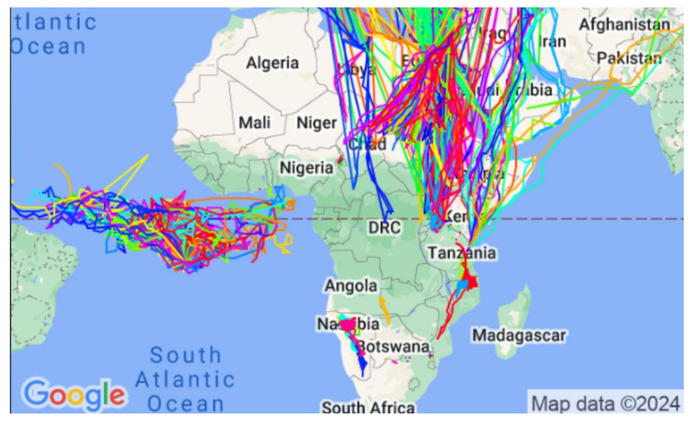
Broader Impact

Societal Benefits

- Acoustic monitoring coupled with location tracking enables entirely new applications that facilitate census gathering and monitoring of threatened and endangered species, including detecting poachers of elephants in Africa or caribou in Alaska, and evaluating the effects of mining and logging on wildlife
- Provides insights into biodiversity loss, a severe but underappreciated problem of our time

Education & Outreach

- Female students tend to be drawn to STEM applications in other domains, particularly when related to the social good. Engagement will be fostered by creating a K-12 curriculum that combines ecology and wildlife conservation with computer science
- A project-based curriculum will be tested and refined over multiple summer camps, then publicly released for free to K-12 educators



Engaging animal migration visualization project in NetsBlox using publicly available Movebank data

Award ID#: 2312391